SYNTHESIS, APPLICATION AND FUTURE PERSPECTIVES OF SMART NANO-MATERIALS

PART 2

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Bentham Books

Synthesis, Application and Future Perspectives of Smart Nano-materials

(Part 2)

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ISBN (Online): 979-8-89881-048-1

ISBN (Print): 979-8-89881-049-8

ISBN (Paperback): 979-8-89881-050-4

Published by Bentham Science Publishers Pte. Ltd. Singapore, in collaboration with
Eureka Conferences, USA.

First published in 2025.

Bentham Science Publishers Pte. Ltd.
No. 9 Raffles Place
Office No. 26-01
Singapore 048619
Singapore
Email: subscriptions@benthamscience.net

BENTHAM SCIENCE

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FOREWORD

The field of nanomaterials continues to grow at a remarkable pace, and within it, smart nanomaterials—engineered to respond dynamically to external stimuli—stand at the forefront of innovation. Their versatility spans from environmental remediation to targeted drug delivery and advanced diagnostics, offering promising pathways for addressing many of the pressing challenges faced by modern science and society.

In this context, the book, *Synthesis, Application and Future Perspectives of Smart Nanomaterials (Part 2)*, edited by Dr. Laxman Singh and Prof. R.N. Rai, is both timely and impactful. It presents an impressive collection of interdisciplinary research that reflects not only the vibrancy of the field but also the commitment of the scientific community to develop sustainable, functional, and application-oriented nanomaterials.

The part begins with a compelling exploration of the **Application of Nanomaterials in Environmental Remediation** and concludes with a comprehensive discussion on **Nanomaterials in Environmental Science: Applications, Impacts, and Sustainable Solutions**. These chapters underscore the use of engineered nanoparticles for adsorption, detection, and catalytic degradation of pollutants, firmly anchoring the book in real-world applicability. Complementing this environmental focus, chapters on **polycarbonate nanocomposite fibers** showcase how nanoscale engineering can be harnessed to enhance optical and mechanical properties, highlighting their promise in the development of advanced textiles and optoelectronic devices.

The chapter on the **Green Synthesis of Nanoparticles Using Plant Extracts** is particularly noteworthy, as it addresses both sustainability and functionality. The emphasis on biogenic synthesis methods highlights the growing trend towards environmentally benign processes in nanotechnology—a direction I believe the field must continue to embrace.

Equally impressive is the treatment of biomedical applications, including chapters on **drug delivery systems** and **tissue engineering scaffolds**, which underscore how nanoscale engineering is revolutionizing therapeutic approaches. The contributions dealing with **chemical sensing and biosensor development** illustrate how smart nanomaterials can be tailored for high sensitivity and specificity—an area with direct implications for environmental monitoring and clinical diagnostics. Further enriching this theme, the chapter on **NMR Spectroscopic Characterization of Self-Assembled Peptide Nanomaterials** offers deep insight into the structural elucidation and functional behavior of bioinspired nanoarchitectures, highlighting their potential in biomaterials research and biomedical applications.

Throughout, the chapters are characterized by technical rigor, clarity of presentation, and a strong translational outlook. The editors have successfully brought together a range of contributions that not only reflect the state-of-the-art but also stimulate further inquiry and innovation.

I commend Laxman Singh and R.N. Rai for their editorial leadership and all contributors for their scholarly efforts. This part will undoubtedly serve as a valuable reference for researchers, postgraduate students, and practitioners in materials science, chemistry, biotechnology, and allied disciplines. It also holds relevance for those working at the interface of academia and industry, where the need for functional and scalable nanomaterial solutions is far more pressing than ever.

I extend my best wishes for the continued success of this book and hope it finds wide readership and appreciation across the scientific community.

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PREFACE

The book "**Synthesis, Application, and Future Perspectives of Smart Nanomaterials (Part 2)**", edited by "**Laxman Singh and R.N. Rai**", describes and provides the latest comprehensive literature on the various modern applications of smart nanomaterials in various fields, *i.e.*, environment, drug delivery, chemical sensors, green chemistry, pollution mitigation, *etc.* This book covers the pace and productivity of each chapter at a consistent level with respect to the audience, from graduate students to postdoctoral researchers, or from postdoctoral researchers to multidisciplinary field researchers with a background in physics, chemistry, materials science, and biology, who are already working with smart nanomaterials and their applications. This book includes a total of seven chapters, which discuss the wide range of ultra-modern applications of smart nanomaterials in today's science and technology world. Chapter 1 covers a wide range of topics related to the use of nanomaterials for various forms of remediation and describes the nature of the environmental problem. Chapter 2 describes the synthesis of polycarbonate nanocomposite fibers, which have excellent optical properties, especially green light emission, which can be used for various electronic and sensor applications. Chapter 3 focuses on natural products and also covers other methods of nanoparticle preparation using plant extracts, *i.e.*, proteins, pigments, amines, amides, alkaloids, flavonoids, phenols, and terpenoids. Chapter 4 discusses the characterization of different structural classes of self-assembled peptide nanomaterials using spectroscopic methods, in particular, NMR spectroscopy. The importance of characterizing peptide nanomaterials using spectroscopy is highlighted due to their wide applications in biomedical science. Chapter 5 provides an overview of recent breakthroughs in an innovative nano-based material to develop smart DDS for therapeutic applications in various terminal diseases. Chapter 6 focuses on an exclusive vision of chemical sensors integrated by various functionalized, hybrid or composite nanomaterials having strong adsorption capacity, selectivity, and high surface reactivity on the broad scale of limits and structural diversity. Chapter 7 emphasizes the long-term environmental consequences of nanoparticles and also discusses the need to identify the barriers and negative consequences and maximize their benefits. Our book is aimed at those audiences who are looking for a single source for a comprehensive understanding of the strategies and their challenges in terms of material fabrication, emerging applications, and future prospects.

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CHAPTER 1

Nanomaterials in Environmental Remediation: Innovative Solutions for Pollution Mitigation

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Abstract: Nanomaterials have emerged as a promising technology for environmental remediation due to their unique size, surface area, and physicochemical properties. Nanomaterials can be used to remove pollutants from water, soil, and air, as well as to degrade hazardous waste. Examples of nanomaterials used for environmental remediation include metal nanoparticles, carbon nanotubes, and other engineered nanomaterials. Metal nanoparticles, such as silver, titanium dioxide, and zinc oxide, can be used to degrade organic pollutants. Carbon nanotubes can also be used to adsorb heavy metals such as lead and mercury from water and soil. Additionally, certain nanomaterials can be used as catalysts to speed up the degradation of hazardous chemicals. Nanomaterials can also be used to create more efficient and less energy-intensive processes for environmental remediation. For example, nanofiltration membranes can be used to reduce energy consumption when removing pollutants from water. Nanomaterials can also be used to create more effective adsorbents for the removal of pollutants from air. The use of nanomaterials for environmental remediation is still in its infancy, and research is needed to understand their potential applications and risks. However, the potential of nanomaterials to improve the efficiency and effectiveness of environmental remediation processes is clear.

Keywords: Air purification, Contaminant removal, Contamination, Environmental, Efforts, Environmental impact, Green nanotechnology, Innovative solutions, Nano-sorption, Nano-filtration, Nano-catalysis, Nano-sensors, Nano-adsorption, Nanomaterials, Nanoparticles, Nanocomposites, Pollution, Remediation techniques, Remediation, Sustainable technology, Soil remediation, Toxicity mitigation, Water treatment, Waste management.

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Laxman Singh & R.N. Rai (Eds.)

INTRODUCTION

The environment has been polluted by organic, inorganic, and pathogenic microbes. Human activities, such as intense agriculture, domestic chores, and temporary industrial procedures, are accountable for the emission of detrimental chemicals. The rapid growth of polluting industries, such as textile production, tannery operations, food and beverage manufacturing, cosmetics development, and pharmaceutical production, leads to the release of dangerous, long-lasting, and harmful substances into the nearby environment. The extensive use of natural resources by the growing population has had a profound effect on the long-term viability of the environment [1 - 3]. Persistent organic pollutants, such as Aldrin, Dieldrin, Endrin, Toxaphene, Dichloro Diphenyl, and others, have caused disruptions in the life cycle of certain organisms. The problem of nanoplastic seepage into the environment has recently been recognized as a notable concern [4 - 6]. The hydrodynamic force exerted by water can disintegrate microplastics into smaller particles, with a size of up to 400 nm, that possess the capability to penetrate the surrounding ecosystem. Nanoplastics have the capacity to penetrate the skin and cause harm to different organisms. Observations revealed that the mortality rate of zebrafish exceeded 54% as a result of the passive diffusion of micro plastics into the aquatic system [5]. The primary obstacle encountered by civilization is the deterioration of the environment. Current research is focused on investigating emerging technologies to purify air, water, and soil [6]. The contaminants of concern encompass particulate matter, heavy metals, pesticides, herbicides, fertilizers, oil spills, toxic gases, industrial effluents, sewage, and organic compounds [7, 8]. It is crucial to monitor pollution levels in order to effectively address these challenges. The existence of contaminants in the environment has led to harmful consequences on several biological systems. Thus, it is crucial to identify and treat these conditions early in order to avoid their spread [9 - 12].

The Detection of Pollution through the Utilization of Nanoparticles

Nanomaterials have the capability to monitor hazardous chemicals in diverse environmental matrices [13]. The unique properties of nanomaterials, including their composition, large surface area, and electrical, magnetic, mechanical, and optical characteristics, enable a wide range of applications [14]. The nanosensors are capable of detecting surface indicators of pollutants or enhancing analytical signals. Nanosensors have been found to exhibit heightened sensitivity in detecting pollutants at exceedingly low levels, surpassing the capabilities of conventional methods [15]. The present article provides a discourse on the nanoparticles of silver, zinc oxide, and silicon oxide. Nanosilver particles (AgNPs) are utilized in pollution detection owing to their distinctive optical, electrical, and thermal characteristics [16]. Devices utilizing silver nanoparticles (AgNPs) have been shown to enhance electron kinetics and promote uniformity [17]. In the experiment, a pencil graphite electrode was employed along with AgNPs and folic acid to detect the presence of Hg^{2+} ions in tap water. The nanosensor exhibited a linear range of 10-25 μM and a detection limit of 8.43 μM. The sensor for Hg^{2+} exhibited high sensitivity, selectivity, and rapid response [18].

The intensity of surface plasmon resonance (SPR) and the memristive switching of silver nanoparticles (AgNPs) exhibit alterations. The colorimetric and memristor-based assays exhibited detection limits of 6.2 and 8.7 ppb, correspondingly [19]. The electrochemical detection of 4-nitrophenol has been achieved through the utilization of AgNPs-functionalized reduced graphene oxide (4-NP). The presence of 4-nitrophenol was detected through the utilization of cyclic and differential pulse voltammetry. The sensor's linear range spanned from 0.1 to 363.9 M, while its limit of detection (LOD) was determined to be 48.6 nM. The sensitivity of the sensor was measured to be 35.25 A/M/cm^2. In their recent study, Shah and colleagues (2021) detected the presence of *Staphylococcus aureus* and *Candida albicans* in *Dodonaea viscosa* AgNPs. The researchers also detected 2-nitrophenol (2-NP), 4-nitrophenol (4-NP), and additional contaminants such as 2-nitrophenol and 4-nitrophenol (RB).

The utilization of nanomaterials in the detection of water pollution is a crucial aspect of water treatment, as disinfection of contaminated water is imperative in light of the prevailing water scarcity. Pharmaceutical wastewater is composed of various substances, including endocrine disruptors, radionuclides, flame retardants, surfactants, and microbiological contaminants. The conventional techniques are inadequate in detecting these contaminants. The commonly employed techniques for detecting pollutants in wastewater are ICP-OES, ICPMS, FAAS, GFAAS, and XRF [20]. Nonetheless, the aforementioned techniques necessitate the collection of samples, pre-treatment, skilled personnel, costly apparatus, and heightened energy consumption. Nanomaterial-based sensing devices have been found to effectively address the challenges encountered in conventional sensing devices. This is attributed to their affordability, selectivity, sensitivity, and versatility. Sensing devices that utilize nanomaterials have the capability to detect pollutants present in wastewater.

Elimination of Pollutants from the Environment

The environment is subject to the release of toxic substances as a result of human activities, including industrialization [21 - 23]. It has the potential to impact the climate. Hence, organisms have the potential to experience pain or distress. Efficient, cost-effective, rapid, on-site, and eco-environmentally sustainable

CHAPTER 2

Recent Advancement in the Formation of Polycarbonate Nanocomposite Fibers and its Properties

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Abstract: Polycarbonate nanocomposite fibers of beadless surface morphology were prepared using electrospinning technology. The spinning and solution parameters were the same as those used for the preparation of plane polycarbonate nanofibers of the lowest average diameter. There was not much variation in the average diameter and surface morphology of the polycarbonate nanocomposite fibers obtained by the incorporation of the nanofiller. The homogeneous dispersion of the nanoparticles on the entire area of the fibers was observed from TEM investigation. Agglomeration of nanoparticles in the fibers was also prevented by providing a uniform coverage of surfactant on the nanoparticle surface. UV-Visible and photoluminescence spectroscopy studies show that polycarbonate nanofibers embedded with oleic acid-coated cadmium sulfide nanoparticles exhibit attractive optical properties. The augmentation of filler nanoparticles increased the visible light absorption capability of the polycarbonate nanocomposite fibers. The nanocomposite fibers also exhibited attractive red and green luminescence, as shown by phase contrast fluorescent microscopy analysis. The crystalline area calculated from the XRD data established a semicrystalline attribute for the nanocomposite fibers. The present work utilized versatile electrospinning technology to prepare a composite material in which both the matrix and filler are in the nano dimension. Polymer composites with excellent optical properties, particularly green light emission, can be utilized for various electronic and sensor applications.

Keywords: Amorphous, Aspect ratio, Agglomeration, Band gap, Bead, Beadless, Bragg angle, Drawing, Entanglement, Electrospinning, Flow rate, Flow rate, Gaussian function, Histogram, Nanocomposite, Nanotechnology, Nanofiller, Photoluminescence, Thermoplastic, Tauc relation.

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INTRODUCTION

Recent advancements in the arena of nanotechnology are mainly due to the brilliant modification of bulk material by fine tuning its surface morphology. The large surface area of a material is the inevitable parameter needed to improve different physio-chemical properties [1 - 4]. There were a lot of attempts to improve the aspect ratio of polymer materials to enhance or modify their mechanical, optical, electrical, morphological and thermal properties. Nanofibers of natural and synthetic polymers have gained immense attention from the scientific community due to their unique properties, suitable for many advanced applications. There are different nanofiber fabrication methods like drawing, template synthesis, centrifugal spinning, phase separation and electrospinning based on the type of the polymer and the application [5]. Among these, electrospinning is known to be a versatile and advanced technology to make polymer and other nanofibers with suitable surface morphology [6 - 8]. The nanofibers prepared by this method have many unique properties such as large surface area-volume ratio and excellent porosity. This fabrication method enables the mass production of long and continuous fibers with uniform surface morphology and diameter [9, 10]. Polymer solution of suitable concentration is to be subjected to a high applied potential. All the solution and spinning parameters should be adjusted in such a way as to eject long and continuous fibers from a charged needle tip. A jet of polymer solution will be ejected rapidly from the needle tip only when the applied potential value outweighs the surface tension forces experienced by the polymer solution. Optimization of parameters like applied potential, needle tip-collection plate distance, flow rate and solution concentration is inevitable in forming bead-free and uniform nanofibers [11, 12].

Polycarbonate (PC) is an indispensable thermoplastic material in many areas of modern industry. It possesses a large number of properties that are in fact suitable for many advanced applications. These include lightweight, excellent transparency, high heat distortion temperature, good mechanical strength and low density combined with good optical performances [13 - 16]. All these extensive ranges of properties have enabled PC to be widely used in the automotive, aerospace, construction field and conventionally used as materials for industrial skylights, prescription lenses, safety glasses, synthetic glasses, office partitions, window shades, walkways, commercial greenhouses, curtain walls, bullet-resistant windows, sliding doors and many other essential utilities [17, 18]. Much research was conducted to improve the polymer properties that enabled them to be utilized in many nanotechnology applications. Molding polymer into a tunable nanocomposite by the incorporation of different nanofillers is a highly accepted methodology. PC is a suitable matrix for the preparation of nanocomposites by embedding different nanofillers.

Jaleh *et al*. reported the UV irradiation properties of PC–TiO_2 nanocomposite films by incorporating TiO_2 nanoparticles into PC solution [19]. Chow *et al*. prepared intercalated PC nanocomposite by melt compounding method associated with injection molding [20]. Yoonessi *et al*., Kim *et al*. and Gedler *et al*. reported the preparation of PC-graphene nanocomposites by methods like compression molding, melt compounding, supercritical CO_2 two-step-foaming and microcellular foaming, respectively [21 - 23]. Sharma *et al*. prepared PC-single walled carbon nanotube composite membrane to investigate the effect of an electric field on the alignment of nanotubes in PC [24]. Yao *et al*. tried a melt blending method to prepare PC-CeO_2 and PC-stearic acid modified CeO_2 nanocomposites [25]. Al Jafari *et al*. prepared PC-ZnO thin film and studied the dielectric properties [26]. Abbasi *et al*., Ayesh *et al*., Babal *et al*., Yadav *et al*. and Castillo *et al*. prepared PC-multiwalled carbon nanotube by methods like melt mixing technology, solvent casting, micro twin extruder following backflow channel method and twin screw micro compounder method respectively [27 - 31]. Amirchakhmaghi *et al*. provided a method to prepare PC-alumina nanocomposites by the incorporation of alumina nanoparticles into PC solution to study the mechanical properties [32]. Carrion *et al*. and Dhapte *et al*. investigated the tribological properties of PC-ZnO nanocomposites prepared by nanodispersion and blade coating method, respectively [33, 34]. Carrion *et al*. reported several properties of PC-nanoclay nanocomposites formed by extrusion and injection molding methodology [35]. Charde *et al*. synthesized PC-$CaCO_3$ nanocomposites having better tribological properties using the melt extrusion method [36]. Christmann *et al*. prepared PC nanocomposites reinforced with silica and alumina nanoparticles and studied the mechanical behavior [37]. Hakimelahi *et al*. synthesized alumina reinforced PC nanocomposite films by *in-situ* polymerization method [38]. Lagashetty *et al*. prepared PC nanocomposites with Fe_2O_3 and CuO dispersions by solvent casting method [39]. Nouh *et al*. synthesized nickel oxide reinforced PC films by solution casting method [40]. Derazkola *et al*. introduced a versatile powder-fed friction stir process to prepare alumina nanoparticles incorporated in polycarbonate nanocomposite material [41]. Mohamed *et al*. used thermolysis and casting methods to prepare nano tin disulfide-based polycarbonate nanocomposites [16]. Eskandari *et al*. studied the optical qualities of polycarbonate-TiO_2-ZnO nanocomposite films synthesized by solution casting method [42]. Bagotia *et al*. prepared polycarbonate-multiwalled carbon nanotube composites able to absorb mechanical shock by melt-blending method [43]. Mirji *et al*. adopted solvent casting method to prepare polycarbonate-bismuth nitrate thin films with gamma radiation shielding power [13]. T Baby *et al*. reported the preparation of polycarbonate nanocomposite fibers incorporated with superparamagnetic magnesium zinc ferrate nanoparticles by electrospinning [44].

CHAPTER 3

Green Synthesis of Metal Nanoparticles: The Role of Plant Extracts in Sustainable Nanotechnology

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Abstract: Plant extracts contain a wide range of substances, including proteins, pigments, amines, amides, alkaloids, flavonoids, phenols, and terpenoids. During the green manufacturing of nanoparticles, the aforementioned phytochemical ingredients aid in the stability and reduction of metal ions. The emerging nano-revolution has garnered significant attention for its exploration of the role of plants in the green synthesis of nanoparticles, with the aim of producing stable nanoparticles. A variety of traditional techniques have been utilized for the production of nanoparticles. However, traditional techniques are associated with numerous limitations, including the production of harmful and dangerous chemicals, as well as high costs. Due to the aforementioned constraints, scientists have devised safe and environmentally friendly alternative methods for synthesizing nanoparticles. Among these methods, biological systems have been particularly emphasized and utilized as a preferred green approach for nanoparticle synthesis. The utilization of plant extracts for the synthesis of metal nanoparticles is a financially feasible approach, which renders it a practical and sustainable substitute for the mass production of metal nanoparticles. It has been observed that extracts derived from plants found in nature possess the ability to function as both reducing and capping agents during the process of nanoparticle synthesis. Biological organisms possess a distinctive capacity to generate highly specific shapes and regulated structures. The synthesized nanoparticles that are eco-friendly and green in color exhibit a wide range of biological activities.

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Keywords: Applications, Biosensors, Biomedical applications, Catalysis, Drug delivery, Energy storage, Environmental remediation, Future advancements, Functionalization, Materials Science, Nanotechnology, Nanoparticles, Nanocomposites, Nanomedicine, Nanoscale sensors, Optoelectronics, Self-assembly, Sustainable materials, Smart Nanomaterials, Synthesis.

INTRODUCTION

A medicinal plant is defined as a plant that has one or more compounds in its different parts that can be used for therapeutic reasons or as a basis for the development of helpful medicines [1]. The use of medicinal plants is essential for the advancement of life-saving medications, as they may produce a wide variety of bioactive chemicals through metabolic pathways, ultimately improving the health of individuals. The employment of herbal treatments and healthcare, as recorded in ancient literature such as the Vedas, Holy Quran, and the Bible, is based on the customary use of traditional herbs and medicinal plants. Organisms produce a wide range of organic compounds, although most of these compounds do not appear to have a direct function in encouraging growth and development. Secondary metabolites, also referred to as such, are acknowledged for their substantial contribution to plant adaptation to their environment and act as an essential repository of medicinal compounds [2]. Pharmaceutical and biotechnology businesses generate substantial profits from the pharmaceuticals that are produced from natural substances. The causes listed above have led to a renewed interest in research on nanoparticles, particularly those derived from natural products. The incorporation of herbal extracts into novel formulation processes has resulted in further advantages, such as improved availability and secure manipulation.

India is acknowledged as one of the twelve nations with mega-diversity, showcasing an extensive range of biotic resources [3]. India is host to two significant areas of high biodiversity, specifically the Western Ghats and Eastern Himalayas, which are among the 34 designated hotspots. The worldwide tally of higher plant species is roughly 500,000, and India is home to 15,000 of these species, with 3,000 being specifically used for ethnomedicinal purposes [4]. India is home to more than 25% of the world's known medicinal plant species, totaling around 30,000 of these, 90% are found in forest habitats [5]. The chemical components of medicinal plants have a crucial role in the realms of medicine, nutraceuticals, and the synthesis of metal nanoparticles. Plant extracts consist of a variety of metabolites, such as flavonoids, proteins, terpenoids, tannins, polyphenols, and related substances. These biomolecules aid in the reduction of metal ions to form metal nanoparticles (MNPs). These compounds have the dual purpose of decreasing metal ions and preventing nanoparticles from clumping together. The stability of the nanoparticles leads to regulated shape and enhanced biological potential. Water-soluble antioxidative compounds, such as ascorbic acids, are responsible for reducing MNPs. Ascorbic acid acts as a reducing agent, successfully minimizing the harmful effects of reactive oxygen species by producing an electron and ascorbate radical. The emancipated electron undergoes the process of reducing the metal ion, resulting in the creation of metallic species. The decrease in metal ions and the stability of nanoparticles are mainly due to the polyol constituents and the water-soluble heterocyclic constituents, respectively.

Metal nanoparticles are extensively acknowledged for their wide array of uses in numerous disciplines. Changing the size of particles leads to changes in the physical, chemical, optical, electrical, and catalytic properties of the material. Plasmonic theory is used to explain the optical properties of metal nanoparticles, considering factors including their shape, size, and distance from one another. The factors [6] have a significant impact on the plasmonic resonance frequency of metal nanoparticles. When the dimensions of the nanostructure are in the range of a few nanometers or smaller, an explanation based on quantum mechanics is required to accurately reproduce its optical response. Simulations that employ classical physics, specifically the mechanism of fluctuating charges and fluctuating dipoles that rely on frequency, can accurately reproduce quantum-scale phenomena, such as the change in plasmon resonance [7]. Establishing a link between actual measurements of individual nanoparticle scattering and computer-generated spectra is crucial for understanding and predicting plasmonic properties [7]. The discrete dipole approximation method can be used to analyze the plasmonic properties of metallic nanoparticles embedded in a matrix, providing insights into how their optical properties are affected by factors such as size, shape, and plasmonic coupling [8]. Intense, femtosecond laser beams can be used to modify the plasmonic properties of nanoshells. By solely adjusting the incident intensity, one can achieve precise manipulation of the optical response [9]. UV-Vis spectroscopy and FTIR are indispensable techniques for the characterization of nanoparticles. UV-Vis spectroscopy is employed to determine the correlation between the band-gap and the dimensions of nanoparticles, as well as to quantify the concentration of carbon nanostructures in suspensions [10, 11]. FTIR spectroscopy is a valuable technique for examining the surface characteristics of nanoparticles and identifying the specific chemical groups found in polymer/metal nanocomposites [12]. Fourier transform infrared (FTIR) spectroscopy is frequently employed to identify and classify possible biomolecules that have the ability to efficiently stabilize gold and silver nanoparticles, which can be utilized for the purpose of capping. UV-Vis spectroscopy has significant benefits in analyzing the optical properties of nanoparticles, including silver nanoparticles, and can aid in determining their size

CHAPTER 4

NMR Spectroscopic Characterization of Self-assembled Peptide Nano-materials

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Abstract: The structurally and functionally significant moieties created by the immediate assembly of molecules by themselves are known as molecular self-assemblies. Molecular self-assemblies are having a large number of applications in science and medical science. Among molecular self-assemblies, peptide self-assembles, specifically self-assembled peptide nano-materials, are of much importance because of their wide biomedical applications, like tissue engineering, wound healing, gene delivery, drug delivery, and vaccines. Peptide self-assemblies, in general, molecular self-assemblies, are stabilized by non-covalent interactions like van der Waals interaction, π−π stacking, hydrogen bonding, halogen bonding, ionic dipolar interaction, metal−ligand coordination, organic−ionic compound interaction, *etc*. Self-assembled peptide nanomaterials form mainly three different types of structural classes *viz* peptide nano-fibers, peptide nano-tubes and peptide nano-vesicles. Apart from these important applications of peptide nano-materials, the self-assembly of peptides in our body forming amyloid fibrils leads to different disease conditions like Alzheimer's disease. Characterization of different structural classes of self-assembled peptide nano-materials is very important in understanding their specific properties and hence, their applications in science and medical science. Furthermore, the characterization of amyloid fibrils formed in our body is very important for the discovery of anti-amyloid agents. Nuclear Magnetic Resonance (NMR) spectroscopy, particularly solid-state NMR (SSNMR) spectroscopy, is a very useful tool for the characterization of different self-assembled peptide nano-materials. In this chapter, we are discussing the characterization of different structural classes of self-assembled peptide nano-materials using spectroscopic methods particularly NMR spectroscopy. The best way to characterize various structural classes of self-assembled peptide nanomaterials is to use NMR spectroscopy in conjunction with other experimental approaches.

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Keywords: π−π interaction, Amphiphilic peptides, Cyclic peptides, Drug delivery, Hydrogels, MD simulation, NMR, NOE, Nanotube, Nanofiber, Nanovesicle, Nanomaterials, Peptides, Peptide self-assembly, Self-assembly, Secondary shift, Solid state NMR, Solution state NMR, Self-Assembled Monolayers, Spectroscopic characterization.

INTRODUCTION

Molecular Self-assembly

Molecular self-assemblies are the structurally and functionally important moieties formed as a result of the instantaneous assembly of molecules by themselves. It is an upcoming feasible way of generating advanced functional materials of interest. Molecular self-assemblies of several macro-level entities such as proteins, polymers, colloids, cells, and nano/microparticles are of biomedical importance [1]. The interactions involved in the self-assembly process are non-covalent and weak covalent intermolecular interactions such as van der Waals interaction, Pi-stacking, hydrogen and halogen bonds, ionic dipole interaction, coordination between metal and ligand, interaction between organic and ionic species, *etc*. Self-assembly is based on the idea that the molecules are self-programmed to assemble at a particular time in a particular fashion, generating useful functional materials [2].

Exploiting the diversity in the self-assembling molecules, a wide range of functionally useful entities are possible by self-assembly at a molecular level. An example of the same is self-Assembled Monolayers (SAM), which is getting wide acceptance for its uses in the organo-electric field [3]. All organic-electronic devices depend to a certain level on the basic one-dimensional arrangement of molecules. SAM could prove to be significant in this field due to its advantages such as low-temperature process, regio-selective monolayer adsorption, and the easefulness of controlling the film thickness [3]. Molecular self-assembly of natural and synthetic polymers is being studied for its usefulness in the bio-medical field, especially drug delivery [4]. These self-assemblies prove to be alternatives to existing cancer-drug delivery solutions. Scientific reports explain the application of EISA, which stands for Enzyme Instructed Self Assembly [5], which would produce assemblies within the cells at a supramolecular level, capable of efficiently accelerating the bioactivity of cisplatin against drug-resistant cancer cells that affect ovaries. Here, the precursors may be inactive against the cancer cells, but their usefulness arises from their ability to multiply the activity of cisplatin. Molecular self-assemblies are thus a simple and side-effect-free innovations that can be introduced into combination therapies like anti-cancer therapies safely [6].

Peptide Self-Assemblies

A significant division of the molecular self-assemblies is the peptide self-assembly, which has gained a high level of attention among the scientific community [7] due to numerous applications in the biomedical field, like healing of wounds, biomedical engineering of tissues, gene introduction, delivering drugs and vaccines [8, 9]. The main advantage is that these peptides are biocompatible and are used for immunotherapies. The immune responses generated by such self-assembled peptides are found to last for at least a year. Several self-assembled peptides may generate immune responses, whereas there are also peptides that do not generate any response. Both of these properties are exploited to their advantage based on the situations of usage. For example, self-assembled peptides required for regenerative medicinal purposes require no strong immunogenic response, whereas for vaccination purposes, strong and lasting immunogenic responses are needed [10]. The natural biocompatibility and the selective nature of peptides make it a suitable candidate for producing functionally active molecules *via* self-assembly. Various other significant applications of materials based on peptides include the regeneration of bone, enamel, cartilage and the central nervous system, transplantation of islets, treatments for cardiovascular diseases and erectile dysfunction following prostate surgery, *etc* [11 - 16]. Self-assemblies based on peptides are a very significant class of functional materials because they are easily synthesized and structurally similar to biological signals. Self-assembled peptide amphiphiles, peptide-based hydrogels, *etc*. are various types of peptide self-assemblies [17]. By exploiting the secondary interaction capability of such molecules, multiple nanostructures, such as tubes, spheres, cylinders, *etc*. can be obtained *via* self-assembly [18].

Self-assembled Peptide Nano-materials

Peptide nano-materials are yet another important section of nano-scale self-assembled peptide material, whose characterization is being discussed in this chapter. They are a very promising group of bio-materials, mainly in the biomedical field. There are many features possessed by the peptide nano-structures that contribute to their wide acceptance. Peptide nano-materials are generally obtained from peptides that contain 20 to 30 amino acid moieties, and they can self-assemble at various dimensions with satisfying stability and functionality [19]. The important advantages of peptide self-assembled nano-structures like high biocompatibility, adjustable bioactivity, higher capacity to carry drugs, low cost, specificity, and introduction of drugs based on stimulus response on specific disease target sites, make them an inevitable part of the bio-medical field. Among different reported self-assembled nano-structures, which are synthesized from various biomolecules like carbohydrates, amino acids, peptides,

CHAPTER 5

Recent Developments in Synthesis and Application of Smart Nanomaterials for Drug Delivery System, Tissue Engineering, and Advanced Therapeutic

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Abstract: Today's growing population and the increasing global pandemics have made inroads for new technologies and developments for effective treatments and bringing in holistic health for scores of patients affected. Nanotechnology and nanomedicine are emerging technologies wherein the use of nanomaterials for drug deliveries has replaced the conventional systems of drug delivery, which are generally associated with side effects. Cancer nanotherapeutics has made skewed progress, bringing in a sea change in the delivery mechanisms whereby the problems of nonspecific biodistribution and targeting are being decimated to no-problem deliveries. The synthesis of smart nanoparticles has brought much hope and resilience to scores of patients needing the applications of tissue engineering and regenerative medicine. The smart drug delivery systems based on pH and temperature, magnetic, redox, and enzyme responsiveness have shown excellent therapeutic applications in autoimmune diseases and metabolic disorders. Tissue engineering is a field that has brought in new technologies in the medical world that improve, repair, and replace damaged tissue or organs. The applications of smart nanomaterials have envisaged new methods and developments in end applications like biomimetics. This review gives an overview of nanomaterial synthesis, smart drug delivery systems and their applications using nanomaterials, the role of nanomaterials in nanomedicine and tissue engineering, and finally, the significance of amalgamations of Theragnostics nanomedicine with nanoscience, therapeutics, and diagnostics.

Keywords: 3-D scaffolds, Bone-tissue engineering, Drug delivery system, Extra-cellular matrix, Hydrogels, Helical-rosette nanotubes, Hydroxyapatite, Liposome, Metal nanoparticles, Nanotechnology, Nanomedicine, Nanoparticles-hydrogel composites, Nanofibers, Nanodiamond composites, Polymeric nanoparticles, Polymeric micelles, Peptide drug, Theragnostic and Nanotherapeutics, Thermos-sensitive nanogels, Tissue-engineering.

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INTRODUCTION

Under the rapid pace of advancements in the nano-based available scientific knowledge and technology, many innovations with cutting-edge research in the major scientific disciplines such as medicine, pharmaceuticals, and biotechnologies have been reported [1, 2]. Over the past decade, a remarkable development in the synthesis of smart nanomaterials in terms of lightweight graphene materials, carbon nanostructures (CNSs) and its metal composites, protein-based nanomaterials, and nanosystems (PNNS), conjugated polymer nanoparticles (NPs), and especially the synthesis of bio-inspired nanomaterials and smart structures are reported [3, 4].

The advent of these novel smart nanomaterials has opened tremendous transformative possibilities in applying nanomaterials in the different domains of science and technology beyond the currently available technologies. These smart materials have catalyzed a dramatic shift in the key innovations in flexible electronics, drug delivery, nanomedicine, environmental remediation, and sustainable agriculture [3]. Similarly, the available smart nanomaterial and nanotechnology revolutionized medicine and pharmaceutical sciences to develop an excellent, cost-effective, and sustainable drug development and delivery system. Many pharmaceutical companies focus on smart nanotechnology to overcome the challenges of novel drug development and delivery systems related to cost-effective, safe, and susceptible techniques. The recent advancements in nanotechnology tools and techniques have added tremendous realistic value to the existing pharmaceutical products by opening new opportunities in the different segments of pharmaceutical R&D [5, 6]. The primary domains of pharmaceutical sectors, where future R&D lies on exploiting nanotechnology tools, are product and process development and personalized medicine [7]. Under process development, the synthesis of drugs and their intermediates and the development of analytical tools for diagnostics are encouraged. However, under nanotechnology-based drug discovery and synthesis, a miniaturized automation platform can be used to develop high-throughput synthetic routes [8].

Since the emergence of nanoparticles (MSNs)/nanomaterials and nano-technologies, they have been extensively used in biomedical applications, *e.g*., controlled drug/gene delivery, cell tracking, tumour targeting, and photodynamic therapy. Carbon nanostructures (CNSs) are widely used in the target delivery of drugs and other biomedical applications. Besides, several other noncarriers have been reported as excellent and smart carriers in the potential drug delivery vehicle to target tumors in cancer therapy. Several novel and advanced protein-based nanomaterials and nanosystems (PNNS) have also been attracted in recent decades for various applications in the biological system [9]. It is reported that the constructed PNNS possess diverse properties, including biocompatibility, which make them suitable for various applications in biological systems [9].

Smart Drug Delivery Systems

Recently, enormous development has occurred in the advanced and sophisticated drug delivery systems (DDS) to provide therapeutic agents/active compounds to their target location for treating various ailments [10]. Nano-based drug delivery systems are leading the currently available advanced drug delivery system and assuring the safe and sustainable delivery of drug carriers to the human body, possessing excellent biocompatibility and non-toxicity properties. In recent years, the development of an extensive range of nanoparticulate drug delivery systems (NDDS) and carriers such as polymeric micelles, liposomes, polymeric-nanoparticles, metal (*e.g.*, gold, silver) and silica-based nanoparticles, nano-gels, and dendrimers have been reported [11]. First-generation NDDS faced challenges *in vivo* stability, including specific tissue targeting and overcoming by stimuli NPs based on novel drug delivery systems. These drug delivery systems can respond to external and internal stimuli, especially at the target site, with long circulation time and enhanced drug delivery [11]. The external stimuli include a magnetic field, ultrasound field, and light, whereas internal stimuli include pH, temperature, redox, and certain biological molecules such as enzymes for specific tissues/diseases. The most extensively used internal stimuli in the Drug Delivery System (DDS) are pH and temperature. It is reported that any imbalances in these internal body stimuli lead to autoimmune and infectious diseases and metabolic disorders such as cancer, diabetes, and Parkinson's disease [11]. Autoimmune diseases are primarily associated with changes in body fluid pH, whereas an increase in temperature is reported under inflammatory conditions. The temperature changes can stimulate the immune cells to release several inflammatory markers, including cytokines, interleukins, interferons, and tumor necrosis factors in the cell. It is also reported that the proliferation of malignant cells (in cancer) exhibits higher temperatures and an acidic microenvironment [11]. Thus, developing nano-controlled release DDS, which can release drugs under these physiological changes, such as high temperature and reduced pH (acidic), can be a boon in targeted drug delivery with reduced cell toxicity. This concept led to the designing and development of specific polymeric nanomaterials of thermo- and pH-stimuli in various applications. Some recent research work developing different DDS is summarized in Table **1**. These are considered next-generation DDS, which are efficiently capable of responding to external and internal stimuli with less toxicity, increased therapeutic efficacy, and less exposure to normal cells [11].

CHAPTER 6

Integrated Visions for Enhancing Sensitivity in Functional Nanomaterials dependent Chemical Sensors

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Abstract: Nanomaterials' surface (high surface to volume ratio) acts as an electron mediator to trigger chemical reaction and sensing phenomenon. Sensing element is an important chemisorptions site in chemical sensor. The adsorbed oxygen molecules play an energetic role on the surface of nanomaterials in sensing reaction and recognition at optimum temperature. Low molecular Volatile Organic Compounds (VOCs) evaporate at room temperature exclusively because of high vapor pressure. Sensing requires special structural design (large number of surface sites, defects and oxygen vacancy) to trigger rapid chemical reactions for detoxification and decontamination. Chemical reaction triggers sensing phenomenon over specific surface sites and selective structure. Nanomaterials may enable specific functional groups that are selected to align with targeted applications. Surface functionalized sensors are highly susceptible to chemical interaction with contaminants to deliver digital information. The recognition element enables extensive porosity, high binding affinity and excellent physico-chemical stability. The chromophoric group grafted nanomaterial extends the optical properties through the interaction of the analyte. Strong adsorption capacity and high surface reactivity hold better sensitivity. The present chapter focuses on an exclusive vision of chemical sensors integrated by various functionalized, hybrid or composite nanomaterials having strong adsorption capacity, selectivity and high surface reactivity on the broad scale of frontiers and structural diversity.

Keywords: Adsorption, Binding affinity, Chromophoric group, Chemical selectivity, Chemical sensor, Chemisorbed oxygenic anion, Dimensional selective, Dopants, Energetics, Hybrid materials, Interface, Metal oxide, Nanomaterials, Nanocomposite, Oxygen deficiency, Organic pollutants, Reaction site, Surface defects, Sensor resistance, Sensitivity, Target analyte.

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INTRODUCTION

Semiconductor metal oxides are emerging nanomaterials used for the development of sensitive electrodes in the modern era of sensor technology [1]. Sensing reaction is promoted by a chemisorbed oxygenated anion. Size and density of nanoparticles greatly influence the sensing capability. The n-type semiconducting nanomaterials reduce the adsorbed chemical species. Carbon Nanotube (CNT) functionalized conjugated metal oxides have been explored extensively as chemical sensor to detect toxic chemicals or contamination in the environment. Metal oxide-based chemical sensors are highly interesting because of excellent sensitivity, nanosize, low cost and minimum energy consumption. Classically, metal oxide sensors entail electrocatalytic reaction on the surface of the sensing element [2, 3]. Surface defects facilitate adsorption of oxygen and gaseous analyte impressively [4, 5]. The silver (Ag^+) doped nanometal oxide enhances the affinity of analyte to accelerate the chemical reactions *i.e.*, catalytic activity and catalytic oxidation. Metals nanoparticle supported semiconducting metal oxides dissociate oxygen molecules into oxygenic species and catalyze oxygen sensitivity [6]. Chemical reactions are catalyzed by the receptor layer to produce current or temperature change, which is primarily assessed through a specific transducer. As a whole, receptor and analyte interaction contributes to changes that are transformed *via* sensor elements. Receptor layer must be integratively selective for specific analyte to receive rapid response. There should be a mobile equilibrium between analyte A and immobilized reagent R and AR. The integration of nanoparticles into nanomaterials benefits the generation of sufficient cavities which develops fast equilibration in catalytic activity of the surface with analyte [7, 8]. For chemical sensing, oxygen adsorption at the nanomaterial surface initiates sensing phenomenon [9 - 11]. Chemisorbed oxygen comes in contact with nanomaterial surface to apprehend electron from the conduction band of nanomaterials resulting in the generation of functional oxygenic species *i.e.*, O^{2-}, O_2^{2-} and O^- [12]. Oxygenic species are temperature sensitive and are produced only when O_2 traps the electrons to generate O_2^- ions at 150 °C while above 150 °C, other types of oxygen ions become supreme species [13]. The emissions of electrons lead to a decrease in the conductance of the nanomaterials and, hence, increase the resistance. Thus, the sensing capacity of adsorbing oxygen depends on the thickness of the depletion layer. The exposure of gaseous chemical causes enhancement of sensor resistance whereas it decreases upon the release of chemical. Zeolite imidazole framework-8 (ZIF-8) has been used to hybridize metal oxide based chemical sensors to grow higher internal surface and cavities with their high thermal stability and chemical stoichiometry [14]. Functionalized design develops interface for selective sensing performance [15]. The selective combination of two or more distinct materials have been always developed for sensing of volatile organic compounds [16]. Hybrid nanomaterials hold integration of chemically distinct inorganic metal oxide, metal nanoparticles or organic components to renovate final properties [17]. The extended surface area improves the interaction between materials and analytes enabling rapid adsorption/desorption kinetics within less time. Thus, the sensor signal is directly proportional to the nature of nanomaterials or functional materials. Advanced chemical sensors have been invented for the detection of various chemicals such as ethanol, phenyl hydrazine, methanol, hydrazine, chloroform, dichloromethane, acetone, ethanol, *etc*., which are toxic to human life [18, 19]. Electric signal proportional to the concentration of chemical analytes and gas sensitivity of sensitive materials is affected by the change of sensor resistance [20]. Selectivity varies with sensing elements and its operating temperature [21]. One dimensional material(CNT)-integrated metal oxide has often been used for chemical processes, air-water contamination and de-toxification. The conducting polymer functionalized chemical sensor proceeds through redox reactions, ion adsorption and desorption as well as charge transfer and screening. The mesoporous nanocomposite allows better recycling with constant sensor efficiency. Chemo-resistive nature of ZnO nanomaterials originates because of variations in chemical signal when analyte is exposed to exterior surface [22]. At elevated temperatures, the surface electron carriers get easily activated due to the absorption of thermal energy. As a consequence, it further reacts with O_2 in the air to generate galaxy of oxygenic species which in turn result in better sensing response [23, 24]. The improvement in sensitivity of nanosensors is developed on account of their high reactivity, large surface density, multiple functional groups and size-dependent properties. Moreover, various designs *i.e.* nanocomposite formation, functional covalent group and organic ligand, contribute mostly towards enhancement of sensitivity and selectivity for the detection of heavy metal ions. The functional properties of nanomaterials are heavily dependent upon the microstructure, crystalline surfaces, and surface dopants. Hybrid nanomaterials exhibit outstanding performance as a result of the synergistic interaction between the constituent components [25]. The n-type semiconductor enriches with electrons as major charge carriers, which easily interact with a reducing gas to elevate electrical conductivity. Likewise, p-type semiconductors holds positive holes as major charge carriers, which interact with oxidizing analyte and lead to enhancement of conductivity because of the generation of excess positive charge carriers. The adsorbed oxygen species and surface oxidation are the principal factors that perform during the detection process. Thus, nanocomposites have better sensitivity compared to individual components and more importantly, super nanostructure and interface of nanocomposite is developed between p-type and n-type nanomaterials [26]. Nanostructures mediate the rapid diffusion of gaseous molecules over extended reactive sites, which could enhance the response magnitude. The doping or substitution of specific functional

CHAPTER 7

Nanomaterials in Environmental Science: Applications, Impacts, and Sustainable Solutions

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Abstract: Nanotechnology is an interdisciplinary field that serves as a bridge between scientific inquiry and technological innovation. It is a highly appealing area of study. Due to their unique properties, nanomaterials possess the potential to be utilized in a diverse range of applications across various fields. This is due to the inherent capacity of nanomaterials to be employed in a diverse range of applications. Research has demonstrated that nanoparticles possess the capability to cause detrimental impacts on the adjacent ecosystem. Furthermore, the singularity of these compounds has been demonstrated to yield beneficial outcomes. This has yielded a favorable outcome, in conjunction with the exceptional results that have arisen from the uniqueness of these compounds. Various technologies, including nanotechnology in its diverse applications, have been developed to facilitate the conduction of environmental risk assessments over a period of time. Nanotechnology is among the diverse technological advancements. Furthermore, each country has established a prescribed set of guidelines that must be adhered to in order to mitigate the potential hazards associated with said undertaking. The objective of these regulations is to mitigate the potential risks associated with the said activity. The objective of enacting these laws is to mitigate the degree of risk that is linked with the particular activity to a level that is deemed acceptable. Notwithstanding, there exists a clear imperative for a proficient educational framework to mitigate the likelihood of challenges emerging in both the immediate and distant future.

Keywords: Diverse range of applications, Environment Protection, Ecosystem impacts, Environmental risk assessments, Educational framework, Future challenges, Guidelines, Interdisciplinary field, Nanotechnology, Nanomaterials, Potential hazards, REACH, Regulation, Research, Risk mitigation, Singularity of compounds, Scientific inquiry, Technological innovation, Technological advancements, Unique properties.

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INTRODUCTION

The origins of nanotechnology and its utilization in natural settings can be traced back to the inception of life itself. The earliest life forms were unicellular organisms that possessed RNA, DNA, and genes that encoded fundamental information necessary for the organism's survival. The genetic units encompass their own, a quality that is construed in the field of nanoscience as a defining feature of a nano assembler. Since the inception of human interest in the production of nanostructured materials for diverse applications, there has been a remarkable growth in both the volume of research and the level of attention it has garnered [1]. In 1974, N. Taniguchi introduced the word “nanotechnology” to describe the processes and mechanisms involved in manufacturing materials at the nanoscale level [2]. Later on, progress in this field has broadened and applied concepts of nanotechnology in several study areas. The emergence of nanotechnology's “golden age” can be attributed to the 1980s, a period characterized by the identification of fullerene and the release of Eric Drexler's influential publication “Engines of Creation: The Coming Era of Nanotechnology.” The scientific subject and its applications gained major attention at the beginning of the 21st century, becoming a top priority in the United States of America [2]. In 2001, the United States of America implemented the “National Nanotechnology Initiative” (NNI) with the aim of promoting the development of nanotechnology within the country. Following this, some governments, such as Japan and various European nations, have created their own dedicated departments to foster the progress of nanotechnology and its prospective uses [3].

Nanotechnology is a highly influential and revolutionary technology in the modern period, bringing about significant transformations in several industries by offering numerous advantages. The advancements in nanoscience and nanotechnology are expected to not only enable the exploration of new phenomena and ideas but also spark a revolution in several industries, making it the main driving force for economic growth in the present day. This advancement is anticipated to have a significant influence on future society. Nanotechnology is an emerging subject that focuses on the use of nanoparticles, which are particles measuring 100 nm or less. This enables enhanced and innovative attributes of the particles in comparison to their larger counterparts that are commonly employed. The potential applications of nanotechnology are practically boundless. Nanotechnology has produced several goods, including hydrophobic textiles, polymers with tensile properties akin to steel and aluminum, cosmetics containing nanoparticles capable of permeating dermal pores, and microscopic aerial drones [4].

Nanotechnology demonstrates promising prospects in various domains like agriculture, engineering, manufacturing, and medicine. Modern research focuses on improving and making nanotechnology more practical. Estimates indicate that the nanotechnology market will have a value of 55 billion US dollars by 2022. The electronics, energy, and medicinal sectors are anticipated to contribute to around 70% of this growth [5]. The use of nanomaterials (NMs) has greatly increased, leading to a large rise in their presence in natural resources such as air, water, and soil [6 - 9]. The increased use of nanomaterials (NMs) is also supported by the rise in research on their environmental fate and potential health effects in the last ten years. Furthermore, nanomaterials, whether they occur naturally or are created artificially, can pass through filters with a pore size of 0.2 m. This can make it difficult to accurately identify them when analyzing water samples.

What is Nanotechnology?

Nanotechnology is the application of technology at the nanoscale, which has practical uses in diverse fields. Nanoscience is the scientific field that focuses on the study of materials and phenomena at the nanoscale. The properties of matter at the nanoscale display significant differences compared to those observed at the macroscopic scale. When a substance is made smaller, its qualities initially stay the same but later undergo slight changes. Once the magnitude decreases to below 100nm, noticeable changes in features may occur. The unique physical and chemical properties of nanoparticles can be utilized for economic benefits and for creating creative features that provide advantages to the general public. The discovery of new materials, processes, and phenomena in the nanoscale, along with the advancement of experimental and theoretical approaches, has enabled the development of innovative nanosystems and nanomaterials in the late 20th century. The specified domain is offering new prospects in the field of research and technology [10, 11]. Nanotechnology is the scientific discipline that focuses on manipulating physical, chemical, and biological processes at the nanoscale, which encompasses dimensions ranging from individual atoms or molecules to submicron sizes. This field involves diverse facets, such as nanomanufacturing, nanomaterials, and the incorporation of nanostructures into larger systems. The subject matter spans various scientific fields, including chemistry, physics, material science, engineering, and manufacturing. Comparable to 20th-century semiconductor, computer, or cellular and molecular biology technology, 21st-century technology has a tremendous impact on our society and economy. The integration of nanotechnology into large-scale systems has resulted in creative solutions to many modern ecological, medical, and industrial challenges. The areas encompassed are intelligent materials, nanofabrication, electronics, pharmaceutical administration, energy and water management, biotechnology,

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Laxman Singh is currently working as head and associate professor in the Department of Chemistry, Siddharth University, U.P. He has more than a decade of research and teaching experience (<5 of them are from abroad) in the field of materials chemistry. He has been selected as National Research Fellow for South Korea. He has published more than 75 research articles in well-reputed international journals listed in the Science Citation Index which include books, book chapters, research papers, short commentary, and editorials. He has been granted five international patents from the Korean Intellectual Property Office of South Korea. He is editor, associate editor, guest editor, and board member of more than 20 internationally reputed journals. He is a well-recognized reviewer of more than 30 international journals. He has extensive experience in the synthesis and characterizations of nanomaterials, metals, mixed metal oxide (perovskite oxides, spinels), ceramics energy related perovskite materials for Li ion battery, fuel cell, capacitor, supercapacitor, etc.

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