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RESEARCH ARTICLE

NANOPARTICLES UNVEILED: A COMPREHENSIVE REVIEW OF CLASSIFICATION, PROPERTIES, SYNTHESIS, AND APPLICATIONS

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Abstract

Nanoparticles, defined as particles with dimensions ranging from 1 to 100 nm, represent a groundbreaking domain of nanotechnology. NPs have immense importance across various scientific disciplines and industries. NPs can be classified into zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) structures based on their dimensions. NPs are also classified into carbon, semiconductors, ceramics, polymers, and metal NPs based on their materials. NPs exhibit remarkable physicochemical properties, such as high surface area-to-volume ratios, exceptional thermal conductivity, and catalytic activity, making them crucial in fields such as materials science, medicine, and environmental engineering. Nanoparticles can be synthesized through both top-down approaches, where bulk materials are broken down into smaller particles, and bottom-up methods, involving the assembly of atomic or molecular components. Their applications are diverse and include drug delivery systems, advanced catalysts, nanoelectronics, and environmental remediation technologies, demonstrating their pivotal role in shaping our technological landscape.

Introduction:-

The study of the characteristics of matter at the nanoscale is known as nanoscience. The International Organization for Standardization (ISO) defines nanoparticles as nanosized (1–100nm) objects with consistent exterior dimensions and lengths. If the dimensions change significantly, nanofibers or nanoplates may be preferred(Jara et al., 2021). NPs come in various forms, sizes, and topologies, including irregular, spherical, spiral, conical, cylinder-like, tubular, and hollow cores. In the field of nanotechnology, substances with sizes (1-100 nm) known as nanomaterials are synthesized, engineered, and used(Najahi-Missaoui et al., 2020). The origin of nanoscience and nanotechnology theories is widely attributed to Nobel laureate Richard Feynman's renowned speech, "There's Plenty of Room at the Bottom," presented at the American Physical Society conference in 1959. However, nanotechnology and

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nanomaterials have been used for a very long time. Nanomaterials are the fundamental building blocks of nanotechnology and have been defined as materials showing no less than one dimension at the nanoscale(Mitchell et al., 2021). Surface and quantum impact are two significant factors that lead nanoparticles to behave considerably differently from larger-scale materials. These aspects cause nanoparticles to have enhanced or unique mechanical, catalytic, thermal, electronic, optical, and magnetic capabilities(Yusuf et al., 2023). Because of their unique qualities, they are applicable in water treatment, agriculture, catalysis, electronics, and medication deliver. The particles are likely to be employed in medical applications, e.g., for tumor treatment, medical imaging, biochemical detection, and medication delivery(Gavas et al., 2021). ZnONPs have the capacity to precisely target cancer cells, therefore they have been researched for medication delivery. Copper NPs are being investigated for delivering drugs to heal bacterial infections because they have been proven to exhibit antibacterial characteristics(Astruc, 2020). NPs have the potential to increase the specificity as well as the sensitivity of sensors applied to security measures, such as those used to detect biological, chemical, or radioactive dangers. Nanoparticleshave the potential to increase the efficiency and effectiveness of devices that store energy used in defense apparatus, such as batteries or fuel cells(Algar et al., 2021). Nanoparticles have the potential to change the electronics industry in numerous ways and are applied in a wide range of electric applications. NPs are employed to enhance the functionality of screens like LCD and OLED screens via improving the illumination, shade, and contrasting qualities of the images. AgNPs and AuNPs have been investigated in LCD and OLED screens for enhancing the display's conductivity(Joseph et al., 2023). Nanoparticles are useful in many environmental applications because of their small size and unique physical and chemical properties. Environmental pollutants, including heavy metals found in water and organic pollutants from soil, can be eliminated by nanoparticles. FeNPs are the most often employed nanomaterials for remediation and water treatment(Pandit et al., 2022).

Nanoparticles

The International Organization for Standardization (ISO) defines nanoparticles as nanosized (1–100nm) objects with consistent exterior dimensions and lengths. If the dimensions change significantly, nanofibers or nanoplates may be preferred. NPs come in various forms, sizes, and topologies, including irregular, spherical, spiral, conical, cylinder-like, tubular, and hollow cores(Yetisgin et al., 2020).

Classification of Nanomaterials According to Their Dimensions

Nanomaterials are classified into the following four categories according to their dimensions, as shown in **Figure 1.**

Nanomaterials With Zero Dimensions (0-D)

These tiny objects, which have all three dimensions, include fullerenes, quantum dots, and nanoparticles(Liu et al., 2023).

Nanomaterials With One Dimension (1-D)

One dimension exists outside the nanoscale for this family of nanomaterials. Several examples include nanohorns, nanowires, nanorods, nanotubes, and nanofibers(Astruc, 2020).

Nanomaterials With Two Dimensions (2-D)

Beyond the nanoscale, this group of nanomaterials has two dimensions. Examples include nanosheets, nanolayers, and nanofilms(Liu et al., 2023).

Nanomaterials With Three Dimensions (3-D)

The materials in this class are not constrained in any way to the nanoscale. Bulk powders, nanotube arrays, nanowire and nanoparticle dispersions, and other materials fall under this category(Algar et al., 2021).

Classification of Nanoparticles According to Their Chemistry

Carbon-based nanoparticles, organic nanoparticles, and inorganic nanoparticles are the three main types of nanoparticles, as shown in **Figure 1**.

Carbon-Based Nanoparticles

This class includes NPs formed entirely of carbon atoms . Carbon quantum dots, carbon black NPs, and fullerenes are well-known representatives of this class. Carbon quantum dots comprise distinct, spherical carbon nanoparticles with diameters less than 100. Carbon black nanoparticles are clusters of tightly linked spherical particles that look like grapes(Kumah et al., 2023).

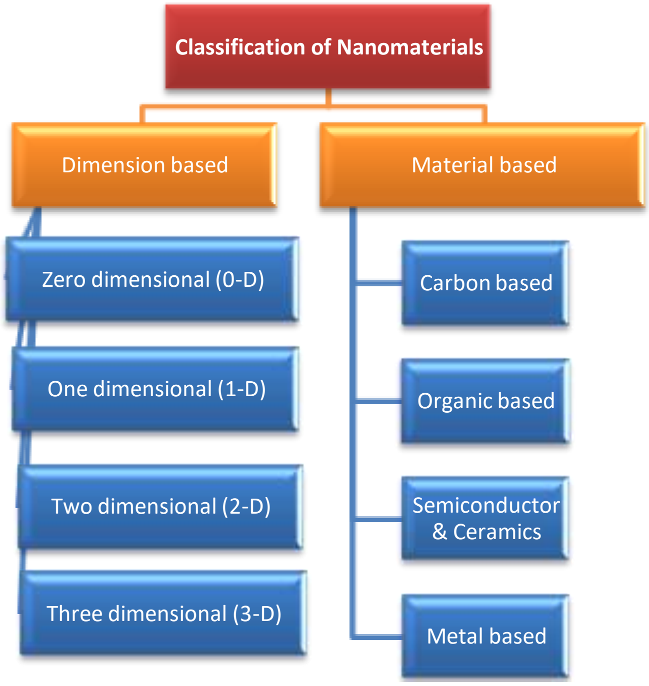

Figure 1:-Classification of NPs.

Fullerenes are compounds with symmetrical closed cages. Aside from C60 fullerenes, which contain 60 atoms of carbon arranged in a football form fullerenes (C70) and fullerenes (C540) have been identified. Carbon-based NPs' physicochemical features at the nanoscale are combined with the specific characteristics of sp2-hybridized carbon bonds(Gavas et al., 2021). Carbon-based NPs (CBNPs) are useful in; power storage biological imagin, drug delivery, photovoltaic panels, and environment-related applications, for instance, to monitor microbial communities or to detect pathogenic microbes owing to their distinctive electrical behavior, electron affinity, outstanding strength, sorption, optical, and thermal properties. They are also helpful in medication and biological engineering because they are not toxic and biocompatible(Bruna et al., 2021).

Organic Nanoparticles

Organic nanoparticles are made of carbohydrates, proteins, lipids, polymers, or any other type of organic substance. The most eminent members of organic NPs are dendrimers, micelles, liposomes, and complex proteins such as ferritin (Fig. 2). These NPs are normally biodegradable and toxic-free and may contain a hollow core in certain situations, such as liposomes(Li et al., 2021). Organic nanoparticles are susceptible to heat and electromagnetism. The prospective area of application of organic NPs is determined by various parameters such as composition, shape, strength, and load capacity. Organic NPs are now mostly employed in drug delivery and cancer treatment(Gu et al., 2020).

Inorganic Nanoparticles

Inorganic nanoparticles are not composed of organic or carbonelements. Semiconductors, ceramics, and metal NPs are familiar examples(Huang et al., 2020).

Semiconductors Nanoparticles

Semiconductor nanoparticles are composed of semiconductor materials with characteristics that fall between metals and nonmetals. These NPs have distinct broad bandgaps and exhibit considerable property changes with bandgap scaling relative to massive semiconductor stuff. Consequently, these NPs are useful in catalysis, optics, and electronics(Terna et al., 2021).

CeramicsNanoparticles

Inorganic compounds called ceramic nanoparticles are made of metal and metalloid oxides, including calcium and titanium, as well as carbonates, phosphates, and carbides(Wang et al., 2022). Ceramic nanoparticles are typically manufactured during consecutive heating and cooling processes and exhibit an amorphous, crystalline, densely packed, or porous nature. Their excellent solidity and carrying capacity make them useful in biomedical fields. Nonetheless, they are also employed in catalytic processes, dye deterioration, photonics, and optical electronics(Singh et al., 2016).

Metal Nanoparticles

Metal NPs with regulated facets, sizes, and shapes are critical in today's innovative entities. Metal nanoparticles entirely composed of metal predecessors may be mono-, bi-, or polymetallic. Bimetallic nanoparticles can be sculpted using alloys or manufactured using various laying methods (core-shell)(Mody et al., 2010). These NPs have unusual optic and electric features because of their localized surface plasmon resonance properties. Furthermore, certain metal NPs have distinct thermal, biological, and magnetic characteristics. Consequently, they have become increasingly crucial building blocks for the creation of nanodevices that have a wide range of biological, physical, chemical, pharmaceutical, and biomedical uses(Jamkhande et al., 2019).

Gold Nanoparticles

In chemistry, gold nanoparticles (AuNPs) haveachronichistory since the Roman period, whenthey were first used for decorating glassware by coloring it.The modern era of AuNP production started over 170 years ago through the efforts of Michael Faraday, who is believed to be considered the first to recognize that gold particles in colloidal solutions exhibit properties that are different from pure gold.In 1857, Michael Faraday studied the processes involved in creating and influencing suspensions of gold (Ruby) colloidal particles(Giljohann et al., 2020).

AuNPs are classified as magnetic nanoparticles because of their unique optic and electrical properties.Faraday demonstrated how nanoparticles of gold may produce a range of colored liquids when illuminated in particular ways. Nanometer-sized gold particles are known as AuNPs.They can absorb and disperse radiation in both visible and near-IR spectra because of their special physical and chemical characteristics.Gold nanoparticles exhibiting unique molecular-recognition, light-sensitive properties, and electrical proficiency are the subject of intense research along with several potential and ensured applications in electronics, catalysis, biomedicine, andelectron microscopy(Sani et al., 2021).

Silver Nanoparticles

AgNPs, small silver particles, have unique physical and chemical properties due to their small size, light absorption, and radiating capabilities, and high surface area-to-volume ratio, potentially offering additional antibacterial properties compared to bulky silver. AgNPs can be produced through chemical reduction, with the most common method being chemical reduction of AgNO3 aqueous solution.The experiment was conducted in an argon atmosphere using 70 mL of PVP-containing solution and 21 mL of aloe vera extract.The mixture was stirred in an ultrasonic for 45 min, heated at 80°C, and left for 2 h to produce a clear solution with minute suspended elements(Bruna et al., 2021).

Iron Nanoparticles

Small, nebulous FeNPs range in size from 1 to 100 nm.Energy storage, sensors, catalysts, conversion, and medication delivery mechanisms are just a few potential applications of FeNPs. They are also under investigation for application in solar and photovoltaic cells, as well as water treatment and remediation of the environment. FeNPs can be utilized as contrast substances to make tissues as well as organs more visible during magnetic resonance imaging. FeNPs, like other nanoparticles, may pose safety and health risks, particularly in the case of water purification processes, cancer treatments, and MRI applications(Pasinszki& Krebsz, 2020).

Zinc Nanoparticles

Zinc nanoparticles (ZnONPs) are 1-100 nm zinc-based particles with a 3.37 eV energy gap, serving as a wide band gap semiconductor with significant benefits in photochemical, catalytic, electrical, and optoelectronic applications.For catalytic reaction operations, ZnO nanostructures are excellent.Different methods such as laser ablation, thermal decomposition, chemical vapor deposition, hydrothermal, sol–gel, co-precipitation, precipitation, combustion, electrochemical deposition, anodization, ultrasound, and electrophoretic deposition are used to produce zinc nanoparticles (Czyżowska & Barbasz, 2022).

Physicochemical Properties of Nanoparticles

The most significant physicochemical properties are detailed in subsequent sections.

Thermal Properties

Energy conduction, thermal conductivity, thermal stability, thermoelectric power, and heat capacity arekey thermal characteristics for heat transmission in nanoparticles.The thermal and electrical conductivities of NPs are directly affected by the NP size.As the NP size decreases, the particle surface area/volume ratio increases.Substantial surface/volume ratio in NPs offers a greater supply of electrons, allowing heat transfer, which corresponds to one of the two major methods where heat is transported. In addition, microconvection promotes thermal conduction in NPs.However, such spectacle occurs when crystalline nanoparticles are dispersed in a liquid, resulting in the formation of a nanofluid.For instance, ethylene glycol with the addition of Cu NPs exhibits a 40% increase in thermal conductivity(Liu et al., 2022).

Electronic and Optical Properties

Semiconductor and metallic nanoparticles exhibitfascinatingphotoluminescence emission, linear absorption, andnonlinear optical features because oflocalized surface plasmon resonance and quantum confinement effects.When the frequency of the entering photon is constant while the conductive electrons are collectively excited, LSPR events occur.This phenomenon causes noble metal nanoparticles (NPs) to display an intense, ultraviolet - visible absorption stripe, which is absent in bands of bulky materials. The photosensitive characteristics of NPs are often influenced by their size, structure, and surrounding dielectric environment(Qiao et al., 2021).

Mechanical Properties

Composition, environment, and variousexternal forces under varioussituations and external forces are a few factors that determine the material'smechanicalcharacteristics.Similar to normal materials, mechanical characteristics usually exist in ten parts: rigidity, strength, hardness, ductility, brittleness, toughness, fatigue strength, flexibility, elasticity, and yield stress.Inorganic materials are brittle, lacking elasticity, plasticity, or toughness, whereas organic materials are elastic.Nanoparticles differ mechanically from bulk materials because of their display and quantum phenomena.For example, traditional FeAl powder is brittle, whereas ultrafine FeAl alloy powdery form offers a balance of ductility, toughness, and improved plasticity(Qi et al., 2021).

Magnetic Properties

With the three exceptions of TiBe2-xCux, Sc3In, and ZrZn2, all magnetic materials containa magnetic element such as iron, cobalt, or nickel.Other diamagnetic elements include Pd, Au, and Ag.It involves nanoscale modifications.Irregular electrical dispersal leads to the accumulation of various materials that become magnetic in NPs. FeAl, a non-magnetic material, is magnetic when it exists as NPs, unlike its non-magnetic appearance in bulk additional examples are Pd and Au. Composition, vacancy defects, crystallographic framework, and magnetic anisotropy are the main factors that affect bulk materials' magnetic characteristics.On a nanoscale level, however, shape and size are two crucial parameters that play a significant role(Nguyen et al., 2021).

Catalytic Properties

A novel strategy in the field of chemical catalysis, considerably improves catalytic properties compared withbulkieralternatives.The catalytic characteristics of NPs are affected by their size, composition, shape, oxidation state, interparticle spacing, and support.The relationship between catalytic activity and NP size has been extensively studied.The relationship is inverse, with smaller NPs being more catalytically active.Researchers have observed a relationship between size-selected gold nanoparticles (Au NPs) and indium tin oxide in electrocatalytic carbon monoxide oxidation, with the smallest NPs exhibiting the highest averaged present densities.Studies have shown that the addition of alloys to nanoparticles can enhance their catalytic activity by modifying the electronic characteristics associated with the catalyst, minimizing toxic impacts, and providing unique reflectivities(Luo et al., 2021). Aligning platinum with Ru, Co, and Ni metals enhances the hydrogenation and oxygen reduction activity of nanoparticle catalyst materials, thereby enhancing their resistance to CO poisoning Pt alloying with Fe, Pd, and Ru led to reduced reactivity for methanol breakdown.The decrease in reaction was justified by the possibility of surface occupancy with additional metal atoms because the original Fe, Pd, and Ru groups tend to be less reactive for methanol breakdown compared with similarly original Pt collections. Overall, changing the makeup of NPs alters the electrical structure of metallic surfaces by forming bimetallic connections and altering metal–to–metal link lengths(Czyżowska& Barbasz, 2022).

Synthesis Approaches of Nanoparticles

NP preparation involves three main approaches: physical, chemical, and biological. Physical techniques are top-down, whereas chemical and biological approaches are bottom-up.The biological approach is also known as the green approach(Khan et al., 2022).The synthesis approaches for the NPs are illustrated in **Figure 2.**

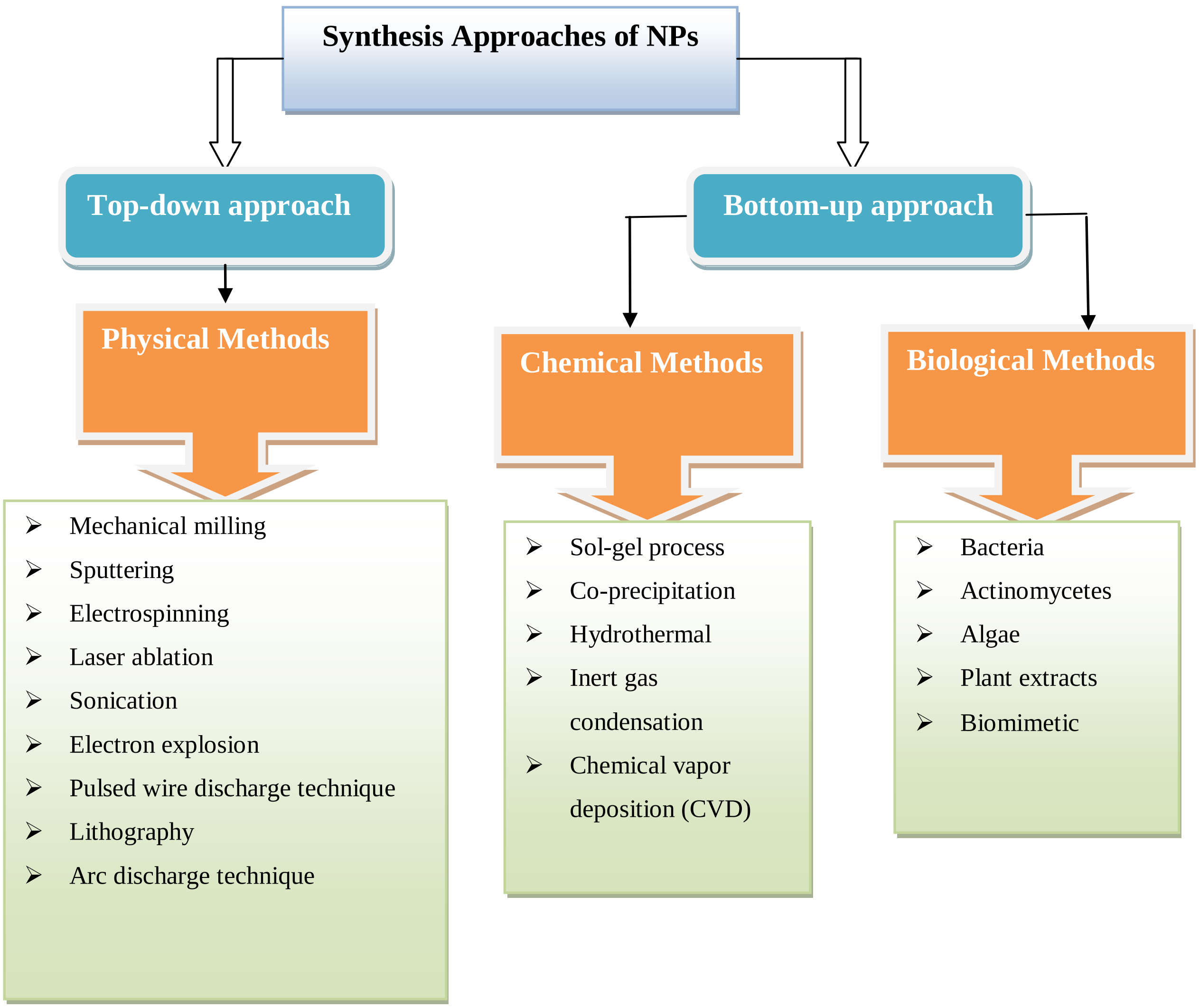

Figure 2:-Synthesis approaches of NPs.

Top-Down Approach

To develop Nano-structured materials, top-down techniques or physical methods are used to fragment bulk materials as shown in Figure 3.A top-down strategy may be achieved using the following methods:

Mechanical Milling

Mechanical milling is an efficient method for converting bulk materials intonanoscale materials(Iqbal et al., 2012).

Mechanical milling is a high-energy impact procedure that commonly involves pellets in the vessels performing function in a variety of mills, including shaker and planetary mills(Iqbal et al., 2012).

Sputtering
Sputtering is the process by which small particles of a material are expelled off its surface when it isassaultedby gas particles or intense plasma.Sputtering is appealing because it is less expensive than electron-beam lithography. During the sputtering deposition method, vigorous gaseous ions are employed to physically eject small atom clusters from the targeted region based on the initial gaseous ion's energy(Teo & Sun, 2006).

Electrospinning
Electrospinning is a method used to create nanofibers from various materials, primarily polymers, by pulling charged fibers from melted polymers or solutions. Coaxial electrospinning is a significant advancement in the field of electrospinning.Two coaxial capillaries make up the coaxial electrospinning spinneret.Two viscous fluids serving one as the shell and the other as the core, may be used inside of these capillaries to produce core-shell nanoarchitecture.This method has been used to create coreshell and hollow polymers as well as hybrid, organic, and inorganic materials(Qin & Riggs, 2013).

Laser ablation
Laser ablation synthesis is a method for creating nanoparticles by vaporizing a single substance with a powerful laser beam.This process evaporates the source substance or precursor, forming nanoparticles, and is an eco-friendly method for manufacturing meta nanoparticles.Laser ablation can produce various nanomaterials e.g., ceramics, metal, and carbon nanomaterials(Qin & Riggs, 2013).

Sonication
Sonication is crucial for producing nanofluids, which are prepared by magnetic stirring in a magnet stirrer and ultrasonic vibrators.Sonicators are industry standard for probe sonication, outperforming ultrasonic cleaned baths for nanomaterial preparation(Kumar et al., 2023).

Electron Explosion
With that technique, a thin strip of metal is shocked with a high voltage to cause ionization, eruption, and vaporization.The metal reacts with the adjacent gas or liquid to get ionized, vaporized, expand, and cool.Finally, nanoparticles are formed from the condensed vapor.The electron explosion method may produce NPs without employing Pt material as a reducing agent because it generates a flame from the electric explosion of a metallic cable(Kumar et al., 2023).

Pulsed Wire Discharge Technique
For producing metal nanoparticles, this technique is most frequently used. Metallic strips are commonly used to produce nanoparticles by vaporizing under pulsing current, which is then cooled by an outside gas, providing rapid power production(Qin & Riggs, 2013).

Lithography
Lithography is a technique for creating nanoparticles that usesa focused stream of light or electrons.The two main subcategories of lithography are mask- and mask-less lithography.In mask-less lithography, any nanopattern may be printed without the use of a mask.Furthermore, it is inexpensive and simple to implement(Teo & Sun, 2006).

Arc Discharge Technique
The Arc Discharge technique entails setting two graphite rods in an enclosure with a uniform helium pressure.Helium must be pumped into the enclosure because oxygen or any moisture will stop the production of fullerenes.The evaporation of the carbon rods is fueled by an arc discharge that occurs at the end of each graphite rod.The conditions under which the arc discharge occurs play a key role in producing novel forms of nanoparticles.This method may be used to produce a variety of nanostructured substances. Nanoparticles, including carbon nanotubes, graphene, fullerenes, and carbon Nano horns, are produced using an established method(Kumar et al., 2023).

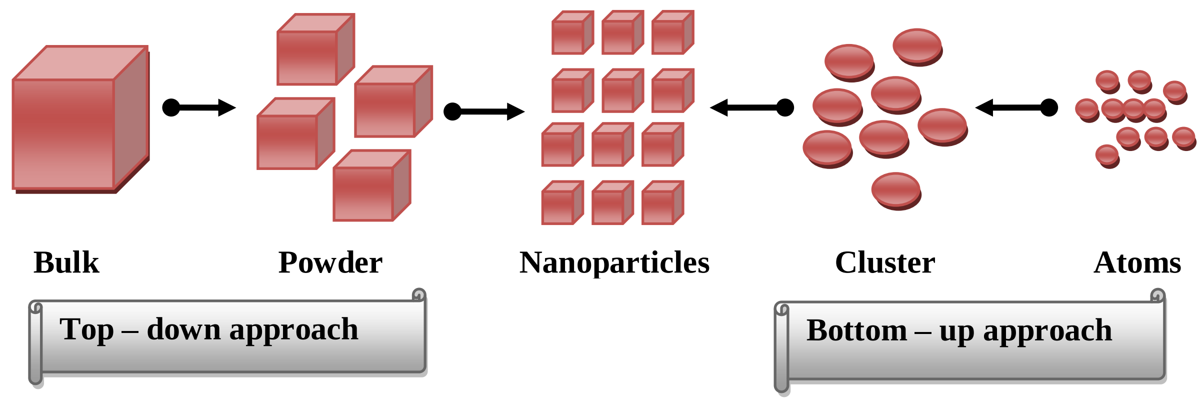

Figure 3:-Difference between Top- down and Bottom-up approach.

Bottom-Up Approach

Bottom-up approaches are usedto create nanostructured entities by assembling small atoms and molecules using chemical and biological practices, asshown in Figure 3.

Sol-gel process

A popular wet-chemical approach for creating nanomaterials is the sol-gel method. Metallic forerunners are reduced, processed into water, and thermally degraded in solution, resulting in a stabilized solution, commonly known as a sol.Hydrolysis increases the density of the gel.Adjusting pH levels, concentration of precursor, and temperature, can indicate the particle size.The solvent removal, Ostwald ripening, and phase shift that is required to allow the development of solid mass at the time of the mature stage might require some days to complete.The chemical components that are unstable are separated to produce nanoparticles.The sol-gel method is responsible for the created material's various advantages, including its environmental friendliness.A few of the numerous benefits of the sol-gel approach are-;the simplicity of the procedure, the homogeneous property of the product produced, and the lower processing temperature(Feuerbacher et al., 2022).

Co-Precipitation

This wet chemical approach uses the solvent displacement mechanism. Solvents include things like ethanol, acetone, polymers, and hexane that don't dissolve in water. Naturally occurring or synthetic polymer phases are also possible. Rapid transfer of the polymeric solvent into a non-solvent state of a polymeric material is accomplished by combining the polymer solution. The creation of nanoparticles is caused by interfacial tension in two phases(Lombardo et al., 2020).

Hydrothermal

In this technique, hydrothermal synthesis utilizes a broad range of temperatures from room temperature to exceedingly high temperatures to produce nanoparticles. There are various advantages comparing this approach to biological and physical ones. The hydrothermal synthesis-produced nanomaterials might become unsustainable at more extreme temperature levels(Eicken et al., 2021).

Inert Gas Condensation/Molecular Condensation

This technique yields a significantamount of metal NPs.The inactive compressed gas technique has been widely used to make small NPs by forcing a metallic supply to vanish in a inert gas.Metallic materials evaporate at a reasonable rate at a temperature that is attainable.Copper metal is vaporized in a neon, argon, or helium-filled vessel to produce CuNPs.After boiling out, the atom is cooled with a gas that is inert to swiftly lose its energy.When the gases are cooled with liquid nitrogen, 2-100 nm nanoparticles are created(Eicken et al., 2021).

Chemical Vapor Deposition (CVD)

During CVD, a light coating is produced on the surface of the substrate by a chemical procedure employing vapor-phase intermediates or precursors.A precursor is considered suitable for CVD if it demonstrates enough volatility, low cost, good chemical purity, harmless nature, great evaporation reliability, and extended shelf life.Itsdecomposition should also not produce any pollutants. CVD modifications include vaporized phase epitaxy, atomic layered epitaxy, plasma-enhanced CVD, and metallic organic CVD.The advantages of this technique include the production of stiff, homogenous, and durable highly pure nanoparticles. Outstanding nanomaterials can be produced very effectively using CVD. Two-dimensional nanoparticle production is another notable characteristic of it(Imperial, 2021).

Biological Approach

Term "green" or "biological" synthesis of nanoparticles refers to fabrication of different metallic nanoparticles (MNPs) manipulating bioactive components, like; microbes, material from plants, and different biowastes like vegetable scraps, fruit peel trash, shell of an egg, scrap from agriculture, algal biomass, and so forth.To avoid the development of unwanted or hazardous byproducts, trustworthy and sustained green synthesis procedures are required (Figure 3). Green nanotechnology offers severalbenefits as well, such as being simpleand inexpensive, creating NPs with significant strength, requiring relatively little time, yielding harmless residues, and easily enable forsynthesis of NPs atlarge scale(Rónavári et al., 2021).

Bacteria

Nanoparticles are produced by microbes via metal capturing, capping, and enzyme reducing. Metallic ions are primarily entrapped onto the outside or inside of the cells of microbes before being transformed by enzymes into nanoparticles.It is quick, easy, and affordable to synthesize metallic nanoparticles using microorganisms, particularly marine bacteria.Metal NPs are created using a variety of microbes, such as bacterial cells, which are considered to be potential biofactors for the production of Au, Ag, and CdSnanoparticles.Bacteria use their cell to create inorganic chemicals either externally or internally.Metal NPs based on Escherichia coli VM1, Desulforibriocaledoiensis, Ochrobactrumanhtropi, and Enterococcussp. have been reported primarily in favor of prospective photocatalytic attributes action against cancer, andactivity against bacterial disease(Adeyemi et al., 2022).

Fungi

Due to their many enzymes and simplicity of handling, fungi are perfect for producing metallic and metallic sulfide nanoparticlesbecause they can quickly produce nanoparticleswith a variety of sizes, dimensions, and chemical compositions.Verticilliumluteoalbum has been shown to produce AuNPs ranging in size from 20 to 40 nm.Metal NPs derived from Penicillium brevicompactum KCCM 60390 and Aspergillus terreus have been found to have cytotoxic and antimicrobial activities , correspondingly(Roy et al., 2021).

Actinomycetes

Actinomycetes, also known as ray fungus, are prokaryotes with similar characteristics to fungi, producing nanoparticles in the sameway as fungi.Thermomonospora sp., a new extremophilic actinomycete, has been reported to generate spherical, extracellular, and monodispersed gold nanoparticles (AuNPs) approximately 8 nm in size.Streptomyces sp. and Rhodococcus sp. have been have been observed to have antibacterial properties(Pryshchepa et al., 2020).

Algae

Algae's polymeric compounds can break down heavy metallic ions, forming bendable forms in their extracts, which typically contain pigments, minerals, carbohydrates, polyunsaturated fats, and proteins, and other bioactive components such as antioxidants that function as reducing, stabilizing, and capping agents. Algae, either alive or dead, are employed as biological models for the ecologically friendly production of nanostructures.Silver and gold are thoroughly explored elements in NPs synthesized by algae, either inside or outside the cell.Ochloropsis oculate, Chlorella vulgaris, Scenedesmus sp. IMMTCC-25, Chlorella vulgaris, use in Li-ion batteries, antimicrobial effects and effective catalytic properties have been noticed based on these metallic nanoparticles(Naganthran et al., 2022).

Plant Extracts

Plant extracts are substances or active ingredients of the required quality that are prepared from plant tissues for specific use.To make nanoparticles, herbal extracts are blended with a solution of metal salts at room temp.The reaction is complete in a short period of time.This process has been utilized to produce silver (Ag), gold (Au), and a variety of other metal NPs.Numerous plants are used in the biosynthesis of nanoparticles. Plant extract nature and its concentration, metal salt concentration, pH value, level of heat, and time frame collectively have an influence on the production, quantity, and characteristics of nanoparticles(Naganthran et al., 2022).

Solanum nigrum, Clitoriaternatea, Cinnamomum zeylanicum, Coffea arabica, Euphorbiaantiquorum L, Emblica officinalis, Anisomeles indicia, Coleus forskohli, Azadirachta indica, and Bergenia ciliate are some glimpses of plants used in the green production of metal nanoparticles (AgNPs). These were tested for their cytotoxicity, antibacterial and catalytic, anti-filaria, mosquitocida, and antioxidantactivities respectively(Pryshchepa et al., 2020).

Biomimetic

Chemical procedures that mimic biological synthesis and are frequently carried out by means of organisms are referred to as "biomimetic synthesis". Cells, pollen, proteins, enzymes, and viruses are employed during the biomimetic method to generate NPs.Functional biomimetic synthesis employs a variety of materials and methodologies to mimic certain qualities of natural stuff, infrastructure, and procedures.This approach endeavors for various desired nanostructure production by mimicking the synthesis routes, procedures, or systems of natural substances.For example, by replicating the protein production process, various unique Nano-superstructures (e.g., structures like dendrimer, satellite, pyramid, cube, 2D arrays, 3D AuNPs tubes, and so forth)have been assembled in vitro(Roy et al., 2021).

Table 1:-Different NPs synthesized by applying different methods and their applications.

Sr No.	NPs	Applied Method	Particle size	Application	Reference
1	TiO_2	Ball milling method	10–20 nm	Liquefied petroleum gas sensor	(Naganthran et al., 2022)
2	ZnO	Laser ablation method	40-119 nm	Photocatalytic activity	(Adeyemi et al., 2022)
3	Cu	Laser ablation method	45 nm	Dental applications as bacterial agents	(Eicken et al., 2021)
4	ZnO	Sputtering method	16-20 nm	Photocatalytic applications	(Feuerbacher et al., 2022)
5	ZnO-Ag	Electrospinning method	450 nm	Protective clothing application	(Imperial, 2021)
6	Ag	Electrospinning method	18-30 nm	Catalytic activity (4-nitrophenol)	(Kumar et al., 2023)
7	Zn-TiO_2	Sol-gel method	12–18 nm	Photocatalyticactivty	(Lombardo et al., 2020)
8	TiO2	Sol-gel method	3- 30 nm	Antibacterial application	(Qin & Riggs, 2013)
9	Ag	Hydrothermal method	20-30 nm	Antibacterial activity	(Rónavári et al., 2021)
10	Fe_3O_4	Hydrothermal method	160 nm	lithium-ion battery	(Bruna et al., 2021)
11	Fe_3O_4	Co-precipitation method	14.96 nm	Biomedical applications	(Czyżowska & Barbasz, 2022)
12	ZnO	Co-precipitation method	140 nm	Photodegradation activity	(Iqbal et al., 2012)
13	Au	Green method (Coffea arabica L.)	5 - 50 nm	Bacterial activity	(Khan et al., 2022)
14	Au & Ag	Green method (Aloe vera)	10-30 nm	Optical coatings and cancer treatment	(Liu et al., 2022)
15	Ag	Green method (Citrus limon)	<50 nm	Cancer treatment	(Luo et al., 2021)
16	Cu	Green method (Tinospora cordifolia)	50–130 nm	Catalytic degradation	(Nguyen et al., 2021)
17	Cu	Green method (Citrus medica Linn)	33 nm	Antimicrobial activity	(Pasinszki & Krebsz, 2020)
18	Fe	Green method (Amaranthus dubious)	43 - 220 nm	Photocatalytic and antioxidant	(Qi et al., 2021)
19	Al	Green method (Honey)	10 - 100 nm	Removal of heavy metal	(Qiao et al.,

					2021)
20	Au	Biological method (E. coli)	8-50 nm	Electrochemistry of hemoglobin	(Giljohann et al., 2020)
21	Ag	Biological method (Bacillus cereus)	20-40 nm	Antibacterial activity	(Gu et al., 2020)
22	ZnO	Biological method (Candida albicans)	15-25 nm	Catalytic application	(Huang et al., 2020)
23	Ag	Biological method (Arthrodermafulvum)	20.56 nm	Antifungal activity	(Jamkhande et al., 2019)

Applications of Nanoparticles

Nanoparticles have unique characteristics and benefits. There are a few potential applications of NPs in various fields, as shown in **Figure 4.**

Medical field

Nanoparticles are small and unique particles with unique physical and chemical properties that make them ideal for various medical applications owing to their small size. Technological attraction has been observed in AuNPs because of their distinct optical characteristics, simplicity of production, and chemically stable nature. These particles are likely to be employed in medical applications, for example, for tumor treatment, medical imaging, biochemical detection, and drug delivery(Mody et al., 2010). NPs have the ability to administer medications to specific body parts for specific and efficient therapies. AgNPs are being explored as medicines because of their resilience and potential use in specific malignant tumor types. ZnO NPs have the capacity to precisely target cancer cells; therefore, they have been researched for medication delivery. Copper nanoparticles have been investigated for the delivery of drugs to treat bacterial infections because they have been proven to exhibit antibacterial characteristics. Because AuNPs may aggregate in some malignant tumors and have special electric, optical, and catalytic capabilities, they are being investigated for medication delivery. Bone cement, implants, and wound dressings include AgNPs. Iron oxide nanoparticles can be used as magnetic resonance imaging (MRI) materials for the visualization of specific body parts. Nanoparticles (NPs) may stimulate tissue and organ development and repair. Since titanium dioxide nanoparticles exhibit the capacity to promote the formation of bone cells, they have been considered for the purpose of tissue engineering. Furthermore, CuNPs and AgNPs exhibit potent antibacterial capabilities and have been investigated for use in a range of medical devices, including wound-care products and medical equipment(Sani et al., 2021).

Defense Field

NPs have the potential to increase the specificity and sensitivity of sensors applied to security measures such as those used to detect biological, chemical, or radioactive dangers. They may increase the efficiency and resilience of safeguarding materials used in defense tools, including chemically or biologically resistant coatings. For example, metal NPs can increase the mechanical characteristics and endurance of the coating, enabling them to be resilient to corrosion. For instance, the corrosion resistance of a polymer coating can be increased by adding NPs composed of Al or Zn. However, introducing Ni or Cr-based nanoparticles might increase their wear resilience(Singh et al., 2016). In addition to their use in the creation of protective and defensive materials, some sources have reported that NPs might be used in defensive and military applications, such as the production of armory and fencing materials. For instance, adding metallic or ceramic NPs to other types of materials such as polymers can enhance their mechanical characteristics and increase their resistance to damage. NPs have also been used in the development of sensors and detection systems for defense reasons. They can enhance the efficiency and long-term reliability of military equipment components. Metal nanoparticles can be used as strengthening agents in polymeric defensive materials. For example, adding metal NPs, such as nickel (Ni), to polymeric materials may increase their thermal, mechanical, and electrical characteristics. Gold and platinum nanoparticles are used to create valuable substances, such as sensors and catalysts, batteries, and fuel cells(Wang et al., 2022). Nanoparticles have the potential to increase the efficiency and effectiveness of devices that store energy used in defense apparatus, such as batteries or fuel cells. Using nanoparticles in the defense industry as cathode components can improve battery capacity, charging efficiency, and cycle stability. Owing to their high capacity and rate function, lithium cobalt oxide and transition metal oxides are widely used. Supercapacitors can also utilize nanoparticles to boost conductance. The use of nanoparticles in the military sector may increase the functionality, efficacy, and security of defense systems(Terna et al., 2021).

Electronics Field

Nanoparticles have the potential to change the electronics industry in several ways. Hence, they are used in a wide range of electrical applications. NPs are employed to enhance the functionality of screens, such as liquid crystal displays (LCD) and organic light-emitting diode (OLED) screens, by improving the illumination, shade, and contrasting qualities of the images(Wang et al., 2022). For instance, AgNPs and AuNPs have been investigated in LCD and OLED screens to enhance the conductivity of displays. NPs increase the energy density and charging speed, thereby enhancing the functionality and longevity of energy-storage systems, including batteries, capacitors, and supercapacitors. ZnO NPs can be employed in energy storage devices such as supercapacitors and battery packs because they can store and release power. Often made of magnet metals like iron, cobalt, or nickel, nanoparticles, can enhanced the capacity and speed of storage media such as hard disks and flash cards by storing and retrieving data via magnetism, thereby enhancing their use in such devices(Huang et al., 2020).

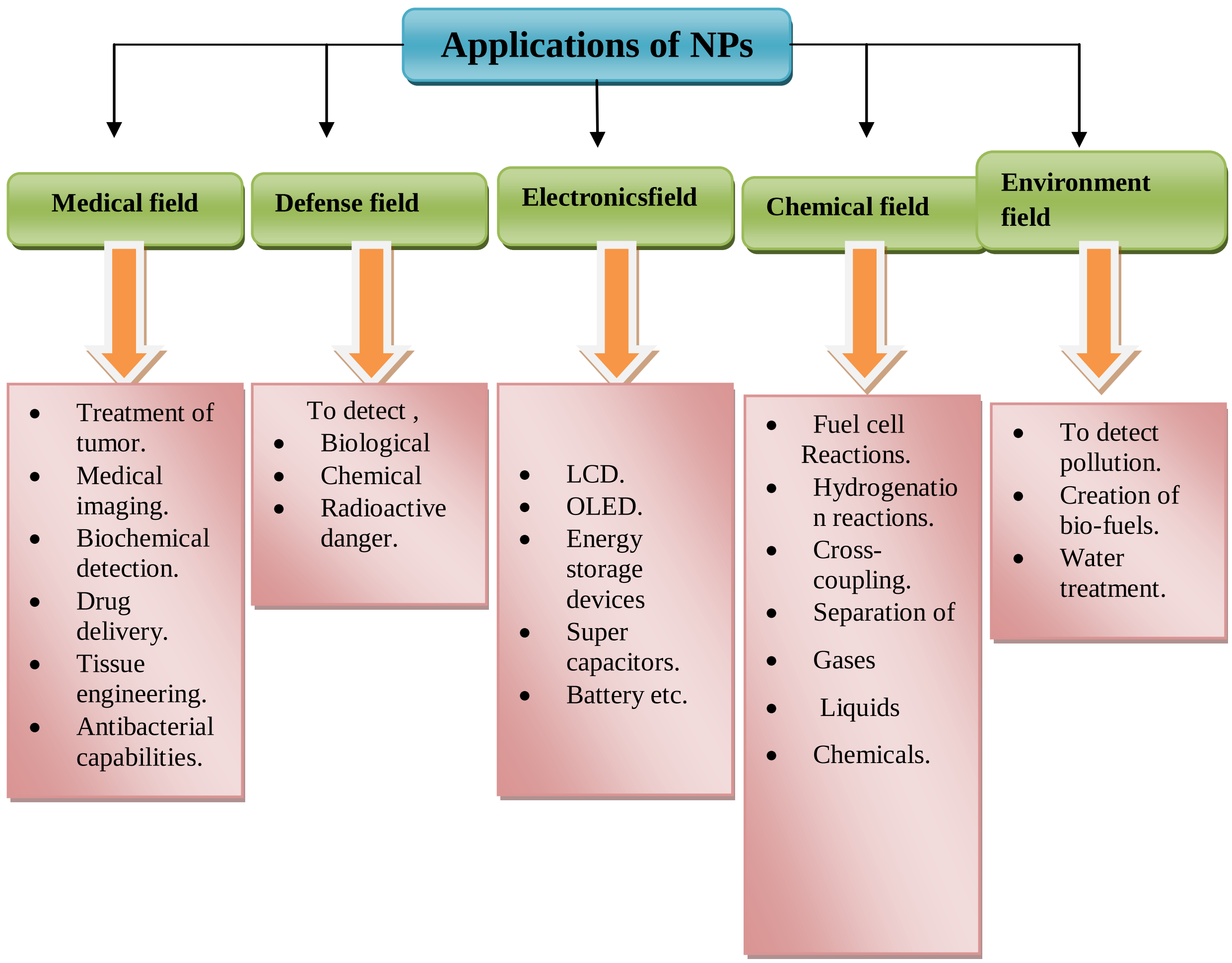

Figure 4:-Applications of NPs in different fields.

Chemical Field

Nanoparticles (NPs) have the potential to revolutionize the chemical industry for various applications. Nanoparticles (NPs) can enhance chemical reactions in more efficient ways at lower temperatures. Metal NPs, such as PtNPs, are used in fuel cell processes, oxidation and hydrogenation reactions, and cross-coupling and hydrogenation reactions.NiNPs have been used as catalysts in hydrogenation and hydrolysis.Owing to their size-based features, NPs are utilized for the separation and purification of chemicals as well as other materials such as gas and liquid(Sani et al., 2021). Iron nanoparticles are utilized in chemical processes, primarily catalyzing oxygen reduction and hydrolysis. Fe2O3 nanoparticles are utilized for the separation and purification of gases, liquids, and chemicals as well as for water treatment. AgNPs and AuNPs are used for water purification, removing microorganisms such as bacteria, viruses, and heavy metals, while filtering water and eliminating pollutants such as germs and viruses.AlNPs are utilized for purifying water, lubricants, and fuels, as well as cleaning gases, and separating and purifying both liquid and gaseous substances(Terna et al., 2021).

Environment Field

Nanoparticles are useful in many environmental applications owing to their small size and unique physical and chemical properties. Environmental pollutants, including heavy metals found in water and organic pollutants from the soil, can be eliminated by nanoparticles. For instance, certain contaminants such as organic chemical compounds and dyes present in wastewater can be successfully degraded by silver nanoparticles (AgNPs). Metal oxides, carbon nanotubes, nanoscale zeolites, and fibers are nanomaterials that are considered for remediation applications. Nanoparticles utilized in remediation can reach locations that larger ones cannot(Wang et al., 2022). They can be coated to make transportation easier and stop any reactions with the surrounding soil matrix before they react with pollutants. FeNPs are the most frequently used nanomaterials for remediation and water treatment. Heavy metal removal from freshwater is crucial because of its environmental and health impacts. Superparamagnetic Fe2O3 NPs are effective as sorbent materials, but no measurements of the intended nanoparticles in the surroundings are available with any logical technique. Nanotechnology and NPs have already been applied to enhance water quality and aid in environmental cleanup efforts. Their use as environmental sensors to detect pollution has become increasingly feasible. NPs can be employed as sensors to determine the presence of particular substances, including heavy metals or contaminants, in the environment. The compact size and broad detection range of nanosensorsoffer significant flexibility in real-world applications. Similar to AuNPs, which are employed as mercury sensors in water, NPS can be tailored to attach to specific pollutants, allowing easy identification at low concentrations(Wang et al., 2022). Nanoparticles (NPs) are utilized as catalysts in chemical processes, including the creation of biofuels and environmental remediation. PtNPs are particularly suitable for transforming biomass into fuels, such as biodiesel and ethanol. The ability to detect Hg ions in water samples, such as MilliQ water, groundwater, and tap water, is another interesting trait of these sensors. The Hg ion limits of quantification were 16.9, 26.3, and 47.3(Wang et al., 2022).

Future Challenges

Metal nanoparticles (NPs) have potential applications in various fields including medicine, defense, electronics, chemistry, catalysis, and the environment. However, there are challenges in the synthesis and processing with precise size and shape control, as high temperatures and harsh chemical conditions can hinder large-scale production. Additionally, the environmental impact of metal NPs, such as toxic silver NPs, necessitates further research on their effects and the development of more environmentally friendly methods. Future directions include energy storage, conversion, environmental protection, improving battery performance, solar cell efficiency, catalysis, and medicine, including drug delivery and cancer therapy. Therefore, further research is required to develop environmentally friendly synthesis and processing methods.

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