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Review Article

MAGNETIC NANOPARTICLE SYNTHESIS AND APPLICATION: COMBINING BIOMEDICINE AND ENVIRONMENTAL USES

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Abstract: *Magnetic nanoparticles have attracted much attention in several industries, most notably medicine, due to their distinct magnetic characteristics and nanoscale size. They are perfect for many applications because they can precisely manipulate data. This study examines the methods used to create magnetic nanoparticles, specifically emphasizing chemical synthesis via reactions that occur in a solution. This approach enables precise control over the nanoparticles' size, shape, structure, and magnetic characteristics. Recent research suggests that despite their promise, magnetic nanoparticles are inefficient for purifying water. Nevertheless, its use in the field of biomedicine, including medication administration, magnetic resonance imaging (MRI), and hyperthermia, is extensively scrutinized. Furthermore, this paper offers a summary of the use of magnetic nanoparticles in the fields of agriculture and wastewater treatment. The paper explores the creation and combination of magnesia materials for different life science uses, emphasizing the adaptability and importance of magnetic nanoparticles in contemporary scientific and industrial fields.*

Keywords: Chemical Synthesis; Magnetic Nanoparticles; Medicinal Uses

Introduction

Nanoparticles have become the talk of the town in medicine and therapy. Their unique physicochemical properties have significantly shifted clinical therapies, resulting in more powerful, less toxic, and innovative results. Furthermore, these tiny particles have garnered interest in prognostics and treatments. Unlike alloys and blends, composites are a unique type of combination substance that consists of magnetic nanoparticles created by blending components with diverse characteristics. The technology of polymer composites has progressed, and nanoparticle composites have gained significant attention due to their superior physical, chemical, and structural properties compared to their components (1-4). Magnetic nanoparticle composites have recently been developed thanks to materials science and technology advancements. Magnetic nanoparticles are now considered a "promising advanced material" due to their numerous valuable qualities, such as high elastic modulus, thermochemical properties, magnetic properties, flame resistance properties, improved density, relatively large surface areas, and optoelectronic properties. (5-8). Magnetic nanoparticle composites are not very popular in industries and are rarely used, including biomedical, construction, car, remediation technology, petroleum, wastewater treatment, and aerospace. In nanotechnology, Non-particle/polymer nanocomposites are not a widely discussed subject, and nanofillers have not shown promise as bio-resin fillers since they cannot establish synergistic bonds with the matrix. (9-12). Therefore, they do not improve the mechanical and physical properties of biocomposites. Nano biocomposites are highly sought-after engineered materials due to their superior thermal and mechanical capabilities, fire retardancy, and heat distortion temperature compared to traditional polymer composites. Using magnetic nanoparticles, bio-resin has been recommended to improve natural fiber-reinforced composites' thermal, mechanical, and other physicomechanical features. Numerous studies have shown that exfoliating the nano clay rather than intercalation can significantly improve the physical and mechanical properties of nano-biocomposites made with bio-resin modified with nanoparticles. A vast array of these combinations are created using natural polymeric substances like chitosan and starch. In contrast, others are derived from synthetic magnetic nanoparticles such as PLA and poly (urethane) (PU) or petrochemicals like PCL and PBS. Researchers have also explored using magnetic nanoparticle filler to modify soy protein and create composites reinforced with flax yarn or fabric.

Furthermore, the fusion of magnetic nanoparticles up to 10% in PGA has not been detected to intensify the durability and water resistance of the final composite. Magnetic nanoparticles and modified SPC resins-based environmentally friendly 'green' composites are remarkable scientific achievements. Medium-density fiberboard (MDF) has been created using aspen and magnetic nanoparticle

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resin, with the best strength and stiffness found in boards with six wt% magnetic nanoparticles. Magnetic nanoparticle composites made with whitened red seaweed fiber (BRAF), kenaf fiber (KF), and cotton pulp fiber (CPF) have also been shown to benefit from the addition of 5 wt% nano clay, resulting in improved dimensional stability and dynamic mechanical characteristics. The use of clay/polymer nanocomposites has been identified as a promising area of nanotechnology, with Toyota's work on clay-exfoliated nylon-6 considered the starting point of this field. Clay-polymer nanocomposite production relies on separating clay aggregates and the polymer matrix to enhance the performance of individual silicate layers. These nanocomposites are peculiar in their characteristics and are progressively being employed in various fields like sewage treatment, medicinal applications, and the petrochemical industry. (13, 14) Integrated bentonite and MMT dual nanofiller into an EVA nanocomposite to create mechanically stable bioimplants with low cytotoxic activity. Murugesan and Scheibel examined the biological application of several clay-laden polymer nanocomposites and found that they are biocompatible, cytotoxic, vascularization-inducing, and compelling for prolonged drug release (15-17).

Moreover, they are sensitive to stimuli, have a shape memory effect, and promote rapid tissue regeneration. It seems unlikely that these magnetic nanoparticle composites would be helpful for anything beyond basic research. Creating magnetic nanoparticles (18-21) I am benefiting from bioprinting and creating wearable devices. This composition offers a compact appraisal of the most current procedures for creating and scrutinizing magnetic nanoparticle nanocomposites.

This study review investigates the primary techniques for producing magnetic nanoparticles and examines their diverse applications. As the market becomes flooded with new nanotechnology products and governmental bodies engage in public discourse on their ecological and fitness implications, many are left wondering what all the fuss is about. Though NGOs responded promptly, it is only now that social scientists have begun to investigate the cultural implications of nanotechnology, creating new discourses and bringing about novel social dimensions.

By analyzing how these discourses intersect with finance, health, the environment, government, and the future, we can gain insight into the various social components at play and the newly constructed imaginations that arise from them. We conclude that ELSI (environmental, legal, and social aspects) must be considered from the outset when discussing nanotechnologies.

The rest of the paper is structured as follows. Section 2 presents the literature review; Section 3 presents the creation of MNPs; Section 4 presents the Strategy for MNPs; Section 5 presents the applications; Section 6 presents the discussion; Section 7 presents the conclusion.

Literature Review

Nanotechnology has become a prominent scientific breakthrough of the 21st century, found in various ecological, scientific, and technical industries. Over the past years, scientists have made considerable advancements in using nanostructured biomaterials for medical aims—the primary techniques for producing magnetic nanoparticles. Magnetic nanoparticle techniques produce GO nanosheets from bulk graphite particles. (22-25). GO and its derivatives have been the subject of numerous studies by biodevice researchers examining their potential use in drug delivery, bioengineering, nanomedicine, biosensors, cellular imaging, energy storage, and antifungal activities. However, separating GO from aqueous solutions is challenging as it tends to clump, and its direct applicability in solid-phase extraction is limited. The unique properties of magnetic nanoparticles make magnetic graphene oxide the most promising solution, as they can be isolated using an external magnetic field. (26-28). Iron oxide nanoparticles have no potential as biomedical candidates due to the inherent cytotoxicity of GO and its derivatives, despite their poor biocompatibility, weak chemical stability, and intrinsic toxicity, such as magnetic nanoparticles. IONPs may alter in response to an applied magnetic field and can be regarded as a magnetic domain without one. If IONPs interact with each other and an external magnetic field, they can result in system-wide energy changes, making them beneficial in biomedical research (29-31). The body's metabolic processes can break down naturally occurring metals such as iron oxide.

The remarkable properties of magnetic nanoparticles, including para-magnetism, oxidation-specific surface area, surface-binding site activity, chemical stability, coordination, functionalization, and biocompatibility, are all attributed to their unique composition as a composite of magnetic nanoparticles and GO. (32-35). Magnetic nanoparticles is a term used to describe various nanocomposites created by combining graphene oxide with magnetic metal oxide, such as Fe3O4/GO, magnetic reduced GO, Mn3O4/GO, and other similar materials. Despite being studied in various applications such as drug loading, chemical extraction, bio-imaging, photodynamic treatment, and magnetothermal therapy of malignancies, the potential medical uses of magnetic nanoparticles remain to be systematically evaluated (36-41). This article aims to provide a concise overview of the methods for incorporating magnetic nanoparticles into biomedical settings, focusing on their medicinal applications. Let us deliberate on the structural and physicochemical characteristics of MGO nanocomposites and their cytotoxicity in relation to their possible medical uses. Furthermore, we will highlight MGO's biological uses, including its role as an MRI contrast agent, biosensor, biochemical extractor, stem cell reprogrammer and differentiator, targeted drug delivery system, and cancer treatment. (42-45). Finally, we will address open issues and make educated guesses about the future of MGO nanocomposite research in biomedical treatment.

Creation of MNps Synthesis

Recently, a profusion of scholarly literature has elucidated the creation of magnetic nanoparticles by utilizing diverse compositions. Numerous areas hold significant promise for improvement in the research and production of MNPs. Two techniques are available to generate nanoparticles: top-down or bottom-up. The former involves reducing an extensive material into its constituent nanoparticles and nanostructures. The strategies for top-down synthesis of micron-sized particles are an extension of those already in use (46). Nanofabrication techniques employ physical or

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chemical forces at the nanoscale, bottom-up, or self-meeting to assemble basic building blocks into more complex structures. The creation and organization of quantum dots (47, 48) Are self-meeting with limited control. With the right approach, manufacturing magnetic nanoparticles is an effortless task. These strategies are conventional approaches to artificially generating MNPs. The primary techniques for forming MNPs involve physical, chemical, and biological synthesis.

Chemical approaches

The chemical method is often used for the sole purpose of making MNPs. This plan is a compilation of many different bottom-up methods.

Sol-gel technique

The sol-gel technique is a wet physical approach utilized to produce an array of microstructures, including steel oxide nanoparticles. By dissolving the precursor molecule, metallic alkoxide, in alcohol or water, heating it while stirring, and subsequently hydrolyzing it to create a gel, this technique is executed. The combination is believed to be dried using this technique when the solvent has evaporated, and the solution appears dry, ultimately forming a gel. The sol-gel method is a complicated and intricate technique for generating nanoparticles that mandates specific equipment. The process yields small, well-defined nanoparticles and operates at room temperature. Although toxic organic solvents are sometimes employed, resulting in pollution, this technique is immaculate, crystal clear, and highly adaptable—the intricacies of sol-gel deposition. As previously stated, the sol-gel method strives to liquefy chemicals to attain precise control over the processes' components. Multi-component compounds can be created by combining different reagent sols with precise stoichiometry. The sol-gel method enables atomic-level mixing, producing small particles that are sinterable without difficulty, as it is not a gelation reaction, which can result in inhomogeneous outcomes.

Synthesis via hydrothermal means

Hydrothermal synthesis, an extensively accepted practice for producing nanomaterials, is highly dependent on the reaction in a solution. The magic of this procedure is its capacity to form nanomaterials at an extensive temperature range, from room temperature to extreme. Of course, the vapor pressure of the reaction's primary components plays a pivotal role in determining whether high-stress or low-stress conditions should be applied to structure the materials. Hydrothermal synthesis has been successfully employed in a plethora of nanomaterials. In reality, hydrothermal synthesis possesses numerous advantages over alternative methodologies. This method seldom produces nanomaterials that are not thermally stable. Additionally, the hydrothermal approach can create high-vapor-pressure nanomaterials while minimizing the scarcity of materials. Some innovative synthesis approaches discussed in this context include using microwaves to facilitate hydrothermal Synthesis and template-free self-assembling catalytic Synthesis. Research also delves into how to achieve optimal synthesis conditions. The published works explore nanomaterials for energy harvesting and biosensing packages. Recycling minerals for environmental benefits is another aspect of hydrothermal synthesis that has been investigated. In this regard, the process yielded magnetic nanoparticles of varying sizes and sorts, including 15nm $Fe3O4$ nanoparticles used in MRI for tumors. That being said, this procedure mandates substantial attention to detail and specialized equipment. Compared to Solgel and other synthesis methods, hydrothermal synthesis stands out for its superior form, size, and high crystallinity.

Technique for creating microemulsions

Microemulsions are an intriguing option for creating non-reactive self-aggregated colloidal structures in nanoparticle regulation. This chapter delves into the production of steel NPs generated through microemulsion techniques. By manipulating response time, temperature, and reaction circumstances, we can effectively create a range of seed shapes and sizes using the same reagents, potentially opening doors to unique applications in various academic fields. A stable isotropic dispersion called microemulsions can be formed using a surfactant to mix water and oil. These digital frameworks could produce many self-assembling forms, including spherical and tube-shaped micelles, layered tiers, and interconnected microemulsions. Water-in-oil (w/o) microemulsions are identified by an aqueous phase composed of Nano droplets dispersed throughout the oil phase due to surfactant interactions. Mixing water and oil to create an emulsion can generate water-soluble SPIONs. Scientists have proposed building in situ magnetic chitosan/$Fe3O4$ NP composites using microreactors within miniature water swimming pools of a water-in-oil emulsion. The magnetic $Fe3O4$ and chitosan NPs were introduced simultaneously, with the leading solution of NaOH being fed into the suspension covering ferrous salt and chitosan.

Strategies for Coprecipitation

Producing iron oxide nanoparticles via coprecipitation is a widely recognized and practical method. The precipitation of salts like sulfates, chlorides, and nitrates in aqueous solutions of $Fe2+$ and $Fe3+$ salts results from adding a base like NaOH. The final nanoparticles' size, composition, and morphology can be adjusted experimentally by modifying the shape of the precursors, ratio, reaction temperature, floor ligand, and pH. It has been proven that using various types of floor ligands, such as surfactants, polymers, and inorganic compounds, as stabilizing agents during precipitation can significantly change the size distribution of the as-organized nanoparticles. This is a remarkable strategy for generating iron magnetic nanoparticles.

Biological Technique

The advancement of natural applications for materials necessitates the development of eco-friendly technologies in textile synthesis. Current research has explored the use of extraordinary microorganisms in the creation of non-organic nanoparticles, which have a variety of applications in the newest technological fields. This examination investigates the most recent progressions in comprehending the biochemistry of non-organic particles, such as metal, oxide, sulfide, and different particles. The processes leading to these nanoparticles' creation are unique and detailed. The criteria for modifying debris size, shape, and stability are also established. The applications for these biosynthesized nanoparticles are vast, ranging from focused drug delivery and cancer treatment to gene therapy and DNA analysis, as well as boosting response rates. The chance of microbial manufacturing of inorganic nanoparticles is also explored. Natural and artificial elements have always had a relationship since the beginning of existence on this planet. This interaction may lead to the formation of a lifesupporting mineral deposit on Earth. Researchers are increasingly interested in how inorganic substances affect biological organisms. It's improbable that multiple microorganisms produce inorganic nanoparticles through extracellular or intracellular pathways. This study portrays metal nanoparticles, such as gold, silver, and different oxide nanoparticles, steel nanoparticles, magnetic and nonmagnetic oxide nanoparticles, sulfide nanoparticles, and other assorted nanoparticles, and how they are formed using natural techniques. Figures 1 and 2 contain additional information

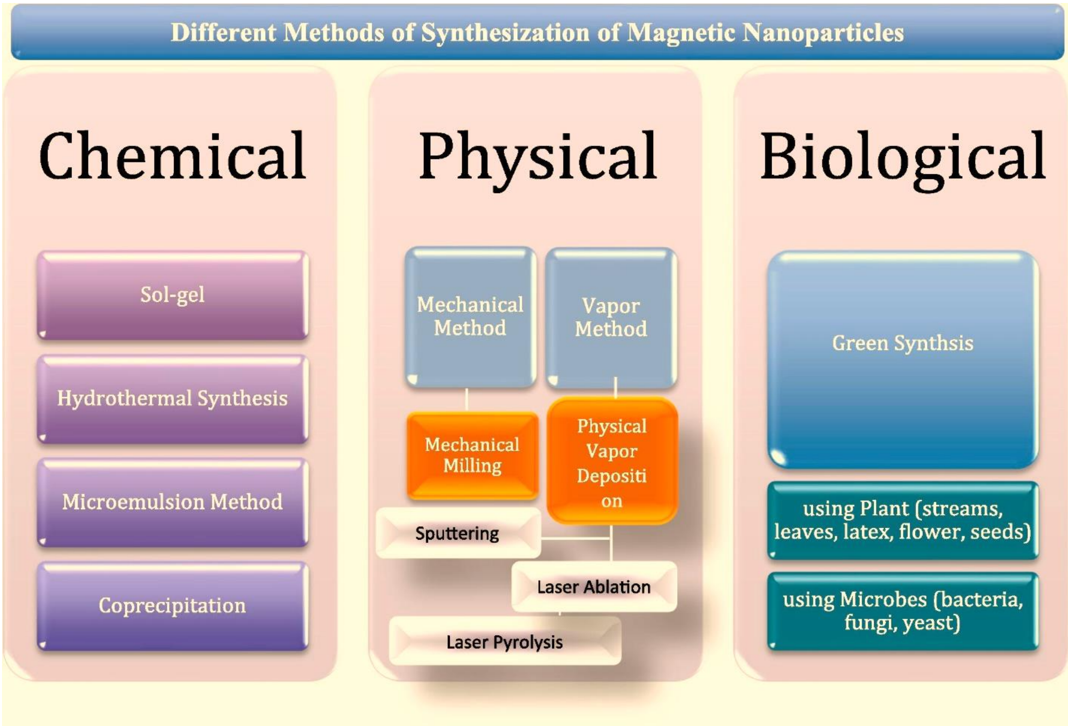

Figure. 1. Magnetic Nanoparticles: Their Synthesis and Application.

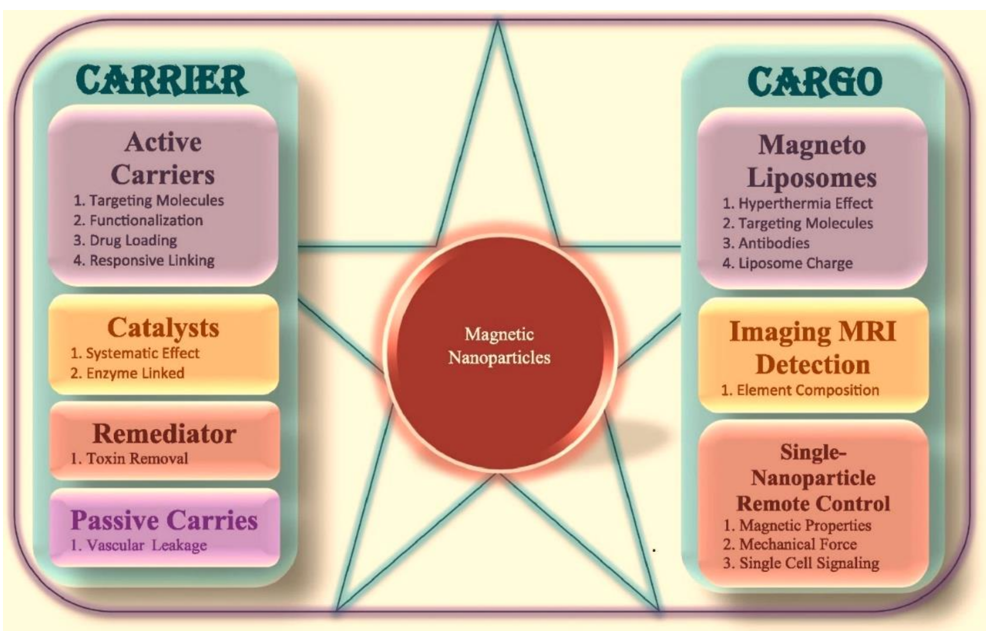

Figure. 2. The MNP's Use Structure.

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Strategy of MNPs

Magnetized nanoparticles are essential in engineering features such as magnetism and surface area. Investigators have implemented a technique of organic-phase synthesis to produce iron oxide nanoparticles with a diameter of less than 20 nm. The size of nanoparticles is primarily affected by the solvent's reaction time and boiling point. Scientists utilize a protective layer to stabilize the system, while the surface charge upholds the strong attraction among the particles. Magnetic characteristics are indispensable for inducing nanoparticle heating through magnetic fields and regulating hyperthermia externally. The transportation and movement of biological entities through magnetic force have broad applications in molecular-level cell signaling and cell fate regulation. Magnetic iron and cobalt nanoparticles generate tremendous magnetism but necessitate a protective layer to prevent oxidation. Platinum magnetic nanoparticles showcase noteworthy potential as a magnetic resonance imaging (MRI) and X-ray computed tomography (CT) contrast agent. Porous magnetic nanoparticles are superior to solids in medical retention and release, though they share many properties with the latter. Based on studies, magnetic nanoparticle-based cancer therapy has proven to minimize drug resistance and side effects. Non-covalent drug conjugation with nanoparticles has demonstrated efficacy in drug delivery.

Applications

Biomedicine

The sphere of biomedical applications is witnessing a boom in innovative technologies, including using magnetic nanoparticles (MNPs) across various healthcare domains. MNPs have proven effective in treating persistent diseases and aiding medication targeting, particularly in cancer treatment, where they are used as heat mediators in hyperthermia therapy, healing vehicles for medicine delivery, and vision advertisers in magnetic resonance imaging (MRI). The advantageous magnetic properties, biocompatibility, and functional floor of MNPs have led to their investigation as potential new MRI contrast agents. Additionally, MNPs have been shown to improve the dispersion of bactericidal drugs to specific microniches and aid in constructing intelligent materials. Surface-functionalization methods and colloidal synthesis have recently undergone developments that have created functionalized MNPs with tunable features and multifunctional abilities that could be utilized in terpsichorean and diagnostic applications. The current analysis highlights the roles of MNPs in treating chronic diseases, medication targeting, and optical and electrochemical immunoassays, as well as contemporary concerns and avenues for future research to improve their technical uses.

Drug transport

In modern times, significant advancements have been made in the field of transportation systems, which has led to the efficient transfer of healing substances and natural energy components to their intended destinations for treating various medical conditions. Even with multiple efficient drug delivery techniques available, specific barriers persist, and it is crucial to develop intricate technologies to ensure the drug reaches the targeted location. Consequently, an expansive study is underway to devise nano-based medication distribution systems that amplify the efficacy of medication distribution procedures.

Cancer theranostics

In cancer theranostics, nanobiotechnology and molecular biology have emerged as cutting-edge techniques thanks to recent advancements. These tactics rely heavily on using bespoke nanoparticles (NPs) with diverse features to tackle the constraints of current cancer therapies and diagnoses. NPs can be utilized to create nanoscale imaging probes, which aid in monitoring cancer progression and detecting early cases. Additionally, NPs' improved infiltration and retention EPR impact can help transport anticancer drugs, genes, or proteins to the intended tumor areas. Nonetheless, producing distinctive nanomaterials remains imperative for enhancing the efficacy of cancer diagnosis and treatment. Magnetic particles (MNPs) are not ideal for cancer hyperthermia therapy, magnetic resonance imaging, biosensing, or targeted drug delivery because of their suboptimal physicochemical characteristics and supermagnetic qualities. Hyperthermia therapy involves the induction of magnetic hyperthermia by heating MNP suspensions within the body using an AMF. The malignant microenvironment's lower pH and reduced thermotolerance make cancerous cells more vulnerable to hyperthermia than normal cells. This approach to cancer therapy is problematic as it could potentially harm healthy tissues.

MNP-based hyperthermia's primary advantage lies in its ability to penetrate tissues deeply and selectively target cancer cells while minimizing harm to the surrounding healthy tissue. Adding cell-targeted ligands to MNPs enables more precise targeting, enhancing the efficiency of intracellular heating and cancer treatments. MNPs can also improve chemotherapy by inducing hyperthermia using a magnetic field, delivering drugs, and providing access to the outside world. The chemotherapeutic agent DOX was blended with oleic acid and PEG to generate a micelle polymer form using superparamagnetic SPMNPs to enhance its delivery to cancer cells. SPMNPs activate the integrated magnetic hyperthermia pathway, providing on-demand synergistic hyperthermia or chemotherapy, which improves drug delivery, cancer cell growth, and chemotherapeutic impact.

Biomedical imaging for cell sorting

Magnetic nanoparticles are the building blocks of molecular firing and separation from a solution of patterns. The residue area acts as a hub of exchange. They lure the molecules of interest utilizing specific binding sites on their surface, then transport them inwardly under magnetic manipulation. The particles' specificity and adjustable binding sites render them versatile in various scientific, technological, and biological applications.

Theragnostic bacteria

Although sterilization and imaging technology have advanced, drug-resistant bacterial diseases like MRSA remain challenging to identify and eradicate. This study introduces a novel approach for developing theranostic nanoprobes that may be activated to target MRSA infections specifically. The innovative sensor utilizes the unique characteristic of polyelectrolyte dissociation from silica nanoparticles when exposed to bacteria. We created non-fluorescent nanoprobes, called SiO2-Cy-Van, using silica nanoparticles coated with polyelectrolyte-cryptate complexes modified with vancomycin. These nanoprobes

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show ground-state suppression in water because the hydrophobic fluorophores on the silica nanoparticles cluster together. Our study's results indicate that MRSA can trigger the detachment of vancomycin-modified polyelectrolyte-cryptate complexes from nanoparticles. This process triggers MRSA-specific near-infrared fluorescence (NIRF) and allows photothermal eradication in a controlled environment. It does this by causing a transition in the cryptate molecule from its aggregated (inactive) form to its disaggregated (active) state, which disrupts the bacterial cell wall and membrane. This method presents a hopeful resolution for accurately identifying and efficiently managing MRSA infections.

Hyperthermia

MHT has been utilized for over three decades as a therapeutic technique for solid tumors. In the ongoing clinical trials of MHT for treating prostate and brain malignancies, a patient-safe 100 kHz AMF applicator is utilized, and iron oxide nanoparticles act as intra-tumoral MHT retailers. However, the effective treatment of MHT requires the specific physical-chemical properties of MNPs, such as magneto-electrical conversion, surface chemistry, heat dose production, and aggregation state, which still need to be approved by the FDA. As a result, new MNPs focusing on MHT have been developed in recent years. This analysis explores MNPs and the latest synthetic techniques used to produce them, explains how MNP abilities have permitted MHT to achieve unprecedented warming productivity, and discusses the role of Nano platforms in preventing magnetic heat loss in the cellular atmosphere.

Environmental

Nanotechnology has immense potential for providing innovative solutions to various ecological issues. From the more efficient reduction of pollutants to the detection of environmental threats, water treatment, restoration of polluted areas, and the optimization of alternative energy sources, engineered nanoparticles can play a vital role in cutting-edge green technology. Nanomaterials' customized properties are ideal for environmental applications, particularly in pristine ecosystems. Over the years, scientists have been improving methods for managing pollution by considering different properties of nanomaterials, including mechanical, electrical, and optical properties and assembly methods. The study of these materials utilized SEM, TEM, and XRD techniques, with a particular emphasis on nanoparticles ranging from 1 to 100 nm in size (49-53). Nanoparticles offer many environmental benefits, including producing solar cells for easy power generation, coating outdoor surfaces, and decolorization without chemicals. Operating on the nanoscale, nanotechnology is a promising approach to modernizing environmental remediation operations, yielding materials, devices, and systems with novel qualities and functions. Moreover, research has suggested that nanoparticles treated with alkaline metals lack the capacity for carbon dioxide absorption, thus rendering them ineffective in promoting environmental safety. Nanotechnology products, techniques, and projects possess the potential to significantly contribute to environmental and climatic safety by reducing greenhouse gas emissions, preserving raw resources, energy, and water, and reducing hazardous waste. Despite this, some have questioned the practical role of modern nanotechnology in environmental safety, although environmental engineering companies remain optimistic about its potential.

Agriculture

Ensuring food security in developing nations is daunting due to factors such as poor agricultural productivity, depletion of natural resources, substantial post-farm losses, unsustainable population growth, and minor or nonexistent fee addition. Researchers are exploring cutting-edge technologies to tackle the issue of inadequately named "gap" meals. One such promising technique is the utilization of nanotechnology to enhance agricultural output by modifying soil qualities, detecting illnesses, and managing wastewater. Nanotechnology has immense potential for processing food, leading to more food with better market value, improved nutritional and sensory qualities, enhanced antibacterial safety, and increased security. Furthermore, it may positively impact livestock production as it reduces waste by employing nanoparticles to increase the shelf-life of goods. Nonetheless, it's imperative to tackle the health and safety worries linked to the innovation via extensive research.

Catalysis application

Utilizing magnetically separable (MNP) catalysts has significantly eased the limitations of heterogeneous catalysis. These nanoporous catalysts can be effortlessly dispersed and magnetically separated, showcasing remarkable reactivity. By immobilizing active species on MNPs, the requirement for pricey catalysts or ligands can be eliminated while enabling easy separation in a quasi-homogeneous setting. Lately, improvements and uses have exploited the catalytic locations integrated inside the magnetic nanoparticles for the catalyzed reactions of transition metals.

Discussion

This article comprehensively surveys the advanced techniques employed in manufacturing magnetic nanoparticles and their diverse applications. As newer nanotechnology products are introduced to the market and governments initiate public programs, many are beginning to wonder about the significance of nanotechnology with environmental and health concerns. The cultural impact of nanotechnology has only recently been explored by social scientists despite the quick response of non-governmental organizations. This has caused new discussions and the initiation of unique societal aspects. Each social aspect and their newly constructed imaginations show how nanotechnology discourses are linked with government, economics, health, the environment, and the future. Therefore, ELSI (environmental, legal, and social implications) cannot be an afterthought when discussing nanotechnologies.

Conclusion

The study of nanotechnology's potential to advance biotechnology and medical research has been intensely scrutinized. Regulatory bodies such as the Food and Drug Administration have opted to employ existing legal frameworks to oversee the rapidly evolving realm of nanotechnology. The decision to abstain from enforcing extensive regulatory standards is a measure to foster secure and prosperous technologies by steering clear of unnecessary regulatory hurdles. As nanotechnology advances and more medical data on its benefits and drawbacks is available, additional regulation may be required for specific product types to ensure public health protection. Establishing cohesive global communication and record-sharing among nanotechnology-associated businesses, universities, and government agencies is crucial to developing practical regulatory guidelines in this field. This could pave the way for the responsible development of nanomaterials that improve human lifespan extension and enhancement.

Declarations

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All data generated or analyzed during the study are included in the manuscript.
Ethics approval and consent to participate
Approved by the department concerned.
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All authors contributed equally

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Conflict of interest

The authors declared the absence of a conflict of interest.

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