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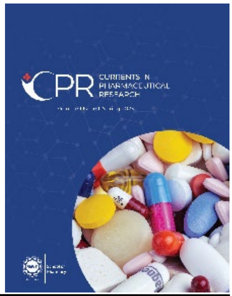

Title:	**Evaluating Frontiers in Nanotechnology: A Review of Novel Nanoparticle Technology in Drug Delivery Systems (DDS)**
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Evaluating Frontiers in Nanotechnology: A Review of Novel Nanoparticle Technology in Drug Delivery Systems (DDS)

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ABSTRACT

Nanotechnology is a groundbreaking field that manipulates materials at the nanoscale, enabling unprecedented control over their properties. In medicine, nanoparticles enable targeted drug delivery and precise diagnostics. In electronics, they contribute to miniaturized devices and high-performance sensors. Additionally, nanoparticles also encompass their role in environmental remediation techniques. The current review article aims to provide a comprehensive and updated overview of recent developments in nanotechnology by highlighting the key advancements, novel applications, and future directions. Moreover, this article also contributes to the current understanding and impact of nanotechnology on multiple sectors by providing valuable insights for future researchers. For this purpose, different preparation methods can be used to prepare nanoparticles and offer various advantages due to their varying size, as they can cross the blood- brain barrier and skin, they are used in cosmetics, and they have many applications in drug therapy and diagnostics.

Keywords: applications of nanoparticles, drug therapy, diagnostics, Drug Delivery Systems (DDS), nanoparticles, nanotechnology.

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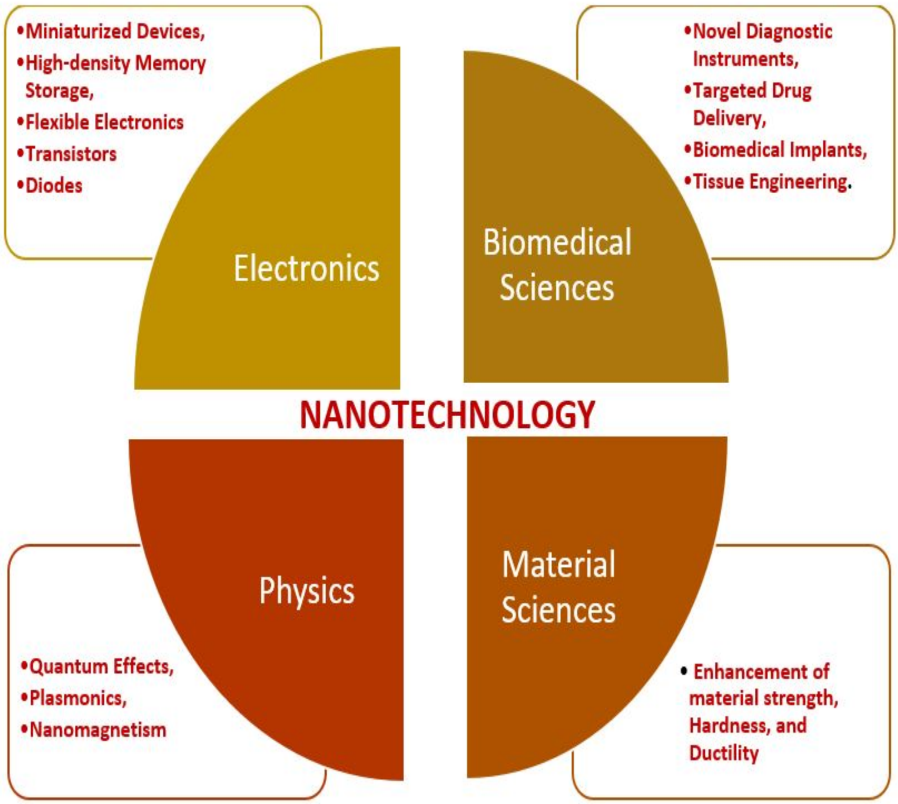
GRAPHICAL ABSTRACT



1. INTRODUCTION

Nanoparticle technology has gained a lot of eminence due to its unique chemical, physical, biological features, and nanoparticles properties. Currently, nanoparticles are active in research and have many applications [1]. Nanoparticles consider the particles in solid and colloidal forms ranging from 1nm-100nm [2]. A drug to be delivered is entrapped, dissolved, attached, or encapsulated in a nanoparticle matrix depend on the preparation method, nanospheres, nanoparticles, or nano capsules that can be obtained, accordingly [3].

Modern world has begun to change the scientific viewpoint concerning nanoscale technology in diagnosing, preventing, and treating various diseases. Nanoparticle technology is a multidisciplinary scientific approach that is involved in creating and utilizing materials, devices, and many other systems on a nanometer scale. The development of generic therapeutic nanoparticles have faced a combination of scientific, patent, and regulatory challenges [4]. Nanoparticles are particulate systems used as a physical approach to improve drug molecules' pharmacokinetic and pharmacodynamic properties [5].

1.1. Nanotechnology

Nanotechnology is derived from a Greek word known as "nano," which means "dwarf." Albert Franks defined it as "area of science and technology where dimensions and tolerances are in the range of 0.1 nm-100 nm" [6].

This can be applied to engineering and electronic principles, including material, and medical science. Nanoparticles possess exceptional characteristics and versatility, rendering them indispensable tools in these disciplines, leading to groundbreaking discoveries.

In the field of engineering, nanoparticles have wide-ranging applications, including but not limited to structural materials, coatings, and sensors. Leveraging their small size and large surface area, nanoparticles offer tremendous potential for enhancing the mechanical, thermal, and chemical characteristics of materials [7].

In the realm of electronics, nanoparticles assist in the development of miniaturized devices, high-density memory storage, and flexible electronics that enable the fabrication of nanoscale components including transistors and diodes [8].

Nanoparticles have the capability that empowers the enhancement of material strength, hardness, and ductility, while preserving flexibility in the field of material sciences. In the realm of physics, they enable the exploration of fundamental phenomena at the nanoscale, thus, by providing platforms for investigating quantum effects, plasmonic, and nano-magnetism [9].

The current study aims to discuss nanoparticles, which have transformative potential in medical science. In the late 90s, scientific evidence about nanoparticles were discovered, which possessed possess magnetic, optical, and electronic properties. This discovery led to an entirely new Nano-World. The nanoparticles are the building blocks of nanotechnology, which are utilized in various fields [10].

1.2. Nanoparticles for Drug Delivery

The nanosized nanoparticles can carry multiple drugs and many imaging agents. Due to their small size, they have a high surface-to-volume ratio and a high surface area. With the help of the nanoparticles, high ligand density can be achieved, which can help a lot in the drug targeting specified receptors, and in other activities. They can also increase the drug concentrations at the specific receptor site by controlling the release rate depending on their size, respectively [11].

The nanoparticles are being used in drug delivery systems (DDS) because of their dissimilar features, such as their high surface-to-mass ratio, ability to absorb other materials, and ability to carry other compounds. Specific unique properties of nanoparticles are often exploited to improve the drug delivery as they have a very minute size they can be quickly taken up by the cells of the human body; otherwise, large particles are mostly removed from the body and are not taken up by the cells [12].

1.3. Properties of Nanoparticles

Specific properties of nanoparticles play an essential role in the drug delivery systems that include:

1.3.1. Size. The size of nanoparticles is critically essential in drug delivery systems, dramatically influencing both clearance and the bio-distribution of nanoparticles in the body [13]. Nanoparticles are colloidal particles ranging in size from 1-1000nm. Drugs in the nanoparticles can either be encapsulated in the nanoparticles or might be attached to the surface of the nanoparticles.

The properties relating to the size and texture of nanoparticles play an essential role in defining the *in-vivo* characteristics of the nanoparticles. There are many barriers in the delivery of drugs, such as the gastrointestinal barrier for oral chemo drugs and the Blood Brain Barrier <BBB> for the delivery of drugs to the Central Nervous System <CNS>. Due to such properties, they can be utilized for the delivery of medicines that are to be used for diseases related to CNS. Their small size makes them easier to be delivered to such areas of the body [14].

Generally, the drugs that carry nanoparticles are either administered orally or intravenously. For oral administration, the particle size should be less than 500 nm; for intravenous administration, it should be less than 200 nm [15].

1.3.1.1. Methods of Particle Size Determination. The following methods can be utilized for particle size determination:

1. Light Scattering (LS)
2. Laser Light Diffraction (LLD)
3. Scanning Electron Microscopy (SEM)
4. Transmission Electron Microscopy (TEM)
5. (AFM) atomic force microscopy
6. (ANUC) analytical ultracentrifugation
7. (FFF) field flow fractionation
8. (CE) capillary electrophoresis
9. (PCH) packed column hydrodynamic
10. (SEC) size exclusion chromatography

Table 1. Methods of Particle Size Determination [15]

Method	Principle	Measure Size
LS	Light interaction	50nm-1μm
LLD	Light interaction	1-1000 μm
SEM, TEM	Microscopy	50nm-100 μm
AFM	Microscopy	10nm-1 μm
ANUC	Centrifugation	-
FFF	Elution	20nm-1 μm
CE	Electrophoresis	20-500nm
PCH, SEC	Chromatography	<100nm

1.3.2. Shape. The shape of the nanoparticles also plays a vital role in drug delivery, affecting the circulation half-life t1/2 of nanoparticles. The filamentous polymer micelles, also known as filo micelles, have long circulating half-lives, usually less than one week after administration.

Contrarily, spherical ones have 2 to 3 days, which depends upon the particles' tendency to align with the blood flow [16].

1.3.3. Surface Charge. Surface charges on the nanoparticles play an essential role in regulating the half-life of a drug. By modifying the surface charge, drug release kinetics can be regulated. Positively charged nanoparticles can prolong drug release through electrostatic interactions, while negatively charged nanoparticles may exhibit enhanced stability. Surface charge manipulation enables fine-tuning of drug delivery systems (DDS) for improved therapeutic outcomes. However, careful consideration of biocompatibility and potential toxicity is essential [17].

1.4. Types of Nanoparticles and their Usage for Drugs Delivery

The nanoparticles used in the drug delivery systems include:

1. Ceramic Nanoparticles
2. Polymeric Nanoparticles
3. Metallic Nanoparticles
4. Liposomes
5. Dendrimers

1.4.1. Ceramic Nanoparticles. Ceramic nanoparticles are formed of entities, such as carbides, oxides, carbonates, and phosphates of metals and metalloids such as calcium, titanium, and silicon [18]. Nanophase ceramics already have been widely used in a broad spectrum of biomedical applications. They are inorganic systems that have porous characteristics and they can be easily modified to attain desired size and porosity they are widely being used in various drug vehicles. Ceramic nanoparticles have several porn characteristics than unique nanoparticles. Ceramic nanoparticles are also called Aquasomes and they make up vigorous drug delivery systems (DDS) that have nanocrystalline that are also ceramic modified consisting surface composites of carbohydrates and comprise 3 layered self-assembly structures, which are composed of solid nanocrystalline core [19].

1.4.1.1. Preparation Methods for Ceramic Nanoparticles. Laser pyrolysis also known as CO_2 Laser pyrolysis is used in the gas/vapor phase precursors in the formation of nanoparticles, which is a very effective technique that allows to cope with various challenges of the nanotechnology. In this method, the nanoparticle preparation starts promptly when a degree of super saturation of condensable products have been done in the form of vapors. When nucleation happens, the fast growth of particles occurs due to coagulation. In this process, condensable products are produced from laser-induced chemical reactions [20].

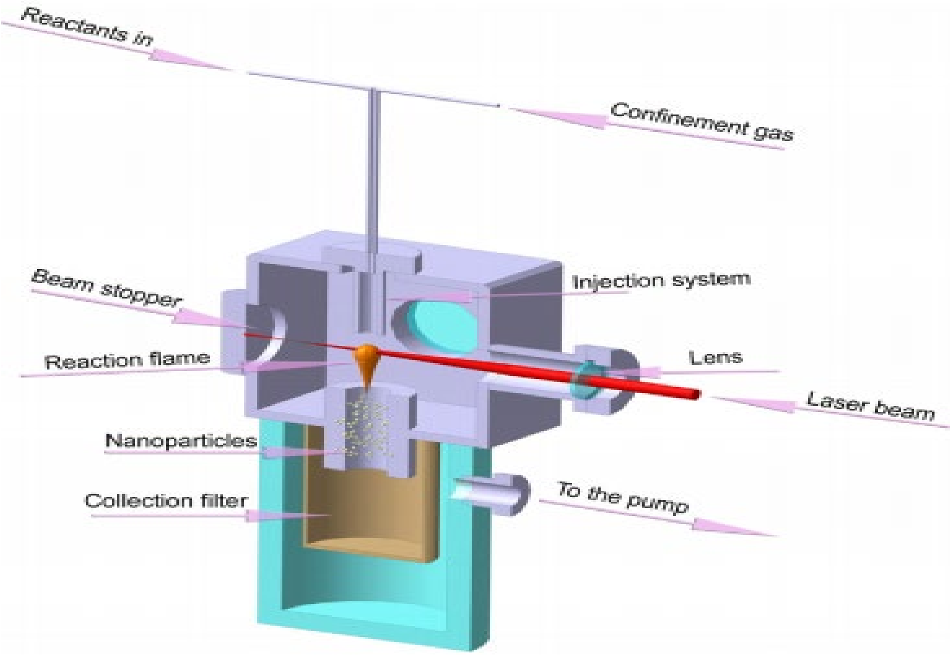


Figure 1. Diagrammatic Display of Laser Synthesis of Nanoparticles [10].

1.4.1.2. The Process of Laser Ablation in the Liquid. Another method for the synthesis of ceramic nanoparticles is Laser Ablation in Liquids (LAL), which has been recently discovered and is the emerging area of interest because it generates nanoparticles with high purity. In an experiment conducted in 2010, this process was done by a commercial Q-switched Nd: YLF laser device that gave 20- 60 nanoseconds full width on ½ max pulses also the central wavelength was 1047 nm. The irradiated corundum target was made by a hot isostatic press of R-Al_2O_3 powder of 97.5% purity. Beam was focused using a laser scanner with a telecentric 58 mm focal lens. The experiments were performed using distilled water at atmospheric pressure and at room temperature [21].

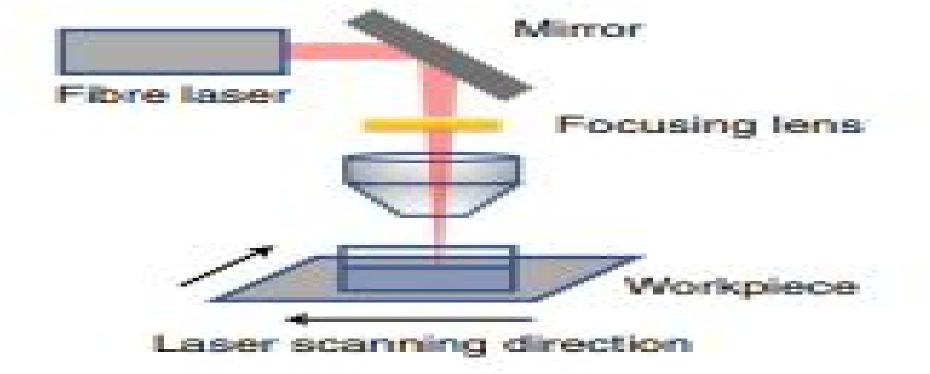


Figure 2. A Schematic of the Experimental Set-Up for the Synthesis of AuFeCoCuCr NPs in Hexane Under the Irradiation of a Pulsed Fiber Laser [22].

1.4.2. Polymeric Nanoparticles. Polymeric materials are being used for about 40 years in the biotech and pharma industry. They are made with biocompatible and biodegradable polymers ranging in size from 10-1000 nm. A lot of researchers are in search of the uses of polymeric nanoparticles acting as carriers for many drugs and their therapeutic applications [23]. Certain advantages of utilizing polymeric nanoparticles include:

1. These can be utilized to deliver volatile drugs.
2. They have high efficacy as compared to regular oral or intravenous drug delivery.
3. A high concentration of the drug can be targeted to a desired location to produce the effects there.
4. They have ideal characteristics to be used in cancer therapy and vaccines and targeted delivery of antibiotic drugs.
5. They can be employed in tissue engineering and drug delivery [4].
6. The *in-vitro* and *in-vivo* degradation of the drug is protected with nanosize polymeric nanoparticles [3].

1.4.2.1. Preparation Methods for Polymeric Nanoparticles. Nano-encapsulation is a promising approach to target the delivery of vitamins [24]. The diameter of nano encapsulated includes diameters ranging from

1-1000 nm drug-loaded particles. The two-step procedure for the preparation of the polymeric nanoparticles from an emulsion can be described as follows:

Step one: Induced Polymer Precipitation by the Solvent Removal method

In this method, the oil-containing nanocapsules can be prepared by pouring oil into a polymer solution having emulsion droplet content. Water-containing nanocapsules can be obtained possibly by applying the method on multiple emulsions. Nanocapsules formed from multiple emulsions have much larger size than the usual ones.

Step two: Preparation of nanoparticles by the method of emulsification solvent evaporation

Emulsions are formed in this method by using polymer solutions made in volatile solvents for nanoparticle preparation. The emulsion is converted into nanoparticle suspension, which happens by evaporation of polymer solvent that diffuses along the continuous phase. This process is performed under vacuum conditions [25].

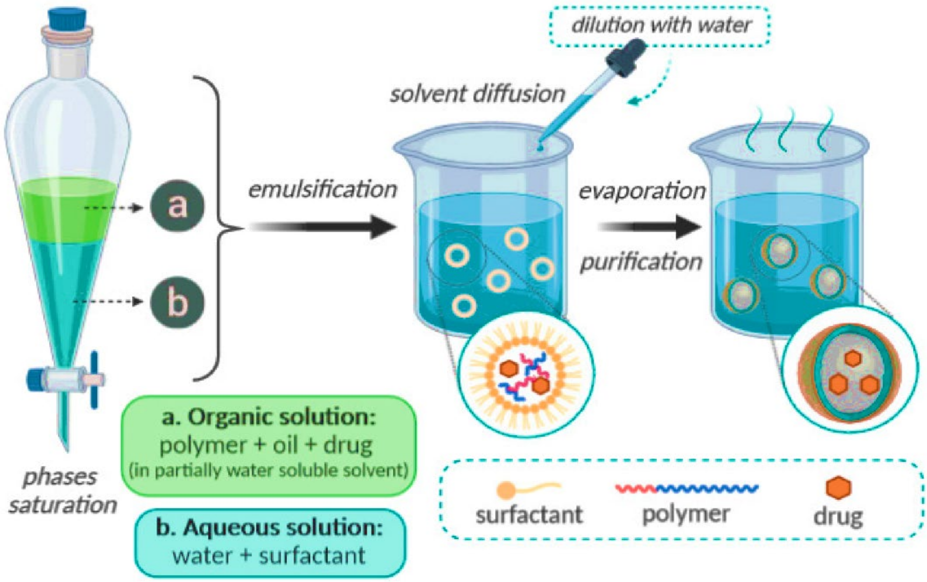


Figure 3. Preparation of Polymeric Nanoparticles by a 2-step Procedure of Emulsion Formation and Solvent Extraction [25].

1.4.3. Metallic Nanoparticles. The metallic nanoparticles have been a fantasy for scientists for over a century and they are currently being utilized widely in biomedical sciences and engineering. Consequently, it has gained a lot of interest because of its utilization in nanotechnology. They have many applications in cosmetics, electronics, packaging coatings, biotechnology, and medicine. Magnetic nanomaterials have been found as a promising candidate in biological applications [26].

1.4.3.1. Preparation of Metallic Nanoparticles. The preparation of these metallic nanoparticles is a revolutionary area of research and study. Two different methods are used for the preparation of metallic nanoparticles:

- Bottom-up approach
- Top-down approach.

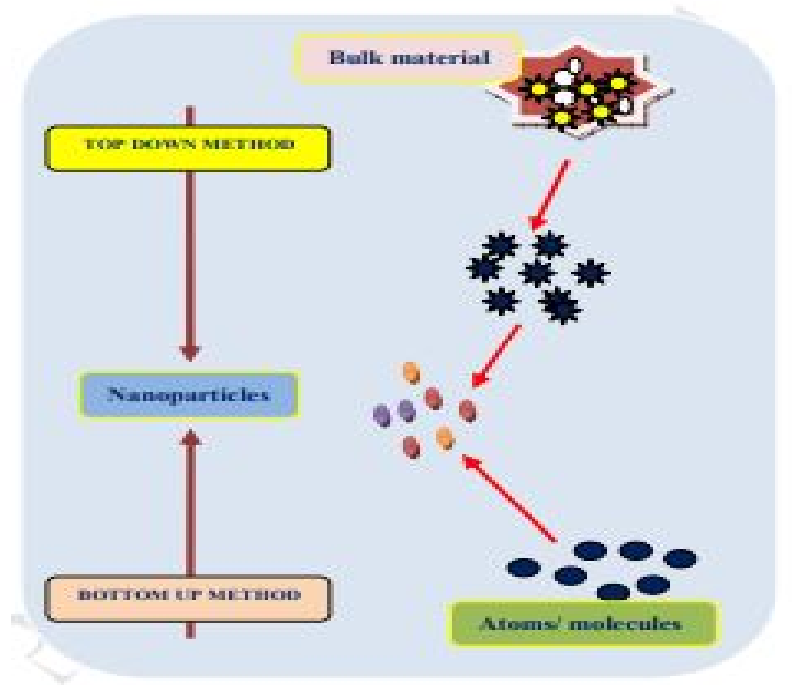


Figure 4. An Overview of Top Down and Bottom Up Method [7].

The Bottom-up or self-assembly process involves the construction of a structure by the process atom by atom and by molecule by molecule that can be a cluster by cluster in this process; initially nanoparticles are produced then assembled with the final material for synthesis by using chemical procedures or biological procedures.

The top-down method involves a process in which a starting material is selected and taken and is decreased in size. The drawback of this method is the perfect surface structure of the particle cannot be obtained, which can have an impact on factors such as surface chemistry and physical properties of the metallic nanoparticles [7].

1.4.4. Liposomes. Liposomes are bilayer vesicles that have found use among other applications, such as drug delivery vehicles [27]. Liposomes are described as closed bilayer phospholipids systems that are proposed to be used to deliver drugs [28]. Liposomes alter the bio-distribution of associated drugs through the delay in drug clearance and retard drug metabolism and decrease the volume of distribution and shift distribution of diseased tissues increasing capillary permeability [29].

Liposomes have applications in medicine, diagnostics, immunology, ecology, cosmetics, and the food industry. They have valuable biological and technological advantages [30]. They provide different products for the treatment of diseases through the smart delivery of drugs to achieve sustained release [31]. Liposomes' PEGylation also reduces the interaction with serum proteins [32].

1.4.4.1. Preparation Methods for Liposomes. Liposomes are such colloidal particles that are prepared with phospholipid molecules of natural or chemical origin [33]. The liposomes are characterized as:

1. Uni-lamellar
2. Multi-lamellar
3. Small Uni-lamellar vesicles
4. Large Uni-lamellar vesicles [27]

These are prepared according to different methods that also include:

1.4.4.2. Preparation of Uni-lamellar Vesicles. Gentle hydration of a phospholipid film is the method used for the preparation of these. This method involves the deposition of phospholipids, on a substrate from a solution of organic solvent such as chloroform or ethanol. Stacked phospholipid bilayers are hydrated over a couple of days flow to get an aqueous suspension of giant uni-lamellar vesicles [34].

1.4.4.3. Preparation of Multi-lamellar Vesicles (MLVs). The multi-lamellar vesicles ac be prepared by hydrating phospholipid film under the hydrodynamic flow process. They are prepared by stacked bilayers of dry phospholipid film, which are deposited on a substrate, for a couple of hours they are rehydrated under the strong hydrodynamic flow. This results in multi-lamellar vesicle suspension containing vesicles that are heterogeneous in lamellarity and size [27].

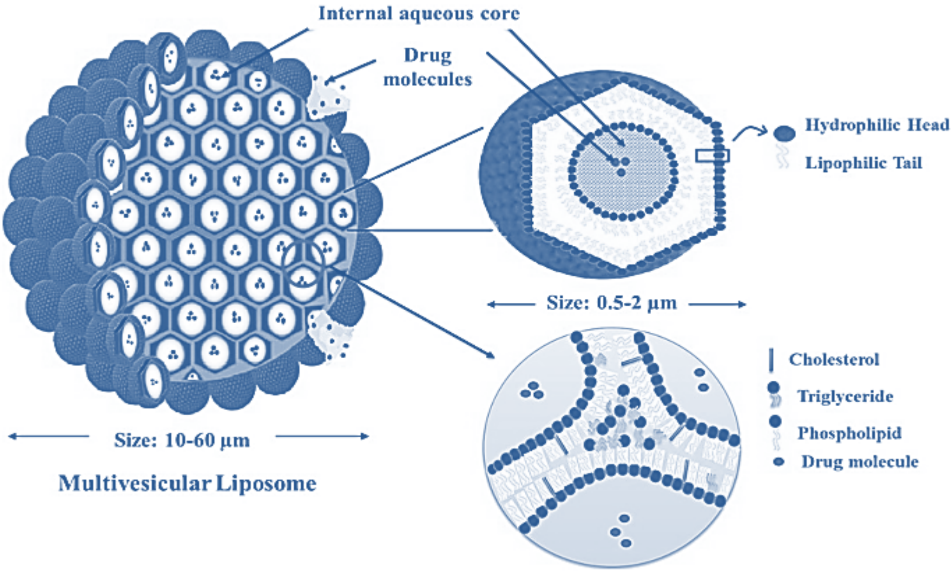


Figure 5. Schematic Representation of Multivesicular Liposome Formation [35].

1.4.4.4. Preparation of Small Uni-lamellar Vesicles (SUVs) and Large Uni-lamellar Vesicles (LUVs). Reverse phase evaporation can be utilized to make SUVs and LUVs. This method includes the hydration of phospholipids, which are dissolved in the organic phase following the addition of water along with the mixing of the material vigorously [36]. The low concentration of the phospholipid in aqueous suspension results in a high fraction of LUVs in comparison to the MLVs formed [37].

1.5.1. Dendrimers. Dendrimers discovery falls back 25 years. The dendrimers are such nanoparticles that present perfect monodisperse macromolecules having highly branched 3D architecture and regularity. Dendrimers are unimolecular micellar in nature and due to this enhances the solubility of poorly soluble drugs. Dendrimers are having well-defined shapes, sizes, monodispersity, and molecular weight. These features have made their application in pharmaceutical and medicinal chemistry particularly attractive. By controlling dendritic structures, the biological fate of dendrimers/dendrimers-based drugs can be significantly altered based on their intrinsic physicochemical properties [38].

The unique structure and properties of dendrimers have shown them as promising carriers in drug delivery [39]. They represent a novel class of polymers, which are different from traditional polymer types. Some biodegradable dendrimers can be directly used as drugs [40]. Dendrimers are interesting particles that have a lot of biochemical applications and other medical applications. The size of dendrimers influences the drug particles to move across the endothelium to enter into interstitial tissue to reach the target sites to achieve the drug of action [41].

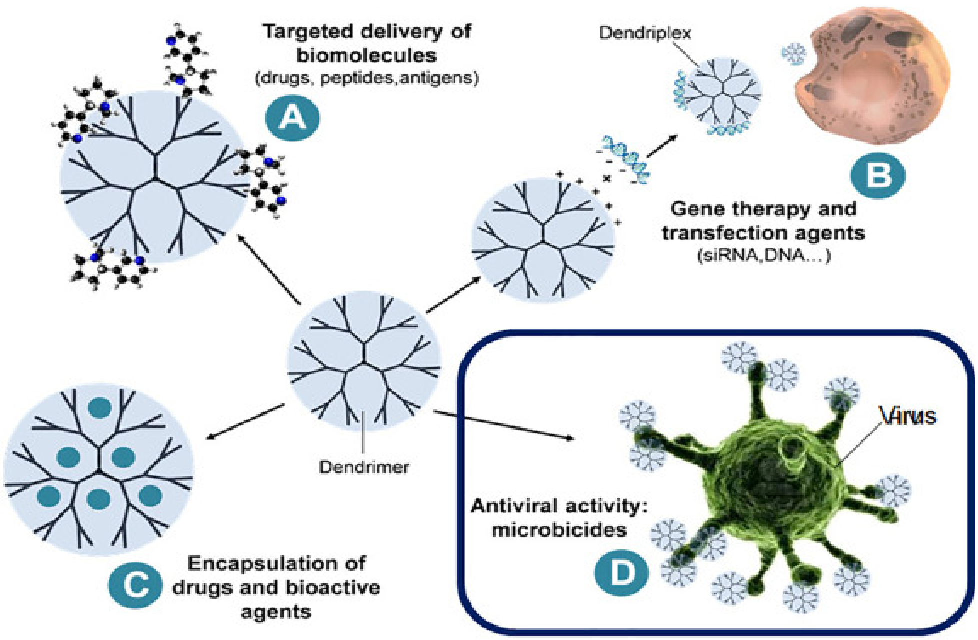


Figure 6. Diagrammatic Illustration of Dendrimers and Their Applications [42].

1.5.1.1. Preparation of Dendrimers. The dendrimers can be prepared by convergent or divergent approaches. The divergent method involves dendrimer synthesis from the core and successive generations would be built on along. The convergent method includes synthesis involving capitalizing the symmetry of dendrimers in that synthesis begins at the periphery of the molecule and seizes at the core where a segment of dendrimers couples. One of the stellar characteristics of dendrimers is that they can carry various drug molecules in their interior.

2. APPLICATIONS OF NANOPARTICLES

Nanomedicine or nanoparticle technology includes the utilization of nanoparticles for the benefit of the health and well-being of humankind. Biomedicine is considered among one of the major areas of nanotechnology applications [43]. Moreover, when combined together biotechnology and nanotechnology have a lot of productive applications. Nanomedicine utilizes biocompatible nanomaterials for diagnostic and therapeutic purposes [44]. Nanosynthesis is an allied field of nanotechnology, which has wider applications [45]. The actual spirit of interdisciplinary expansion of scientific knowledge results from applying nanotechnology in the fields of medicine, biology, chemistry, and physics [46]. The size of the nanomaterials is also similar to biological molecules, so in research they can be used for both *in-vivo* and *in-vitro* studies. The applications of nanotechnology are wider that also involve pest control [47].

2.1. Nanoparticles in the Diagnosis of Diseases

Nanotechnology makes it easier to diagnose single cell or molecular level also it can be used in the new molecular methods for diagnosis for example biochips for diagnosis [48]. The field of medical science is advancing with the use of nanotechnology because of its utilization in cancer therapy as a diagnosis and treatment of cancer [49].

2.2. Nanoparticles Applied in the Field of Oncology

New opportunities are being offered by nanomaterials for the diagnosis and treatment of cancer. Such nanoparticles are widely used in tumor targeting [50]. The nanoparticles are employed in the field of oncology and cancer therapy similar to other science and biology branches employed in this field. Magnetic nanoparticles are used for diagnosis, gene delivery, drug delivery, bioseparation, phototherapy, hyperthermia, and chemotherapy in cancer therapy [50].

Targeted drug delivery systems involve polymeric nanoparticles as drug carriers that can be used in the therapy of cancer. Significant investigations have proved that tissue and cell distributions profile of drugs are anticancer drugs that may be controlled and monitored by the use of submicron colloidal systems as nanoparticles [51]. In the last 2 decades, nanoparticles have shown great potential for their use in cancer therapy and diagnosis [52]. Luminescent nanoparticles are a promising material for future diagnostic implementation in cancer therapy [53].

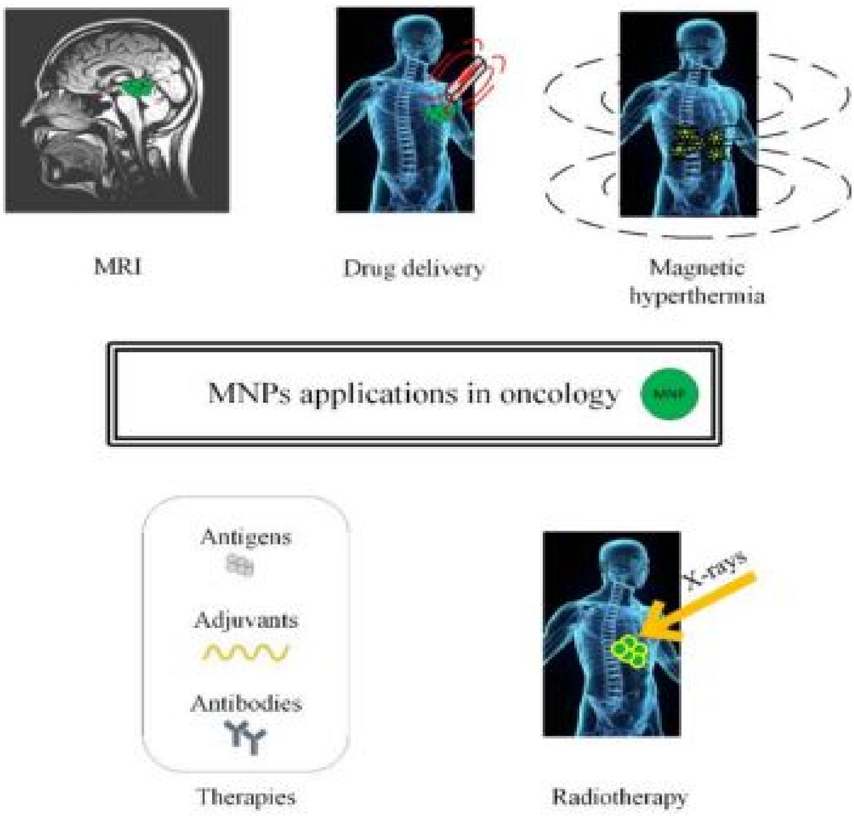


Figure 7. Schematic Representation of Magnetic Nanoparticles' Applications in Oncology [54].

2.3. Nanoparticles Crossing Blood Brain Barrier

The presence of the blood-brain barrier and the complex structure of the brain gives several challenges in the treatment of brain diseases both in diagnosis and targeting of the drug. Nanotechnology provides new tools and creative ideas, which can be utilized to overcome these challenges the path [55].

2.4. Nanoparticles in Diagnosis of Atherosclerosis

Nanoparticles present a new way for the prevention, treatment, and diagnosis of atherosclerosis. The development of nanosystems has provided efficient means for the diagnosis of subclinical atherosclerosis, coronary artery disease, and myocardial infarction [56].

2.5. Gold Nanoparticles

Gold nanoparticles have several medical applications such as attenuation of X-rays has led to their use in tomography imaging and radiotherapy [57]. Gold nanoparticles have been used as therapeutic agents for the treatment of rheumatoid arthritis [58].

2.6. Cantilever Biosensors

Nowadays there is an increasing need for less expensive and highly sensitive methods to measure drug interactions in particular. A new category of nanoparticles known as Cantilever biosensors, includes very highly sensitive electro-mechanical sensors, which can be used for the label-free detection of a lot of biological molecules. These are emerging technology that appears attractive for applications in drug discovery [59].

2.7. Nanoplasmonics

Another form of nanoparticles known as nanoplasmonics is also used for other disease diagnoses and therapy. They provide label-free assays and quick results and the devices employed are user-friendly [60]. Nanoplasmonics biosensors are powerful tools to detect complex analytes of relevant clinical applications. The plasmonic biosensors can be used as diagnostic devices to attain clinical outcomes, which are cost-effective [61].

2.8. Fluorescent Nanoparticles

Fluorescent nanoparticles can be used in cancer diagnostics, for tumor biomarkers and to detect multiple genes and matrix RNA. Three crucial biomarkers can be detected in breast cancer to accurately quantify single tumor sections by using nanoparticles conjugated to antibodies to help in diagnosis [62].

2.9. Diagnosis of Bacterial Infections

Nanotechnology has provided many choices for the diagnosis and treatment of bacterial infections and diseases [63]. Magnetic fields were observed in a study that can be utilized to make the magnetic nanoparticles reach to disease area or location of infections. Metal nanoparticles employed as antimicrobial agents are studied and considered an alternative approach to overcome multidrug resistance in bacteria, thus by improving immunity and therapeutics [64]. Size and shape-dependent properties of the nanomaterials are still under research particularly for the antimicrobial effects of such nanoparticles [65]. The mechanism of bacterial killing includes the formation of reactive oxygen species and biomolecule damages cation release [66]. The silver nanoparticles are used to prevent *Pseudomonas aeruginosa* infections [67].

2.10. Solid Lipid Nanoparticles (SLNs) in Drug Delivery

Solid lipid nanoparticles (SLNs) function as drug carriers, consisting of solid lipids in nanoscale form. They possess numerous benefits as compared to the alternative drug delivery systems (DDS), such as increased stability, heightened drug-loading capacity, regulated drug release, and potential targeting abilities. SLNs are less toxic and have fewer adverse effects. They have more biocompatibility and biodegradability. A range of drugs including lipophilic, hydrophilic, and hydrophobic drugs can be loaded into SLNs [68].

Significantly, another study studied different types of antifungals in SLNs and studied their effects. When compared to other antifungal formulations, solid lipid nanoparticles (SLNs) were more biocompatible and were minimally toxic to mammalian cells. Furthermore, antifungal loaded SLNs were found to be more efficacious in comparison to other conventional antifungal formulations [69].

2.11. Tuberculosis Diagnosis

Tuberculosis diagnostic kits, which are nanoparticle-based are under clinical trials that can reduce the cost, time and man power.

The colorimetric sensing method is used to utilize the gold nanoparticles and a paper assay platform was developed for the diagnosis of tuberculosis [70, 71]. The glassy carbon electrode is modified by a nano triplex, which is a sensitive electrochemical biosensor for detecting

Mycobacterium tuberculosis antigen [72]. Biofunctionalization and characterization of magnetic nanoparticles can be done to produce a sandwich ELISA test to detect antigens of *M. tuberculosis* [73]. Significantly, a study indicated that nanoparticle-based colorimetric biosensing assay can be utilized to rapidly and cost-effectively detect acid-fast bacilli of *M. Tuberculosis* in samples of sputum [74].

2.12. Upconversion Nanoparticles

Upconversion nanoparticles present a new class of fluorophores. The excitation and emission of wavelengths are in the long wave part of their spectrum so that luminescence can penetrate deeply into the tissues causing less photo damage in biological samples. Their high photostability makes them ideal for fluorescent labels bioimaging for thr cancer treatment. Due to their biocompatibility and small physical dimensions, they can be coupled to proteins used in cancer treatment [75].

2.13. Club Drugs

Recently, it has been found that along with traditional drugs, a new group of a drug class called 'club drugs' increases fast and low-cost bioassay to detect drugs that are amphetamine-based, which are beneficial to reduce drug abuse. A study was designed to explore benefits and risks associated with a bioassay that is a sensitive method, thereby, using gold nanoparticles possesses a high affinity toward methamphetamine [76].

2.14. One-step Bioassay

One approach is to combine the frequency of high resolution and time measurement speed increased using one device including 1 step bioassay. This 1 step's magnetic nanoparticle nature decreases the in-between time of the extraction of the sample and the quantitative results also reduced the risk of the contamination involved in the steps of washing [77].

2.15. Quantum Dots

The nanoparticles are largely utilized for fluorescent imaging of mainly cells and tissues. Such nanomaterials are mostly utilized in bioimaging and they involve fluorescent doped silicas, hydrogels, sol-gels, quantum dots, carbon dots, and carbonaceous nanomaterials, which may also be included [78]. Certain materials make the potential for a lot of benefits in applications that are analytical as compared to fluorophores, particularly molecular ones and the quantum dots in diagnosis [79].

2.16. Treatment and Monitoring

During the past decades, nanoparticles emerged for having a variety of applications, such as, diagnostics and therapeutics [80]. Nanoparticles are considered quite promising in the diagnosis of several diseases and targeted delivery of drugs (DD) with minimum toxicity, while monitoring the treatment. Nanomedicine focuses on manufacturing drugs and other biologicals and relevant molecules, which are packed into nanoscale systems to improve the delivery of drugs. Along with the advancement in nanotechnology, the possibility of using engineered nanoparticles has increased, which interact with the biological environment for the treatment of diseases and affective drug therapy [81]. The goal of nanomedicine is to improve the overall clinical outcomes [82].

2.17. Polymeric Nanoparticles

One possible way to deliver drugs into Central Nervous System (CNS) can be done by the use of polymeric nanoparticles, which possess numerous beneficial therapeutic properties and carrier properties. Thus, the ability of such carriers can be used to overcome the blood-brain barrier and to produce biological effects on the CNS, which has also been shown in several studies [83].

2.18. Cancer Therapy

During the past three decades, nanocarriers have been utilized to increase the therapeutic index and tumor tissue concentrations of the drugs. Nanotechnology offers a unique opportunity to develop new diagnostic and treatment strategies to improve the survival of cancer patients. Cancer nanotherapeutics are in progress and are being implemented to solve many limitations of conventional or traditional drug delivery systems (DDS) [84].

2.19. Topical Drug Delivery

Nanoparticles are largely employed in topical drug delivery systems (DDS) and cosmetic industry. The largest organ in the human body by weight is the skin, which contributes to 10% of the total weight of the body and covers a 1.7 m^2 average area [85]. Skin is an organ that is easily accessible and it is an alternative route for the administration of drugs for systemic and local effects. Many cosmetic industries are focusing on the delivery of active drug molecules in the skin. However, these molecules don't easily penetrate in the skin because of their barrier function of the skin.

Nano-carriers have been developed to modulate the skin barrier reversibly. Nanoemulsions, liposomes, transferosomes, solid lipid nanoparticles, polymeric nanoparticles, ethosomes, and niosomes include such particulate carriers [43].

2.20. Targeted Drug Delivery

The targeted delivery of drugs to the organs of the body or special sites or specific areas is the most challenging research area in pharmaceutical science. Colloidal delivery systems can be developed like micelles, liposomes, and nanoparticles to improve drug delivery at the targeted sites. Special characteristics of nanoparticles, such as small particle size, large surface area, and the ability to change their surface properties have several advantages [80].

2.21. Tumor Diagnosis and Therapy

Brain tumor malignancy is a very challenging disease for treatment, diagnosis, and management. The most significant issues for the chemotherapy of brain tumors include distribution, cytotoxicity, and crossing the blood-brain barrier. Nanotechnology can be employed in drug delivery with greater potential to improve efficacy and drug efficiency. Nanotechnology can help in the early detection and therapy of the brain tumors [86].

2.22. Alzheimer's Disease Management

Alzheimer's disease (AD) is a very complex disease that may be characterized as a neurodegenerative disease with few effective treatments [87]. A lot of Nano carriers are under investigation for the treatment and diagnosis of AD that delivers drugs at a constant rate. In a likewise manner, a study established the role of nanoparticles in resolving Aβ aggregation and thus helping cure Alzheimer’s disease [88].

Another study explains that in the brain increase of rivastigmine, uptake was shown in poly (*n*-butyl cyanoacrylate) nanoparticles having 1% polysorbate 80 coating in comparison to the drug that is free [89]. New research also explains that nanoparticles particularly solid lipid nanoparticles get attached to an antibody called an anti-transferrin receptor monoclonal antibody that works as a carrier to transport extract to the target brain for Alzheimer's Disease treatment [90].

2.23. Cerium Oxide Nanoparticles

Cerium oxide nanoparticles are largely used as catalysts due to their free radicle properties, which have a wide variety of applications in the pharmaceutical industry. Given the major role of free radicals in the therapy and management of many human diseases, nanoparticles are now used in the treatment of various diseases, such as oxidative stress disorders and others [91].

3. CONCLUSION

Nanotechnology (NT) is associated to the matter at the nanoscale. Nanoparticles and nanotechnology have emerged as a transformative domain, driving significant advancements across diverse industries, and exhibiting extraordinary potential for the future. Leveraging their distinctive characteristics and adaptable applications, nanoparticles have facilitated groundbreaking progress in various fields, such as medicine, electronics, energy, and environmental remediation. The capacity to manipulate matter at the nanoscale has unleashed a realm of possibilities, empowering the development of enhanced drug delivery systems (DDS), superior electronic devices, heightened energy storage solutions, and more eco-friendly environmental technologies.

Moreover, the collaborative interdisciplinary cooperation among scientists, engineers, and other stakeholders can further expand this knowledge of nanoparticles and nanotechnology. Embracing a balanced blend of caution and forward-thinking can further unlock the vast possibilities inherent in this domain, thus, propelling towards a future characterized by sustainability, efficiency, and technological advancement.

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