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Review Article

A comprehensive review on the classification, synthesis, characterization of nanopartices and their therapeutic impact

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ABSTRACT

The main topic of the document is nanotechnology and the use of nanoparticles in various fields. The document introduces nanotechnology and defines nanoparticles as particles with lengths between 1 nm and 100 nm. Nanoparticles are classified as zero-dimensional nanomaterials and have distinct physico-chemical characteristics compared to bulk materials due to their small size and high surface to volume ratio. Nanoparticles have gained attention in technological breakthroughs due to their adjustable properties and potential applications in drug delivery. The document also discusses the different types of nanoparticles, including organic, inorganic, carbon-based, and herbal nanoparticles. Organic nanoparticles, such as micelles and liposomes, are often used for drug delivery. Inorganic nanoparticles, such as silver and gold nanoparticles, find applications in cosmetics and medicine. Carbon-based nanoparticles, including graphene and carbon nanotubes, have various uses in fields such as energy storage and sensors. The document also mentions the use of herbal nanoparticles derived from plant extracts. Additionally, the document highlights the concept of green synthesis, which offers advantages in terms of environmental friendliness and sustainability. Overall, the review provides an overview of the significance and potential applications of nanoparticles in different industries.

1. Introduction

The term "nanoparticle" has been defined in a variety of ways in literature. Standard Terminology published by the American Society for Testing and Materials (ASTM) "A particle with lengths in two or three dimensions greater than 1 nm and smaller than 100 nm and which may or may not exhibit a size-related intensive property" is the definition given in relation to nanotechnology. To distinguish them from one70 and two-dimensional nanomaterials, which have one or two dimensions larger than nanoscale, respectively, NPs are also classified as zero dimensional nanomaterials. They are distinguished from their bulk equivalents by differences in size, energy absorption, movement, and chemical reactivity, among other factors (Sajid and Płotka-Wasylka 2020).[1] Nanotechnology has advanced to an unparalleled level in the last few decades. It follows that scholars' growing interest in the topic is not unexpected. However, according to the European Commission recommendations, to nanomaterials can be accounted any material of natural, incidental or engineered origin, which comprises at least 50% of the particles (in unbound or aggregated form) possessing one or more external dimensions in the range from 1 to 100 nm (Pryshchepa, Pomastowski, and Buszewski 2020).[2] When compared to other traditional medication delivery methods, nanoparticles have several advantages. Nanoparticles have gained prominence in technological breakthroughs due to their adjustable physical, chemical,

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and biological properties with increased performance over their bulk foils. Because of their small size, nanoparticles can easily travel throughout the body and take a variety of paths to reach even the most complex organs. Nanoparticles are the most ideal drug delivery technology because of their high stability and regulated drug release (Patil et al.. 2021).[3] It is noteworthy to mention that NPs exhibit distinct and frequently enhanced physico-chemical characteristics when compared to the similar bulk material. While the physical properties of bulk materials are often constant, the physical and chemical properties of nanoparticles are determined by their size. Because of their small size and high surface to volume ratio, which result in their reactivity and remarkable chemical, electrical, optical, magnetic, and mechanical capabilities, NPs have garnered a great deal of attention. The platform of nanotechnology allows for the design, modification, and customization of NPs' physico-chemical characteristics, including their size, shape, surface charge, and hydrophilicity (Selmani, Kovačević, and Bohinc 2022).[4] Currently, it is unavoidable in practically all scientific fields, such as engineering, health, environmental studies, and agriculture. Nanotechnology makes use of both biological and inorganic materials, as well as hybrid materials. Because of their antibacterial properties, metals like copper and silver have been used by humans for decades. Today, researchers are investigating the potential uses of these metals in consumer goods including fabrics, shampoo, hygiene products, and contraceptives (Dawadi et al.. 2021).[5] A cutting-edge idea and field of nanotechnology that is gaining attention globally is nanobiotechnology. Green nanotechnology is the best way to lessen the negative consequences of producing and using nanomaterials while simultaneously lowering the possibility of issues arising from using other techniques. Numerous fields, including biomedical, materials chemistry, information technology, agriculture, biomedical, optical, catalysis, electronics, environment, energy, and sensors, have shown interest in nanoparticles due to their potential applications (Pandit et al.. 2022). A wide variety of materials with sizes smaller than 100 nm are considered nanoparticles. They are categorized according to the maximum number of dimensions that an electron can occupy, such as 0-dimensional (0D), 1-dimensional (1D), and so on. Thin films (2D), wires and rods (1D), and spheres (0D) are a few examples of frequent geometries. Because of their special electrical, magnetic, and physiochemical characteristics—such as size control, an improved surface area to volume ratio, and functionalities—nanoparticle production is crucial. The primary causes of these distinctive characteristics of nanoparticles are (i) electron confinement within the particles, (ii) particle size modifications to alter bandgap energies, and (iii) a high surface to volume ratio (Mughal et al.. 2021). The recent developments in the field of nanotechnology have improved and revolutionized several other fields. The number of advantages and uses for nanotechnology is expanding quickly. Among these are magnetic nanoparticles (MNPs), a nanoscale substance with distinct magnetic properties that have found extensive application in a variety of domains, including energy, engineering, biomedicine, and environmental applications. Due to their special qualities that make them potentially useful in biology, catalysis, agriculture, and the environment, MNPs have recently become the focus of intense research (Ali et al.. 2021).[6] Because they occupy a significant portion of the length scale between the macro- and molecular levels, they are the subject of intense investigation by researchers (Khan and Hossain 2022). Important parts of the Earth's biogeochemical system are nanoparticles. However, during the Anthropocene, human activity changed their natural cycle and increased their abundance by adding anthropogenic nanoparticles (ANPs), changing their emissions and releases, and changing the environmental processes that include nanoparticles. The number of anthropogenic particles discharged into the environment, whether on purpose or accidentally, is always increasing. It is well known that both man-made and natural nanoparticles have a significant role in modifying the transport, speciation, bioavailability, and environmental consequences of trace elements and organic micropollutants. Even yet, they are currently treated independently, which is insufficient given the need for a more comprehensive, integrated, and non-sectorial viewpoint that includes particles from diverse origins as well as the multiple processes that are likely to produce and involve them (Lespes, Faucher, and Slaveykova 2020).[7] When treating an illness, targeted therapy involves administering the right amount of medication to the affected part of the body for an extended length of time. To achieve this, creation of safer and more effective therapeutic nanoparticles is vital and one of the ultimate goals of nanomedicine. (Yetisgin et al.. 2020).[8]

Nanoparticles are prone to aggregation and protein opsonization (protein attaching to the surface of the nanoparticle as a tag for recognition by the immune system) as soon as they are incorporated into the bloodstream. The opsonized nanoparticles may be removed from circulation through filtration in the kidney, spleen, or liver, or by phagocytosis. The immune system's quick and indiscriminate clearance causes a shorter retention period, which reduces bioavailability (Yetisgin et al.. 2020).[8]

2. Organizing Nanomaterials into Classes

Based on their size, shape, and morphology—a term that describes their structure—nanoparticles are divided into different groups. Here is a list of some of the most important kinds of nanoparticles that are currently understood.

3. Organic Nanoparticles

A variety of organic nanoparticle forms are shown in Figure 1, including micelles, dendrimers, liposomes, nanogels, polymeric NPs, and multilayer biopolymers. A hollow sphere characterizes some organic nanoparticles, like liposomes and micelles, which are biodegradable and non-toxic. It is also possible for organic nanoparticles to degrade naturally. Additionally, nano capsules—which are incredibly sensitive to heat and light—are referred to by this moniker. Polymeric nanoparticles are another term that is occasionally used to describe organic nanoparticles (Alshammari et al.. 2023).[9] Polymer nanotechnology is regarded as one of the potential systems to address the problems in drug delivery. This includes delivering undelivered molecules, like oligonucleotides, and targeting drugs. The creation of nanoparticles with the right characteristics, which validates appropriate medication transport and pointing, is one of the major issues in nanotechnology. A broad range of polymers and copolymers in different grades are utilized to manufacture the nanoparticles. The synthesis of polymers with carefully controlled structures and conformations opens the door to the development of finely tailored nanoparticles, which are essential for achieving drug targeting objectives. (Sahoo et al.. 2021).[10]

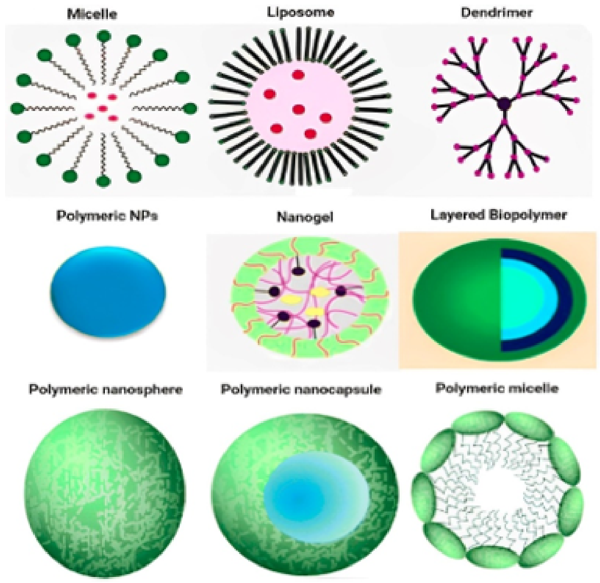

Figure 1: Types of organic nanoparticles (Sahoo et al.. 2021)

4. Inorganic Nanoparticles

Typically, nanoparticles (NPs) have a diameter of less than or equal to 100 nm, or what is known as a nano scale size. They are used in many industries, such as electronics, cosmetics, and medicine, due to their special qualities. Because of its superior medication delivery system, skin-whitening capabilities, and moisture retention qualities, nanoparticles of silver, gold, zinc oxide (ZnO), and titanium oxide (TiO2) are utilized in cosmetic products. Because they don't pierce the skin, their usage in cosmetics is harmless. As a result, when applied topically, they are less hazardous. The use of NPs in therapy and diagnosis is expanding daily. For them to be used effectively in a variety of industries, including food, cosmetics, medicine, etc., safety must be guaranteed. Inorganic NPs, such as metallic NPs and quantum dots, are among the most widely produced and commercially utilized types of NPs (Bhatti et al.. 2021).[11]

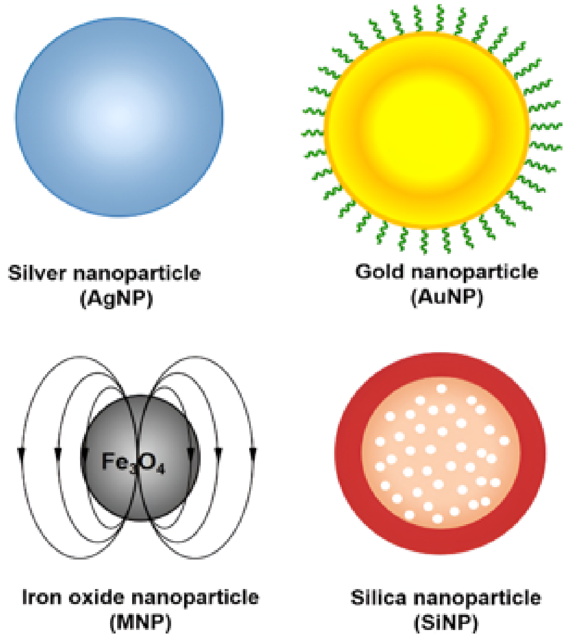

Figure 2: Types of inorganic nanoparticles (Díez-pascual 2022)[12]

5. Carbon Based Nanoparticles

Solid Carbon Material (SCM) are known to exist in a variety of bulk phases, such as diamonds, and molecular forms, such as fullerenes. In fact, because of their extraordinary mechanical, chemical, thermal, and electrical characteristics, CNMs hold a special place in nanoscience. Nowadays, the field of electromagnetic fields (EMs) uses a variety of SCM types that fall into two categories. One type of carbon powder is nano powdered carbon, which includes carbon black (CB) and nanodiamond, the latter of which can be utilized in energetic compositions as a reducing agent. The other is CNMs, which include graphene, extended graphite (EG), carbon nanotubes (CNTs), graphene oxide (GO), and fullerenes. CNMs have a rich pore structure and a huge surface area. A summary of these elements' use in the field of energetic compositions was published lately. Large surface area nano-sized carbon materials can be functionalized with energetic groups or combined with binders, energetic compounds, metal fuels, or combustion catalysts to form novel advanced functional nanostructures with improved properties that can be used in propellants, explosives, and pyrotechnics, thereby broadening the range of their applications in Ems (Yan et al.. 2016).

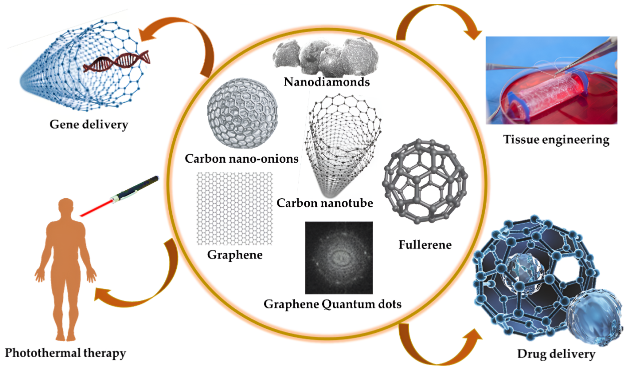

Figure 3: Types of carbon nanoparticles (Mahor et al.. 2021)

6. Herbal Nanoparticles

Herbal remedies are typically taken as a crude extract, dried or not, which is essentially a blend of the plants' primary and secondary metabolites. The term "secondary metabolites" (SMs) describes tiny molecules produced by plants, whether they are bioactive.(Zhao et al.. 2020). Herbal extracts typically consist of a blend of many phytoconstituents with different molecular weights, solubility levels, possible medicinal benefits, and chemical classes. Some substances, like polyphenolics, glycosides, etc., are polar and soluble in water; others, like monoterpenes, sesquiterpenes, diterpenes, and triterpenoids, etc., are non-polar and soluble in fat; yet others, like flavonoids and alkaloids, may be both polar and partially soluble in water or fat. When combined, these differences pose challenges (Teja et al.. 2022).

7. Green Synthesis

Green synthesis offers numerous advantages compared to chemical and physical processes. It is non-toxic pollution-free, environmentally friendly, affordable, and more sustainable. The quality of the finished goods, reaction time, and raw material extraction remain problematic, though (Ying et al.. 2022). The most prevalent chemical components found in plant extracts, including phenols, reducing sugars, flavonoids, ascorbic acids, protein amino acids, and others, oversaw the stabilization of the nanoparticles and the bio reduction of metal ions (Wei et al.. 2017). Currently, sodium/potassium borohydride is commonly used as a reductant in the well-established liquid-phase reduction process for producing NZVI. Another chemical process involves using gaseous reductants created by pyrolyzing carbon-based materials to reduce iron oxide, or hydrous Fe^{2+}, in the form of salts at high temperatures (X. Wang et al.. 2017). The utilization of plant extracts in the production of nanoparticles has a compelling advantage over alternative methods due to its ease of application, lower cost, and increased safety for human health.(Vijaya et al.. 2019). Among the safest, greenest, and most promising ways to create nanoparticles is through green synthesis. Toxic chemicals will be replaced with plant sources used as reducing agents throughout the nanoparticle manufacturing process. Ruellia tuberosa (RT) leaf aqueous extract was used in the current investigation to synthesize FeONPs.(Vasantharaj et al.. 2019). A scanning electron microscope was used to examine the morphology of the nanoparticles (Sougandhi and Ramanaiah 2020). AgNPs are especially important for prospective uses in the biomedical, anti-viral, anti-bacterial, and anti-fungal fields (Sana and Dogiparthi 2018).

Using plant extracts as stabilizing and reducing agents during the fast and environmentally friendly production of metallic nanoparticles is seen to be a good idea. It can greatly eliminate the foregoing difficulties and make the nanoparticles more biocompatible and non-toxic. Many studies have been published on the synthesis of AgNPs with possible antibacterial and anticancer properties. These studies have used extracts from various plants, including oak fruit bark, Thymbra Spicata, Sesbania grandiflon, Rubus glaucus Benth, Alpinia calcarate, green tea, and Sesbania grandiflon (Shahriary et al.. 2018).

I reviewed a lot of papers for plants with their herbal extract on which nanoparticles are made. Here are some of the plants with their nanoparticles.

8. Synthesis of Nanoparticles

In NP synthesis, there are two basic ways known as top-down and bottom-up. The NP synthesis from bulk materials into tiny ones is described by the top-down approach. The top-down approach is primarily classified as a physical method of NP synthesis since it uses a large tube furnace to break large materials into tiny pieces. Conversely, the bottom-up approach proposes that smaller molecules be used to synthesize NPs in the necessary amount. In this process, chemical reduction is generally used, sometimes in conjunction with the capping agent for stabilizing the synthesized NPs. The bottom-up technique also includes the biological process of NP synthesis, in which biomolecules combine with metallic substances to produce nanoscale materials.(Ramanathan et al.. 2021).

Table 1: List of plants with their nanoparticles (Shahriary et al.. 2018)

S. No.	Plant Name	Plant Extract	Plant Family	Nano formulation	Particle Size	References
1	*Cassia fistula L*	Aqueous extract of stem bark	Leguminosae	Gold NPs	55.2–98.4 nm, rectangular and triangular	(Daisy and Saipriya 2012)[13]
2	*Chamaecostus cuspidatus (Nees & Mart) CD Specht & DW Stev*	Aqueous extract of leaves	Costaceae	Gold NPs	50 nm, spherical	(Ponnanikajamideen et al.. 2019)[14]
3	*Cinnamomum cassia (L) J Presl*	Aqueous extract of whole plant	Lauraceae	Silver NPs	NM	(Kouame et al.. 2019)[15]
4	*Citrullus colocynthis (L) Schrad, Momordica balsamina L, and Momordica dioica Roxb ex Willd*	Methanolic extract of fruits	Cucurbitaceae	Nanoliposome	450 nm, −22.7 mV	(Rathee and Kamboj 2018)[16]
5	*Couroupita guianensis Aubl*	Aqueous extract of leaves	Lecythidaceae	Gold NPs	47 nm, spherical, −36.3 mV	(Sengani and V 2017)[17]
6	*Echinacea purpurea (L) Moench*	70% v/v ethanol extract of whole plant	Asteraceae	Chitosan NPs	218 (42) nm	(Mao et al.. 2018)[18]
7	*Elettaria cardamomum (L) Maton*	1,8-cineole-rich supercritical carbon dioxide extract of seeds	Zingiberaceae	PEGylated nanoliposomal formulation	NM	(Paul et al.. 2019)[19]
8	*Eysenhardtia polystachy (A Gray) S Watson*	50% v/v methanol extract of bark	Fabaceae	Silver NPs	10–12 nm, spherical, −32.25 mV	(Garcia Campoy et al.. 2018)[20]
9	*Gymnema sylvestre (Retz) Schult*	Gymnemic acids rich fraction extracted from leaves	Asclepiadaceae	Silver NPs	21.5 nm, spherical	(Shanker, Krishna Mohan, et al.. 2017)[21]
10	*Hibiscus subdariffa Rottb*	Aqueous extract of leaves	Malvaceae	ZnO NPs	16–60 nm, spherical	(Bala et al.. 2015)[22]
11	*Lawsonia inermis L*	Aqueous extract of leaves	Lythraceae	Silver NPs and cerium oxide NPs	50 nm, spherical	(Kalakotla et al.. 2019)[23]
12	*Momordica charantia L*	Aqueous extract of fruits	Cucurbitaceae	ZnO, cerium oxide and silver NPs	22.5–55.8 nm, spherical	(Shanker, Naradala, et al.. 2017)[24]

Continued on next page

Table 1 continued

13	*Morus indica L*	Aqueous extract of leaves	Moraceae	ZnO NPs	6–12 nm	(Anandan et al.. 2019)[25]
14	*Morus spp*	Aqueous extract of leaves	Moraceae	Silver NPs	35 nm, −15 mV	(Nouri et al.. 2020), (Xu et al.. 2019)
15	*Musa paradisiaca L*	Aqueous extract of stem	Musaceae	Silver NPs	30–60 nm, spherical	(Anbazhagan et al.. 2017)[26]
16	*Plicosepalus acaciae (Zucc) Wiens & Polhill and Plicosepalus curviflorus (Benth ex Oliv) Tiegh*	Methanolic extract of whole plant	Loranthaceae	SLN (Compritol 888 ATO as solid lipid and sodium dodecyl sulfate as surfactant)	Size: 22–70 nm, spherical	(Aldawsari et al.. 2014)[27]
17	*Pyrus sp.*	Peer fruit extract	Rosaceae	Gold NPs	200-500nm; triangular, hexagonal	(Ghodake et al.. 2010)
18	*Psoralea corylifolia L*	Aqueous extract of seeds	Fabaceae	Silver NPs	18 nm, circular	(Rani et al.. 2018)
19	*Punica granatum L*	Methanolic extract of fruit peel	Punicaceae	Gold NPs	20 nm, spherical	(Manna et al.. 2019)
20	*Sambucus nigra L*	Aqueous extract of fruit	Adoxaceae	Gold NPs	21.3 nm, spherical, −22.6 mV	(Opris et al.. 2017)
21	*Smilax glabra Roxb*	Aqueous extract of rhizomes	Smilacaceae	Gold NPs	50−90 nm, hollow	(Ansari et al.. 2019)[28]
22	*Stevia rebaudiana (Bertoni) Bertoni*	70% v/v methanol extract of leaves	Asteraceae	Chitosan NPs	< 73.27 nm, spherical	(Perumal et al.. 2016)
23	*Syzygium cumini (L) Skeels*	Aqueous extract of seeds	Myrtaceae	Poly--caprolactone NPs	NM	(Bitencourt et al.. 2017)[29]
24	*Withania somnifera*	Leaves	Nightshade	Silver NPs	5–40 Irregular, spherical	(Kuppusamy et al.. 2016)
25	*Trigonella-foenum graecum*	Seeds	Fabaceae	Gold NPs	15–25 Spherical	(Kuppusamy et al.. 2016)

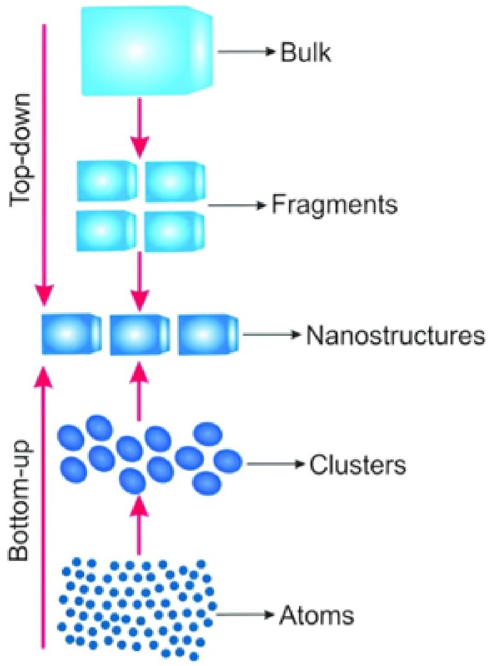

Figure 4: Approaches for nanoparticles (Galstyan et al.. 2018)[30]

9. Top to Bottom Approach

9.1. Ball milling/ grinding

A powder mixture is put in the ball mill and subjected to high-energy collisions from the balls during the ball milling process. The milling process involved rotating the jars for a maximum of 5 and 10 hours, respectively, at a constant milling speed of 500 rpm. Every thirty minutes, the rotational orientation of the ball mill was reversed. To avoid overheating, the air conditioning system kept the temperature at 27 0C during the ball milling operation.(Abhay Kumar Aman et al.., 2018).[31]

9.2. Lithography

Combining nanosphere lithography (NSL), a low-cost method, with a micro propulsive injection technique yields a high output of 3000 wafers per hour. The NSL procedure typically consists of two phases. The substrate is initially immersed in the suspension of nanospheres (such as polystyrene beads) to produce the lithography mask. A self-assembling hexagonal-close-packed (HCP) monolayer forms on the substrate's surface as the suspension solvent evaporates. The formation of the nanostructure is the subject of the second phase, which involves removing the template and depositing the desired material over the lithography mask. In this instance, the material that remains is a periodic array of NPs. By adding further treatment stages, such as reducing the nanospheres by oxygen plasma treatment before nanostructure formation, NHs and other nanostructures can be achieved. (Brady et al.. 2019).[32]

9.3. Electrospinning

The electrospinning method is used to make a nonwoven web of micro- or nanofibers. As the jet dried, fibers developed and were deposited on the collector. One easy and flexible way to prepare micro- or nano polymer fibers is by electrospinning. Another method for creating inorganic fibers is by electrospinning polymers that are present in the precursor solution. The viscosity, conductivity, surface tension, and other characteristics of the electrospinning solution—all of which are essential to the process—may alter in the presence of polymers.(Reddy et al.. 2016).

9.4. Chemical etching

Metal-assisted chemical etching (MACE) is a potent method for creating high aspect ratio surface nanostructures on silicon. Applications for the synthesis of networks of nanowires, nanopores, or nanocores, as well as more intricate patterns, can be found in a variety of sectors, including chemical and biological detection, solar energy conversion, and microelectronics.(Pinna et al.. 2020).

10. Bottom-Up Approach

10.1. Chemical vapor deposition (CVD)

The chemical vapor deposition (CVD) technique involves intricate chemistry. It frequently consists of combinations of surface and gas-phase processes. The volatile precursors are transported to the reaction zone by the carrier gas and/or diffusion. Both kinds of reactions produce gaseous byproducts and a solid thin coating on the substrate as their end products. The difference between CVD and physical deposition techniques like sputtering, evaporation, and molecular beam epitaxy is this chemical process.(Dahmen 2003).[33]

10.2. Sol gel synthesis

One of the most well-established techniques for creating nanophosphors is the sol-gel approach. During synthesis, this approach may provide for total reaction control. Precursors are typically formed using nitrides, sulphates, and chlorides in this process. There are two categories for the sol-gel technique: aqueous and nonaqueous approaches.

1. **Aqueous sol-gel method:** In this method, we use water as a solvent medium.
2. **Nonaqueous sol-gel method:** In this method we use organic solvent as a solvent medium.(Ugemuge, Parauha, and Dhoble 2021).

10.3. Hydrothermal synthesis

The most used technique for creating nanomaterials is hydrothermal synthesis. In essence, it is a solution-reaction-based methodology. The creation of nanomaterials during hydrothermal synthesis can occur at temperatures ranging from ambient temperature to extremely high temperatures. Depending on the vapor pressure of the primary component in the reaction, either low-pressure or high-pressure conditions can be utilized to control the morphology of the materials to be synthesized. This method has been successfully applied to the synthesis of several different kinds of nanomaterials. The hydrothermal process can generate nanomaterials with high vapor pressures while minimizing material loss.(Gan et al.. 2020).

11. Template-Assisted Synthesis

Template synthesis is a relatively simple and easy procedure which has made the fabrication of rather sophisticated nanomaterials accessible to almost any laboratory. Template synthesis requires access to instrumentation capable of metal sputtering and electrochemical deposition. The characterization of the fabricated nanostructures can be done using instrumental techniques including spectrophotometry, voltammetry, optical microscopy, atomic force microscopy, and electronic microscopies (scanning electron microscopy (SEM) and transmission electron microscopy (TEM)).(Ugo and Moretto 2007).

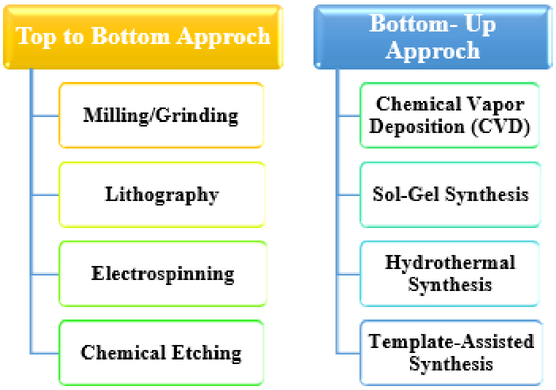

Figure 5: Methods for nanoparticles synthesis (Paramasivam et al.. 2021)

12. Characterization of Nanoparticles

There are several methods are present for the characterization of nanoparticles some few are mention in this paper.

12.1. UV/Vis spectroscopy

It is commonly known that, depending on their size and shape, plasmonic nanoparticles can absorb radiation from the visible to near infrared spectrum (NIR). This characteristic, known as surface plasmon resonance, is linked to the collective oscillation of nanoparticle surface electrons. The dispersion of Plasmonic nanoparticles produces one or more peaks due to their SPR property, which can be used to obtain important information on the size, shape, and size distribution of the nanoparticles. For this reason, characterization of plasmonic nanoparticles put into smart polymer microgels is commonly done using UV/Vis spectroscopy. Farooqi et al.. characterized Ag-P (NIPAM-AA) hybrid microgels and P(NIPAM-AA) microgels using UV/Vis spectroscopy.(Begum et al.. 2018).[34]

12.2. X- ray diffraction

X-ray diffraction is a crucial tool for studying nanomaterials. One of the most crucial characterization instruments in materials research and solid-state chemistry is X-ray diffraction (XRD). For any substance, XRD is a simple tool to use to find the size and shape of the unit cell. The produced nanoparticles were further investigated using energy dispersive spectroscopy (EDS) and X-ray diffraction. The X-ray diffraction data unequivocally demonstrates that the nanoparticles. Using the Debye-Scherrer formula, the average crystalline size of nanoparticles is determined. (S and A 2018).

13. Scanning Electron Microscopy Analysis

EVs are frequently studied using scanning electron microscopy (SEM), which offers details on their size and morphology. SEM uses a concentrated electron beam to scan a material, interacting with the atoms to produce three-dimensional surface topography. On the other hand, high vacuum is used for conventional SEM, which necessitates intricate and time-consuming sample preparation such as metallization, fixation, and dehydration. As a result, exosomes from human serum display a distorted cup-shaped morphology in typical SEM images. Because low-voltage SEM doesn't require a layer of conductive coating, it has recently been shown to be a potential technique for researching EVs.(Pallares-Rusiñol et al.. 2023).

13.1. Fourier-transform infrared spectroscopy

FTIR is an extremely useful instrument for characterizing a nanoparticle's surface. It is possible to identify the reactive surface sites that cause the surface reactivity as well as the surface chemical composition of nanoparticles under circumstances. The method of finding the distinctive functional groups from the spectral bands that enables us to determine the conjugation between the nanomaterial and the adsorbed biomolecules is called Fourier transform infrared spectroscopy (FTIR spectroscopy). The absorption peaks in the FTIR spectrum are indicative of the vibrational frequencies between the atoms' bonds within the nanoparticle. When it comes to qualitative analysis, FTIR is a great tool because its peak intensity can tell you exactly what kind of materials are there.(Torres-Rivero et al.. 2021).

14. Application of Nanoparticles

Herbal medications can be defeated by encasing or connecting them to appropriate nanomaterials. Significant progress has been achieved in the last ten years in the creation of innovative drug delivery systems (NDDS) utilizing extracts and active ingredients from plants. Herbal markets respond well to the creation of novel formulations for nanoparticles, dendrimers, nanocrystals, quantum dots, nanospheres, and nano capsules. The latest strategy in herbals, known as nanotechnology, has a bright future since it uses science to administer the component in a sustained way that improves patient compliance and eliminates the need for recurrent administration.(Patil et al.. 2018).

15. Bacterial Resistance of Nanoparticles

The main justification for NPs' consideration as an antibiotic substitute is their potential to successfully stop microbial drug resistance in specific circumstances. Antibiotic overuse has given rise to several health risks for the public, including superbugs resistant to all current medications and drug-resistant epidemics. To tackle medication resistance, it is important to find new, effective bactericidal materials. NPs have been identified as a viable solution to this problem. NPs, however, occasionally have the potential to encourage the development of bacterial resistance. The advantages and disadvantages of the interactions between NPs and drug-resistant bacteria are discussed in this section.(L. Wang, Hu, and Shao 2017).

16. Nanoparticles in Antiviral Therapy

Because of their small sizes, adjustable surfaces, and high surface-to-volume ratios, nanomaterials have special qualities. The ability to combine several antiviral drugs onto a single nanoparticle is a crucial feature of nanoparticulate carriers. Therefore, the negative effects of specifically designed antiviral therapies are reduced when they are delivered systematically to healthy, uninfected cells. When administered intravenously, nanoparticles can pass through the bloodstream without getting stuck in the capillaries of the lungs or being taken up by mononuclear phagocytic cells.

The utilization of nanoparticulate delivery systems as carriers for the delivery of the most popular antiviral medications will be covered in this article. An outline of viral replication and antiviral drug mechanisms of action will be provided prior to discussing the uses of nanomaterials as antiviral agents. Lastly, a summary will be provided of the nanoparticulate carriers utilized in antiviral therapy for the following viruses: hepatitis C virus (HCV), herpes simplex virus type 1 and type 2 (HSV-1 and HSV-2), and human immunodeficiency virus (HIV). These viruses cause chronic infections with severe clinical manifestations and complications.(Milovanovic et al.. 2017).

17. Nanoparticles in Cancer Therapy

Following the development of nanotechnology, several widely marketed and commercialized nanotherapeutic medications have been developed, and since 2010, numerous more have progressed to the clinical stage. Because they offer the possibility of drug combination therapy and the inhibition of drug resistance mechanisms, nanotherapeutic medicines have advanced the fields of drug delivery systems and anti-tumor multidrug resistance (MDR). In the 1960s, ETH Zurich made a trailblazing attempt to use nanotechnology in medicine. This combination has shown to be more effective in creating a range of diagnostic tools and more effective treatments.(Gavas, Quazi, and Karpiński 2021).[35]

18. Nanoparticles in Diabetics Treatment

Several delivery strategies based on nanoparticles have been put forth to improve oral insulin absorption by circumventing the stomach's enzymatic breakdown and so improving penetration through the gastrointestinal tract (GIT). Drugs may be absorbed more fully by paracellular means with the use of nanoparticles. Hydrophobic nanoparticles are useful for endocytosing epithelial cells. However, cationic nanoparticles limit their absorption by interacting with the negatively charged mucus layer. Although neutral and hydrophilic surface nanoparticles are preferred for removing mucus, their contact with epithelial cells may be hampered. Digestive enzymes (endopeptidase trypsin, alpha-chymotrypsin, elastase, and carboxypeptidases A and B) continue to affect the paracellular and transcellular absorption of insulin-loaded nanoparticles, even after they have withstood pH fluctuations in the GIT. Insulin oral dose forms undergo proteolysis in the stomach, which happens after enterocytes' intracellular peptidase degradation.(Souto et al.. 2019).

18.1. Antifungal activity of nanoparticles

AgNPs are effective antifungal medicines that combat a range of fungal-related disorders. When combined with fluconazole, biologically produced AgNPs have increased antifungal activity against the Candida albicans species phomaglomerata. Comparing AgNPs stabilized by sodium dodecyl sulphate to traditional antifungal medications, the former demonstrated stronger antifungal action against Candida albicans. At a dosage of 8 μg/ml, the AgNPs produced by Bacillus species demonstrate potent antifungal action against the plant pathogenic fungus Fusarium oxysporum. AgNPs damaged the cell wall and other components of T. asahii, exhibiting promising antifungal action at a minimum inhibitory concentration (MIC) of 0.5 ug/ml. Because of their small size, nanoparticles may enter cells with ease. where it binds to several cell constituents and prevents the cell from functioning. Combined with antibiotics such as ketoconazole, which has demonstrated strong antifungal efficacy with MIC less than 0.5 mg/ml against.T. Galatage et al.., 2021).

18.2. Diagnostic, biosensor, and gene therapy applications of nanoparticles

Because they may be made to have certain characteristics or behave in a particular way, nanoparticles have an edge over current therapeutics. They are useful for visualizing cells. Since silver has a sharper and stronger Plasmon resonance than other metals, it is useful in imaging systems. A silver-based biosensor is now a potent method for detecting cytochrome P53 in head and neck squamous cell carcinoma. AgNPs are useful for detecting levels of sulphide as well as heavy metal ions such as nickel, cobalt, and mercury because of their colorimetric sensing characteristic. On the other hand, the rapid collection and identification of the green-colored residue of malachite is caused by the in-situ growth and development of AgNPs on polydopamine traced filter paper. (T. Galatage et al.. 2021).

19. Nanoparticles Avilable in Present

There are so many nano formulations are available in market in current time, and here are some of them-

20. Conclusion

Nanotechnology involves the use of nanoparticles, which are particles with lengths between 1 nm and 100 nm. These particles have unique properties compared to bulk materials. Nanoparticles can be organic, inorganic, carbon-based, or herbal, and they find applications in various fields. They are used in drug delivery, cosmetics, medicine, energy storage, and sensors. Green synthesis, a sustainable approach, is also mentioned. Overall, the document provides an overview of nanoparticles and their potential applications. They are classified as zero-dimensional nanomaterials and have distinct physico-chemical characteristics compared to bulk materials due to their small size and high surface to volume ratio. Nanoparticles have gained attention in various fields due to their adjustable properties and potential applications in drug delivery. The document discusses different types of nanoparticles, including organic, inorganic, carbon-based, and herbal nanoparticles. Organic nanoparticles such as micelles and liposomes are commonly used for drug delivery. Inorganic nanoparticles such as silver and gold nanoparticles find applications in cosmetics and medicine. Carbon-based nanoparticles like graphene and carbon nanotubes have various uses in energy storage and sensors. Herbal nanoparticles derived from plant extracts are also mentioned. The concept of green synthesis is highlighted in the document, which offers advantages in terms of environmental friendliness and sustainability. The document also provides information on nano formulations available in the market, such as liposomes, polymer-based nano formulations, protein-drug conjugates, and surfactant-based nano formulations. Overall, nanoparticles have significant potential applications in different industries, and their adjustable properties make them valuable in areas like drug delivery and energy storage. The use of green synthesis methods contributes to sustainability in nanoparticle production.

21. Future Aspects

21.1. Improved medication

1. **Administration Bioavailability**: When employed as pharmaceuticals, herbal nanoparticles can increase the bioavailability of bioactive chemicals derived from medicinal plants, hence enhancing their efficacy.
2. **Customized Delivery**: By delivering herbal formulations precisely to the afflicted tissues or cells, nanoparticles provide tailored medicine delivery, reducing adverse effects.

21.2. Medical therapy

Combination Therapies: By combining many herbal extracts or substances into a single nanoparticle formulation, herbal nanoparticles can give synergistic effects that may aid in the development of combination therapies.

Disease-specific Treatments: Customizing herbal nanoparticles to address certain illnesses or ailments, like cancer, inflammatory diseases, or neurological illnesses.

21.3. Functional foods and nutraceuticals

1. **Increased Stability:** To maintain the nutritional value of bioactive ingredients in functional foods and nutraceuticals, herbal nanoparticles can improve their stability.
2. **Controlled Release:** Systems with controlled release capabilities can be created to release bioactive substances gradually, offering long-term health advantages.

Table 2: Nanoparticles available in market

S. No.	Name	Nano formulation	Approval/indication	Reference
1	AmBisome®	Liposomes	FDA 1997 Systemic fungal infections (IV)	(Hiemenz and Walsh 1996)
2	DaunoXome®	Liposomes	FDA 1996 HIV-related KS (IV)	(Eckardt et al.. 1994)[36]
3	DepoCyt®	Liposomes	FDA 1999/2007 Lymphomatous malignant meningitis (IV)	(Kim et al.. 1987)
4	DepoDur®	Liposomes	FDA 2004 For treatment of chronic pain in patients requiring a long-term daily aroundthe-clock opioid analgesic (administered into the epidural space)	(Glantz et al.. 1999)
5	Inflexal® V	Liposomes	Switzerland 1997 Influenza vaccine	(Mischler and Metcalfe 2002)
6	Abelcet®	Lipid-based (non-liposomal)	FDA 1995 and 1996 Marketed outside USA as Amphoci	(Janknegt et al.. 1992)
7	Adagen®	PEGylated proteins, polypeptides, aptamers	FDA 1990 Adenosine deaminase deficiency – severe combined immunodeficiency disease	(Hershfield 1993)
8	Cimzia®	PEGylated proteins, polypeptides, aptamers	FDA 2008 Crohn's disease, rheumatoid arthritis	(Weissig, Pettinger, and Murdock 2014)
9	Pegasys®	PEGylated proteins, polypeptides, aptamers	FDA 2002	(Weissig et al.. 2014)
10	Copaxone®	Polymer-based nanoformulations	FDA 1996/2014 Multiple sclerosis (SC)	(Weissig et al.. 2014)
11	Eligard®	Polymer-based nanoformulations	FDA 2002 Advanced prostate cancer (SC)	(Sartor 2003)
12	Genexol®	Polymer-based nanoformulations	South Korea 2001 Metastatic breast cancer, pancreatic cancer (IV)	(Oerlemans et al.. 2010)
13	Abraxane®	Protein–drug conjugates	FDA 2005 Metastatic breast cancer, non-small-cell lung cancer (IV)	(Silas Inman 2013)
14	Kadcyla®	Protein–drug conjugates	FDA 2013 Metastatic breast cancer	(Weissig et al.. 2014)
15	Fungizone®	Surfactant-based nanoformulations	FDA 1966 Systemic fungal infections (IV)	(Weissig et al.. 2014)
16	Diprivan®	Surfactant-based nanoformulations	FDA 1989 Sedative–hypnotic agent for induction and maintenance of anesthesia (IV)	(RxList 2021)
17	Feridex®	Metal-based nanoformulations	FDA 1996 Liver/spleen lesion MRI (IV) Manufacturing discontinued in 2008	(Wang, Billone, and Mullett 2013)
18	Feraheme™ (Ferumoxytol)	Metal-based nanoformulations	FDA 2009 Treatment of iron deficiency anemia in adults with chronic kidney disease	(Weissig et al.. 2014)
19	NanoTherm®	Metal-based nanoformulations	Europe 2013 Local ablation in glioblastoma, prostate, and pancreatic cancer (intratumoral)	(Weissig et al.. 2014)
20	Gendicine®	Virosomes	People's Republic of China 2003 Head and neck squamous cell carcinoma	(Peng 2005)
21	Rexin-G®	Virosomes	Philippines 2007 For all solid tumors	(M. and L. 2011)

22. Applications in the Environment

Water Purification: By exploiting the antibacterial or adsorption qualities of some herbal extracts, herbal nanoparticles may find use in the purification of water.

22.1. Crop protection and agriculture

1. **Biopesticides**: By leveraging the antibacterial qualities of some herbal extracts, herbal nanoparticles can be utilized to create sustainable and environmentally friendly biopesticides.
2. **Nutrient Delivery:** By improving the way nutrients and bioactive substances are delivered to plants, nanoparticles can help them grow and become more resilient.

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24. Conflict of Interest

None.

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