



NANOTECHNOLOGY- A REVIEW

AUTHOR- JASVIR KAUR, STUDENT [B.Sc. (N.M)]

GOVERNMENT COLLEGE FOR GIRLS LUDHIANA

AFFILIATED FROM PANJAB UNIVERSITY CHANDIGARH, PUNJAB.

ABSTRACT

Nanotechnology, the manipulation of matter at an incredibly minuscule scale, stands out as an innovative domain with extensive applications across diverse disciplines. This review probes into the fundamental principles, ongoing advancements, steering away from the usual stories, this abstract encourages readers to embark on a new journey into the realm of nanotechnology. It beckons a fresh exploration into the transformative power embedded in the world of manipulating matter at the incredibly tiny nanoscale. And potential future avenues of nanotechnology, scrutinizing its impact on the realms of medicine, electronics, materials science, and the sustainability of our environment.

KEYWORDS

Nanoscale, Nanoparticles, metal oxides, quantum dots, bionanomaterials, Topology, carbon nanotubes, nanobiosensors, drug delivery, zinc oxide, self assembling system.

Nanotechnology- Characterized as an "atomically precise technology"

It includes systems and materials with components and structures at the nanoscale, which really showcases novel and significantly improved chemical, physical, and, of course, biological properties, processes, and phenomena. Nanotechnology is an integral part of technology and is found within the sub classification, whatever that means, of technology comprising colloidal science, chemistry, physics, biology, and, all those other scientific fields too. It investigates phenomena at the nanoscale, and it's interesting to know that materials' properties at this scale can differ mega loads from those in bulk. Diminishing dimensions below 100nm can lead to dramatic alterations in material properties and not just a little! These nanostructured materials, designed for specific performance or to introduce new properties, exhibit distinct and, I mean distinctly different, physicochemical properties, particularly macromolecules and particles, you know, the ones that are within the 1–50nm size range.

Fascinating Historical Advancements

The term "nanotechnology" was popularized by Richard P. Feynman in his awesome lecture from 1959 called "There's Plenty of Room at the Bottom" [2]. He didn't do all the work himself. Lots of other scientists and researchers have contributed to this field over the years. In the 1980s, man named Eric Drexler [1], who is an engineer and researcher, took Feynman's ideas and made them even bigger. To the point where he proposed this concept of molecular nanotechnology. He wrote a super important book called "Engines of Creation," where he talked about building tiny machines and assembling materials at the molecular level. Richard Smalley, inspired by the Eric's work pursued his life in field of nanotechnology [1]. Nanotechnology's history is, like, evidence of how humans never give up and are always looking for precision and innovation. It unlocks all these crazy new possibilities in different scientific areas.

NANOPARTICLES – The building blocks

Nanoparticles, those tiny particles that are falling within the 1 to 100 nm size range [3], display intriguing transformations in their properties. This changes, occurring in at least one of the dimensions, sets them apart from individual atoms, molecules, and bulk materials. Diverse materials, such as metals, metal oxides, silicates, polymers, and even biomolecules, can form nanoparticles, each with unique characteristics. These particles come in various shapes like spheres, cylinders, and platelets, which are tailored specifically to some particular applications. The world of nanoparticles is vast and varied, which is influenced by different factors like chemical composition, morphology, and surface modifications. This dynamic field of science is continuously evolving by driven by the need for nanoparticles to adapt and excel in many diverse applications.

The nanoscale brings about some significant effects, mainly the very high concentration of atoms/molecules on the surface of nanoparticles. Additionally, there is a substantial increase in surface area per unit volume as particle size decreases. These two factors, magnified in smaller particles, give rise to the distinctive physical, chemical, and biological properties of nanomaterials.

PROPERTIES OF NANOPARTICLES

Nanoparticles boast a surface area that overshadows their volume, which can sparks heightened reactivity. They have this really cool quality that turns them into catalysts [21], making them masters of adsorption. In the captivating realm of the nanoscale, we can observe a fascinating phenomenon called Quantum size effects [19]. These tweaks to electronic, optical, and magnetic properties of nanoparticles are pretty mind-blowing. A great example of this enhancing phenomenon is the captivating fluorescence of quantum dots. When magnetic nanoparticles are below a certain critical size, they become superparamagnetic virtuosos. It's amazing how they respond so vigorously to external magnetic fields. These magnetic nanoparticles deserve applause for their roles in magnetic resonance imaging (MRI) and the truly magical realm of magnetic drug delivery. Nanoparticles, especially the avant-garde carbon nanotubes, flaunt remarkable flexibility and elasticity [19]. They step into the world of polymers and have the power to influence flammability. They raise the glass transition temperature and heat deflection temperature, making them quite the game-changers.

INTERACTIONS IN NANOPARTICLES It's a real maze encompassing various forces and phenomena at the nanoscale. Understanding these interactions is crucial for designing and utilizing nanoparticles in a wide range of applications, including medicine, electronics, catalysis, and materials science.

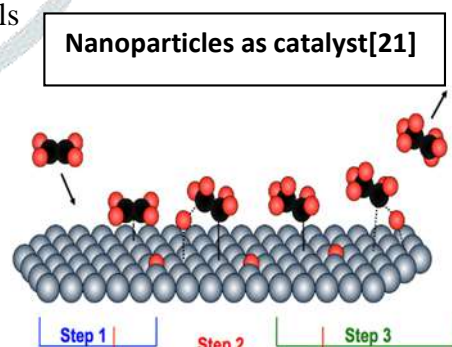
Van der Waals Forces: These London Dispersion Forces are fascinating and have a major influence on the behaviour of nanoparticles.

Dipole-Dipole Interactions: Electrostatic Interactions: Coulombic Forces and Double Layer Forces. When nanoparticles are in aqueous environments, they interact with a layer of ions. This electrical double layer makes things pretty interesting because the interaction between these double layers has a huge impact on the stability and behaviour of nanoparticles.

Chemical Interactions: covalent bonds. Nanoparticles can form these bonds with each other, and it leads to the creation of more complex nanostructures. **Surface chemistry: Magnetic interactions:** They can interact with external magnetic fields. **Hydrophobic and Hydrophilic Interactions,** etc.

Topological Interactions in the Realm of Nanotechnology

Topological interactions in the realm of nanotechnology, they super importantly emphasizes the impact of the size, shape, and surface characteristics of nanoparticles on their interactions with biological entities and surfaces. The exploration of topological interactions in nanotechnology, it unveils a nuanced understanding of how the geometric arrangement and structural features of nanomaterials, they influence their physical and chemical properties. Surface roughness, it emerges as another crucial factor that is affecting nanoparticle interactions. Rough surfaces, they can yield different behaviours in phenomena such as adhesion, catalysis, and sensing, when like compared to their smoother counterparts. This insight, it underscores the importance of considering, like not only the core structure of nanoparticles, it also emphasizes the intricacies of their surfaces, in various applications.



The arrangement of atoms and molecules within nanomaterials, it such as the unique carbon atom arrangement in graphene or carbon nanotubes, it is highlighted as a key determinant of electronic and mechanical properties. This effectively communicates, like, you know, how different shapes, they include nanoparticles, nanorods, and nanotubes, they manifest distinct behaviours based on their morphologies. It provides, you know, a comprehensive view of the, like, you know, diverse landscape of nanoscale materials.

TYPES OF NANOMATERIALS

Nanoparticles can be obtained through the use of modern technology and natural occurrences, which highlights their presence in volcanic eruptions, forest fires, and other sources. It presents a simple classification of nanomaterials based on composition (carbon, inorganic, organic excluding carbon, and composite) and further explores classification criteria such as dimensionality, morphology, and surface properties, providing a comprehensive glimpse into the diverse world of nanomaterials.

Dimensionality-based Classification

The concept of dimensionality in nanomaterials entails categorizing them based on the number of dimensions at the nanoscale. Quantum dots (QDs) are representations of nanostructures with zero dimensions (0D), whereas one-dimensional nanostructures (1D) encompass nanotubes, nanofibers, and nanowires. Two-dimensional complex materials (2D) consist of thin layers with strong in-plane bonds, exemplified by graphene and metal dichalcogenides. Bulk nanomaterials, which form three-dimensional structures (3D), exhibit various arrangements, such as dispersions of nanoparticles and multi-nanolayers, observed in 3D graphite and fullerene. This classification provides a systematic understanding of nanomaterials based on their dimensional characteristics [13][19].

Composition-based Classification

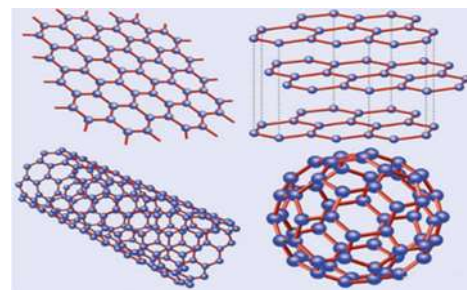
Nanomaterials can be classified based on their composition, including carbon-based, inorganic-based (such as Au or Ag nanoparticles or metallic oxides like TiO₂ and ZnO) [10], organic-based (excluding carbon), composite-based, and biological nanomaterials (encountering DNA and viruses as examples of biological nanomaterials). Additionally, a morphology-based classification is introduced [13], considering the shape and spatial organization of nanoparticles, emphasizing their diverse amorphous or crystalline nature, single or multi-chemical elements, and metallic, ceramic, or polymeric composition. The potential for creating intricate three-dimensional structures within the nanoscale range is highlighted through self-assembling methods, particularly utilizing DNA as building blocks. Overall, the dual classification offers a systematic understanding of nanomaterials from both compositional and morphological perspective.

1-D, 2-D, 3-D Nanomaterials

SYNTHESIS OF NANOPARTICLES

There are three distinct synthesizing ways for nanomaterials : physical chemical, and biological .

Physical courses or components [10], such as gas-phase statement [5], electron bar lithography, Laser removal union utilizes a solid laser bar to vaporize the target fabric, creating a differing run of nanomaterials. Lithography, counting veiled and maskless procedures, utilizes centered light or electrons to make nanoarchitectures. Mechanical processing may be a cost-effective method for producing nanoscale items, especially valuable for mixing unmistakable stages. Electrospinning could be a crucial handle for making nanostructured materials.



The chemical course [10] for nanomaterial amalgamation includes different strategies like coprecipitation, microemulsion, aqueous, electrochemical statement, hydrothermal, sonochemical Techniques, etc. Techniques such as chemical vapor deposition, sol-gel [7] ,reverse micelle, soft template, and microwave-assisted hydrothermal approaches play pivotal roles in producing various nanomaterials, ranging from magnetic nanoparticles to two-dimensional nanomaterials and nanostructured materials with controlled geometries. These

methods offer advantages such as cost-effectiveness, homogeneity, low processing temperatures, and the ability to create complex nanostructures.

The natural course incorporates distinctive strategies [10] e.g., parasites interceded, green growth algae [5], microscopic organisms interceded, yeast intervened [7], etc. Nanoparticles made by a biogenic enzymatic prepare are essentially prevalent to those made by chemical strategies in different perspectives.

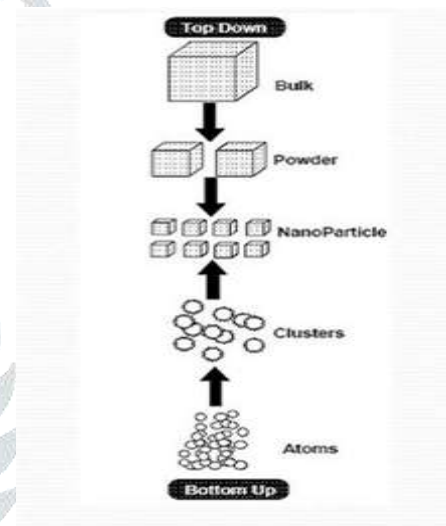
Different methods for the synthesis of nanoengineered materials and devices can accommodate precursors from solid, liquid, or gas phases and encompass a tremendously varied set of experimental techniques. In general, however, most synthetic methods can be classified into two main approaches: “top down” and “bottom up” approaches and combinations thereof.

Before this we should know what is meant by self assembling system [8]. It is defined as the system in which nanofabrication occurs due the interaction of individual small scale components in suitable ways which tends to organisation of components into higher ordered structure. Self organisation have many advantages at molecular and nano levels , like generation of 3-D structures, generation of structures with atmost controlled precision, etc.

There are many applications of self assembling system. For example Epitaxially Grown Self-Organized Solid-State Quantum Dots [8]. Self-Assembly of Nanocrystals and Nanowires, as we know that nanowires and nanocrystals are of the atmost use in incorporating nanotechnology in all aspects of devices, in medicinal values, in all others aspects of sciences, so by this technique the fabrication of nanoparticles is easier.

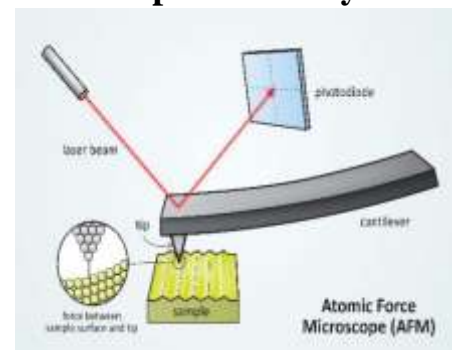
“**Top-down**” engineering involves starting with macroscopic materials and incorporating smaller-scale details [9]. For example, photolithography in the semiconductor industry etch patterns onto silicon wafers to create integrated circuits. Nanolithography methods such as dip pen and electrostatic atomic force nanolithography allow precise placement of features at the nanoscale.

On the other hand, “bottom-up” approaches design custom molecules capable of self-assembly into higher-order structures, driven by thermodynamics and molecular interactions. Templating techniques, such as biomineralization, guide the growth of nanostructured materials using pre-existing structures, which are relevant to applications such as biomimicry of human bone create. Bottom-up engineering includes chemical methods and green methods for fabricating nanomaterials, while top-down engineering includes physical methods [9].



"Advanced Imaging Techniques for Nanoscale Spatial and Temporal Analysis in Nanotechnology"

The molecular building blocks being manipulated are on such a small scale, these substrates have spatial and/or temporal levels of organization that span several orders of magnitude, with different levels nested within higher order levels. The nanoscale systems require advanced tools for studying their complex spatial and temporal organization. Techniques like Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM) [17], and Scanning Tunneling Microscopy (STM) [12] offer spatial and temporal resolutions below 10^6 at the molecular level, enabling visualization, characterization, and manipulation of nanomaterials.



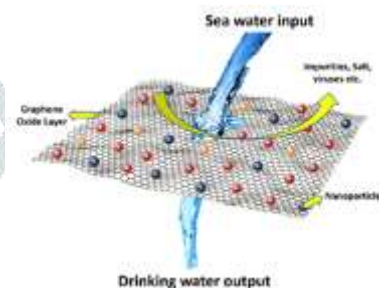
APPLICATIONS OF NANOTECHNOLOGY

NANOTECHNOLOGY IN MEDICIENE- Nanotechnology applications in science and pharmaceutical offer uncommon openings for focused on mediations. In medicate conveyance DRUG DELIVERY [10] – nanoparticles in drug delivery system works as a carrier of free drugs because of their special properties of increased solubility, enhanced distribution etc. nanoparticles like liposomes, micelles, and metal-based materials such as Au-NPs and

Ag-NPs upgrade medicate proficiency by moving forward dissolvability, soundness, and biodistribution. Nanotechnology moreover contributes to antimicrobial arrangements [10] through coatings with materials like TiO₂-NPs and ZnO-NPs, restraining the development of pathogens on surfaces. Chemically functionalized dendrimers appear guarantee in quality treatment, serving as nonviral conveyance vehicles for DNA. Besides, Moreover, ongoing research explores biologically inspired nanodevices, including DNA-based molecular computers and protein-based systems, for innovative medical applications [9].

WATER PURIFICATION- Nanotechnology offers innovative solutions for water purification by leveraging nanostructured materials with unique properties such as high reactivity, controllable pore volume, and electrostatic interactions. Nanoscale metals like silver, titanium, gold, and iron are employed for environmental mitigation, effectively disinfecting water from biological contaminants. Carbon nanotubes, discovered in 1991, are extensively utilized in water treatment, with CNT membranes showcasing potential for desalination by efficiently removing salts without compromising water flow rates [18][23].

APPLICATION IN FOOD INDUSTRY- nanotechnology has a vast impact on agriculture as well as on food industry. Nanofertilizer technology, nanopesticides, weed management ,all these are capable of enhancing the food production [11]. Nanomaterials are used in food processing and in food packaging systems. As nanomaterials are antimicrobial agents, so they are used in active packaging of food. Nanoadditives improves the nutritional values of food, nanobiosensors are used in detecting any pathogen involvement, etc.



NANOTECHNOLOGY IN SUNSCREENS - Nanoparticles (NPs) such as titanium dioxide and zinc oxide are widely used for different applications: in skin care products as an activating agent, as an antiseptic agent, as a pigment in paints, as piezoelectric in microelectronics etc. In modern cosmetic formulations, however, these NPs are exclusively used as an ultraviolet (UV) blocking agent in sunscreens [15,16]. Light-protective properties of ZnO and TiO₂ NPs are the primary reasons for choosing these particles. Because of the absorption, reflection and scattering properties, these particles prevent UV photons from reaching living skin cells.

NANO ELECTRONICS – Nanotechnology is revolutionizing electronics by creating smaller, more efficient devices. Nanoscale transistors and devices such as carbon nanotubes offer alternatives to improve computing power. Quantum dot displays, using semiconductor nanoparticles [20], deliver more vivid colours on electronic displays, while nanophotonics improve data transfer speeds through nano-sized lasers and interconnects. **Optical connector:** Additionally, flexible electronics using nanomaterials such as graphene enable bendable components for applications such as wearables and electronic skins, demonstrating the versatility and advances being made driven by nanotechnology in the electronics industry.

ADVANCED OIL RECOVERY- nanotechnology has made great advances in enhancing the recovery of oil and gas reservoirs. For example, the use of smart fluids or nanofluids that change the wettability of reservoir rocks and reduce the tensile strength of drag and binder towards sand binding or the use of active agents surface to increase the reservoir's output is relatively completely controlled. Nanoparticles in this field are the use of nanomaterials to facilitate the separation of oil and gas inside reservoirs and the use of nanosensors inside reservoir rocks. These nanoparticles, when exposed to crude oil-bearing rocks, release the cargo and recycle the crude oil. The main application of nanoparticles is to change the wettability of reservoir rocks. The resilience of a fluid-filled rock system is defined as the ability of a fluid to propagate to the rock surface in the presence of another fluid. Humidity not only determines the initial fluid distribution but is also a key factor in determining how fluid flows in a reservoir and plays an important role in oil and gas production [4].

NANOTECHNOLOGY IN RENEWABLE ENERGY SOURCES -Nanotechnology enhances solar energy applications by improving efficiency and solving challenges. Nanoparticles increase surface area, thereby improving solar energy capture and the performance of devices such as solar cells. Materials such as lead selenide, enabled by nanotechnology, release more electrons upon impact of a photon, thereby increasing electricity output. Additionally, nanomaterials contribute to cost-effective solutions, making solar energy a more viable and environmentally friendly option, with the potential to significantly reduce emission of carbon dioxide.

Future Directions in Nanotechnology: Overcoming Limitations and Expanding Frontiers-

Despite its progress, nanotechnology faces challenges such as safety concerns, The production of high-quality nanomaterials can be expensive, limiting their accessibility for widespread use, Public awareness and ethical guidelines for the responsible use of nanotechnology are essential, and the need for standardization. Future research should focus on addressing toxicity issues, establishing international regulations, and developing cost-effective manufacturing methods. Ethical considerations and societal implications demand attention, alongside efforts to achieve controlled assembly and manufacturing scalability. Key areas for exploration include advanced drug delivery, personalized nanomedicine, energy storage and conversion, nano-electronics, environmental applications, nanorobotics, and biocompatible nanomaterials. This comprehensive approach aims to overcome limitations and unlock the full potential of nanotechnology for diverse applications.

CONCLUSION

In conclusion, nanotechnology represents a revolutionary field with vast implications across various industries and scientific domains. Operating at the nanoscale, it enables the manipulation of matter at the atomic and molecular levels, offering unprecedented control and precision. The potential applications of nanotechnology span from medicine and electronics to energy and materials science, promising breakthroughs that could redefine our technological capabilities and address pressing global challenges. However, as with any powerful technology, ethical considerations and potential risks must be carefully navigated to ensure responsible development and deployment. The ongoing research and exploration in nanotechnology underscore its transformative potential, heralding a future where the manipulation of matter at the smallest scales leads to significant advancements in science, medicine, and technology.

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