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NANOTECHNOLOGY AND ITS ROLE IN BIOLOGICAL, CHEMICAL, AND PHYSICAL SCIENCES

VOLUME I

Editors:
Dr. Sheerin Masroor
Dr. Sanjeev Rathore
Dr. Shabana Karim

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PREFACE

The convergence of nanotechnology with the vast domains of biological, chemical, and physical sciences has heralded a new era of scientific innovation and discovery. At the nanoscale, materials exhibit unique properties that open up possibilities for applications unimaginable in traditional paradigms. The intricate interactions at this scale allow us to manipulate matter with unprecedented precision, leading to breakthroughs that span across disciplines—from drug delivery systems in medicine to advanced materials in engineering and environmental sciences.

This book, Nanotechnology and its Role in Biological, Chemical, and Physical Science, is a comprehensive exploration of the transformative potential of nanotechnology in these diverse fields. It delves into the fundamental principles of nanoscale science and examines how these principles are applied to solve complex problems, drive innovation, and create new technologies that benefit society.

In the biological sciences, nanotechnology is revolutionizing diagnostics, therapeutics, and the development of biomaterials. Chemical sciences benefit from nanoscale catalysts and sensors that enhance efficiency and enable green chemistry. In physical sciences, nanotechnology is pushing the boundaries of material science, photonics, and electronics, leading to the creation of smarter, more resilient systems.

This volume brings together contributions from leading experts in the field, offering a multidisciplinary perspective that reflects the interconnected nature of modern scientific research. Each chapter is designed to provide a deep understanding of both the theoretical foundations and practical applications of nanotechnology in these pivotal areas of science.

As we stand on the cusp of the next wave of technological advancement, it is our hope that this book will serve as a valuable resource for researchers, educators, and students alike. May it inspire new ideas, foster collaborative efforts, and contribute to the ongoing quest to harness the power of nanotechnology for the betterment of humanity.

Editors

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REVOLUTIONIZING PLANT GENETIC ENGINEERING WITH NANOTECHNOLOGY

Shiny Jaiswal, Neha Misra and Niharika Maurya
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Abstract:

A broad spectrum of scientific equipment and techniques are employed in plant biotechnology (PBT) to screen and genetically modify plants in order to produce valuable plants or plant products. Nanotechnology interventions may enhance the effectiveness of various instruments and methods. Crop biotechnologists can now customize designer crops by using nanomaterials (NMs) as gene or protein delivery systems, and they can also employ nanotechnology in order to understand the biochemical mechanisms behind plant responses. Our main focus was on the state-of-the-art nanotechnology-based delivery system. We went over the many kinds of nanoparticles, how nanomaterials are prepared, how nanoparticles are transported, and their advanced uses in plant genome engineering. We came to the conclusion that genome editing, nanoparticle-mediated gene transformation, and de novo regeneration technologies together can effectively speed up agricultural development in the future based on conventional approaches. A special emphasis is placed on comprehending structure-function interactions in order to rationally design nanocarriers and how these advancements may stimulate breakthroughs in the delivery of proteins and nucleic acids for application in plant biotechnology. An overview of planned and coordinated multidisciplinary research on the application of nanotechnology to biocargo delivery in plant systems is the goal of this chapter. It discusses the advancements, uses, and applicability of genetically based nanotechnology approaches as well as their limitations and future research paths to guarantee the safer deployment of these techniques in agriculture and food security in the future.

Keywords: Nanotechnology, Nanomaterials, Nano-Carriers, Plant Biotechnology, Genome Editing, Biocargo.

Introduction:

For sustainable agriculture to improve crop yield, quality, and resilience to abiotic and biotic challenges, plant genetic engineering is crucial. Plant genetic engineering makes considerable use of agrobacterium, biolistic bombardment, electroporation, and polyethylene glycol (PEG)-mediated genetic transformation methods. These systems do have several drawbacks, though, such as species dependence, tissue damage in plants, inefficient transformation, and high cost. Plant genetic transformation has recently witnessed the development of gene-delivery techniques based on nanotechnology. This nano-strategy exhibits great transformation efficiency, acceptable exogenous nucleic acid protection, good biocompatibility, and plant regeneration capacity[1].

In several areas, including the production of nanoscale matter and the application of its unique optoelectronic and physicochemical features, the discipline of nanotechnology has seen remarkable advancements. Improved accuracy in plant breeding has been made possible by tactics based on nano-genomics. Important genes from distant plants can now be accessed by breeders, and breeding has created intriguing new opportunities for gene selection and transfer that have reduced the time needed to eliminate unnecessary genes[2].

Materials with one dimension less than 100 nm are referred to be nanomaterials. One of the main advantages of nanomaterials over their traditional equivalents is their small size, which results in a high surface-to-volume ratio. The small size, surface structure, chemical composition, stability, form, and aggregation of nanoparticles give them distinctive physicochemical features, including small surface area, unusual surface structure, and enhanced reactivity. In addition to their distinct physicochemical characteristics, nanoparticles may be easily surface conjugated, making them flexible platforms with a wide range of uses in plant science[3].

The phenomenal effectiveness and versatility of the nanoparticle-mediated gene delivery method presents a technological edge over traditional methods. Recent studies have shown a great deal of interest in the application of nanotechnology in agriculture, particularly in the areas of nanosensors, nano-pesticides, and nano-fertilizers. In fact, the delivery of genes to plants using nanoparticle-mediated gene transformation has been widely employed[4].

Fig. 1: Application of Nanotechnology in Plant Bioengineering

In addition, as distinct agrochemical carriers, nanoparticles enable more crop protection through site-specific, regulated nutrient delivery. High-tech agricultural farms are supported by nano-tools like nano-biosensors because of their direct and intended applications in the exact management and control of inputs (fertilizers, insecticides, and herbicides) [5].

A new era of precise genetic engineering has been brought about by the invention of nuclease-based genome editing (e.g., CRISPR-Cas9), which has allowed for the generation of GMO. Nanoparticle delivery is a crucial technology for the advancement of plant genetic engineering because of its ability to overcome the drawbacks of conventional delivery methods. This makes them good candidates for delivering nuclease-based genome editing cargo.

Nanoparticles

Materials classified as organic, inorganic, or hybrids that have at least one dimension in the nanoscale range of 1 to 100 nm are called nanoparticles (NPs). The generation of nanoparticles (NPs) from plants and microorganisms has become a highly effective biological source of green NPs. In recent times, scientists have shown increased interest in this approach because of its eco-friendliness and ease of production when compared to alternative methods.

Every NP is a three-dimensional object (3D). Nanowires and nanotubes are examples of one-dimensional (1D) nanoparticles, whereas nanolayers and nanofilms are examples of two-dimensional (2D) NPs. One-dimensional (1D) NPs have two dimensions at the nanoscale and one dimension at the macro scale. Once more, zero-dimensional (0D) NPs are characterized by all three dimensions at the nanoscale, whereas three-dimensional (3D) NPs have zero dimensions at the nanoscale and three dimensions at the macro scale (nanoballs, nanoflowers).

Quantum dots and other zero-dimensional NPs are widely accepted and utilized in solar cells, light-emitting diodes, and single-electron transistors, which are used in lasers. In the field of nano-engineering research, the creation of two-dimensional nanoparticles (NPs) like junctions (continuous islands), branched structures, nanoprisms, nanoplates, nanosheets, nanowalls, and nanodisks has become essential. The exploration and development of novel applications in sensors, photocatalysts, nanocontainers, and nanoreactors has surged due to the geometric structures of nanoparticles. On the other hand, due to their enormous surface area and other superior qualities including absorption sites for all involved compounds in a short space, which lead to a better transport of the molecules, three-dimensional NPs have recently gained great study interest. As a result, the advancement and creation of innovative technologies for the generation of NPs and their possible applications are extremely important, especially for the creation of environmentally and agriculturally sustainable systems.

Type of Nanoparticles

Nanostructures of DNA, peptides, metal-based NPs, silicon-based NPs, clay nanosheets, polymer-based NPs, and clay nanosheets are among the several kinds of nanoparticles (NPs).

With the potential to cause either temporary or permanent alteration, each class of NPs has unique properties and purposes. NPs have been employed extensively to modify plants.

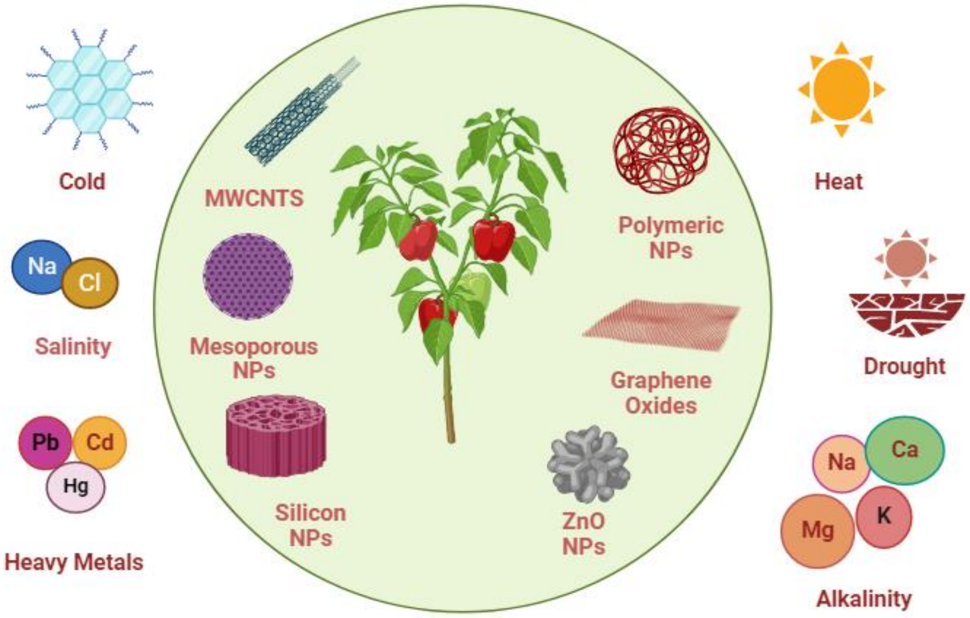

Fig. 2: Types of Nanoparticles

Some examples of nanoparticles as a means for achieving additional improvements in the agricultural industry are as follows:

a) Nanocapsules are utilized to increase the bioavailability of nutraceuticals in regular components and to more effectively distribute insecticides, fertilizer, and other agrichemicals.
b) Vaccines are delivered by nanocapsules, whereas DNA is delivered to plants via nanoparticles (focusing on genetic engineering).
c) Utilizing nanosensors allows for the identification of plant and animal diseases as well as the monitoring of soil conditions and crop growth.
d) To bind and extract chemicals or pathogens from food in a targeted manner, nanoparticles are utilized.
e) For improved nutrient availability and dispersion, nanoemulsions and particles are employed.

Preparation of Nanoparticles

Top-down or bottom-up synthesis is a method for creating nanomaterials by physical, chemical, or biological means. The bulk materials for the top-down method are often broken down into smaller molecules through physical means, which are then further processed into nanoparticles (NPs) as required. The bottom-up strategy allows for the direct preparation of nanomaterials by building nanoscale nanostructures, which is often accomplished using chemical means. Recently, NPs have been produced by green synthetic approaches that use different microbes or plant extracts. These methods show great promise.

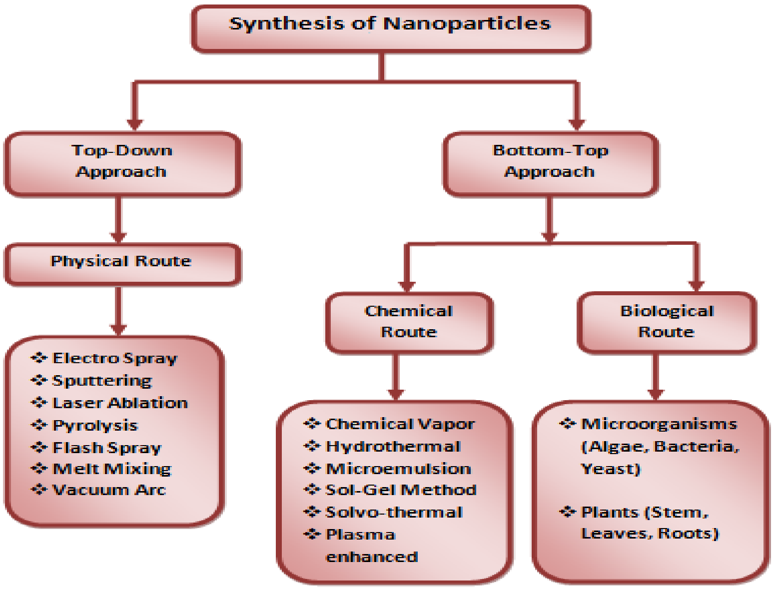

Fig. 3: Synthesis of Nanoparticles

Transportation of Nanoparticles in Plants

Many parameters, including plant species, particle concentrations, size, surface charge, and exposure duration, restrict the uptake and transport of nanoparticles in plants. Plants primarily absorb nanoparticles (NPs) through their leaves and roots. Their diverse morphological traits, meanwhile, result in varied NP transport barriers. Plant leaves frequently have a protective layer called a cuticle that is made up of an impregnated insoluble epidermal membrane that is covered in soluble wax. Hence, NPs bigger than 10 nm pass past stomata to enter cells. Furthermore, the number and activity of stomata differ between species and are dependent on the environment; therefore, these factors must be taken into consideration when absorbing nanoparticles.

Nanomaterials can enter cells and membranes through a variety of mechanisms, including as diffusion, endocytosis, plasmodesmata, or chemical and physical degradation. The strength and tension of the cell wall can be controlled to achieve the internalization of NPs by varying the composition of the NP osmotic buffer, which in turn affects the cell wall's local water potential. Nanoparticles' charge state and form can also affect how easily they penetrate plant mesophyll tissues. Arabidopsis leaves were able to absorb and internalize rod-shaped gold nanoparticles more readily than spherical nanoparticles at comparable particle sizes. Since the majority of plant cell walls are negatively charged, electrostatic attraction should also be taken into account. Positively charged nanoparticles adsorb more strongly than negatively charged nanoparticles.

Additionally, variations in morphology and physiology among plant species affect how NPs are absorbed and moved. Therefore, it is crucial to understand how NP is transported into living plant cells in order to advance the use of plant genetic engineering and NP-based agri-technologies.

The Application of Nanotechnology in Crop Production

A wider use of nanotechnology may offer novel methods to enhance sustainable agriculture and meet food demands. Recent research has demonstrated the broad applicability of nanotechnology in addressing a number of agricultural issues, including overuse of pesticides and fertilizers and plant stress brought on by harsh weather. Additionally, nanomaterials greatly enhance stress tolerance, seed germination, and plant development[6].

Renovations to agricultural divisions can be made with nanotechnology; it can be used to boost production by changing conservative methods for evaluating environmental issues and learning the biochemical routes of crops. The potential application of nanoscale agrochemicals in agriculture, such as nanopesticides, nanofertilizers, nanosensors, and nanoformulations, has changed conventional agricultural techniques and increased their efficiency and sustainability[7].

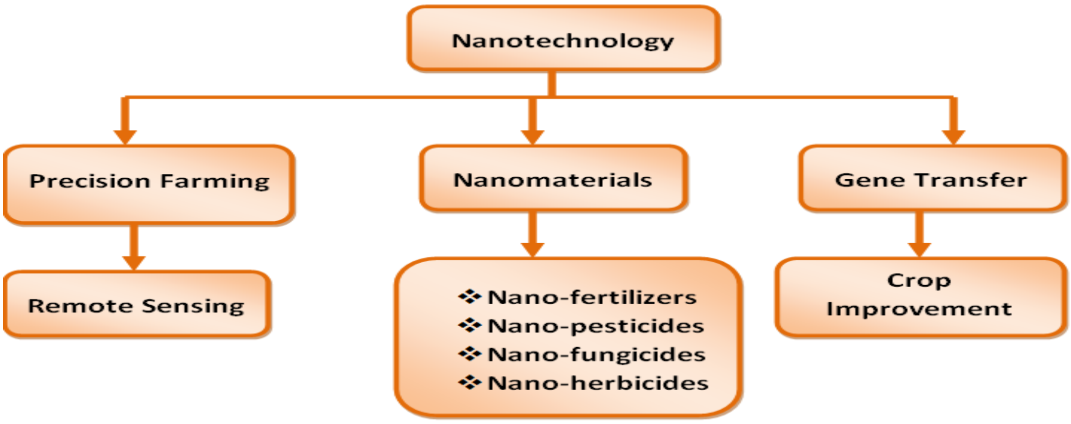

Fig. 4: Role of Nanotechnology in Crop Production

A. Nanofertilizers

The capacity of nanofertilizers—nano-based products—to provide crop plants with nutrients at a controlled rate is one of the most recent advances in nanotechnology. Certain properties of nanoparticles, like their large surface area and smaller particle size, may encourage better interaction and more efficient nutrient absorption for crop fertilization. According to current thinking, including nanotechnology into fertilizer formulation could improve nutrient absorption efficiency and have significant positive effects on the environment and economy.

Recent studies have shown that the controlled and gradual release of nutrients into the soil using nano-fertilizers helps to reduce the danger of nanomaterial toxicity and aids in the site-specific delivery of agrochemicals. For instance, it has been observed that Au, SiO_2, ZnO, SnO_2, and TiO_2 nanoparticles improve plant growth and development by increasing the absorption of nutrients and minerals. Furthermore, it has been demonstrated that nano-fertilizer enhances plant performance in terms of high absorption, increased crop yield, elevated rate of photosynthesis, and appreciable leaf surface area. Nanofertilizers can prevent eutrophication and water contamination by regulating the discharge of nutrients.

B. Nanopesticides

The active ingredients of nanopesticides, which are used to protect crops from diseases, are nanoparticles. Dilution of pesticides with the water that has been nanotreated could significantly increase their efficacy and decrease the amount of chemicals utilized. When it comes to pest management, nano-pesticides are more effective than traditional pesticides. Additionally, it costs half as much as traditional insecticides. Nano-encapsulation can also be used to increase insecticidal value. This method uses a thin protective layer to seal the nanosized active pesticide component. This method reduces the amount of pesticides used and the risks they pose to the environment while also improving effectiveness.

C. Nano-antimicrobials

The use of metallic nanoparticles, such as Ag, Zn, Ti, and Cu, to control microorganisms, especially bacteria and fungi, has been documented in a number of literature papers. As antimicrobials, silver nanoparticles have been widely utilized against a variety of infections, including plant pathogens. TiO_2 and ZnO nanoparticles have also been shown to have antibacterial properties. According to research, TiO_2 nanoparticles may have an antibacterial impact and may also improve plant development[8].

D. Nanoherbicides

Herbicide formulations based on nanomaterials or nanosized preparations are used to develop nanoherbicides. Herbicide formulations based on nanoparticles that take use of the possibility of efficient chemical delivery to a target site are known as nanoherbicides. Since their large specific surface area gives them a high affinity for their target, nanoherbicides are composed of minuscule particles that contain the active ingredients of the herbicide. Nanoherbicides also enhance the wettability and dispersion of agricultural formulations[9].

E. Nano biosensors

Precision agriculture requires nanosensors as a fundamental component. In a variety of environmental settings, nanosensors can be used to identify plant diseases, pesticide residues, nutrient requirements, and soil humidity. Nanosensors have proven to be superior to conventional sensors because to their smaller detection limits, faster response times, higher surface-to-volume ratios, and more consistent outcomes[10].

Advancement of Nanotechnology in Plant Growth and Seed Germination

Agro seeds are susceptible to environmental stresses, which can have a negative impact on crop output, growth, and seed vigor. Different agrochemical-based seed treatments improve germination, but they can harm the ecosystem as well. For this reason, there is an urgent need for sustainable solutions like nano-based agrochemicals. By lowering the dose-dependent toxicity of seed treatment, nano-agrochemicals can increase seed viability and guarantee the regulated release of the active substances in their products.

The sustainable development of nanoscale agrochemicals for seed treatment and the improvement of agricultural input efficiency can both be greatly aided by nanotechnology. There is proof that the biomass output and rate of seed germination were enhanced by nanoparticles. Additionally, the seed's resistance to a variety of biotic and abiotic stressors has risen thanks to the nanoparticles. Seeds' biological activities rely on molecular processes. Regarding nanoparticle-induced mechanisms and seeds, there hasn't been much development at the molecular level, which is crucial for assessing possible mechanisms[11].

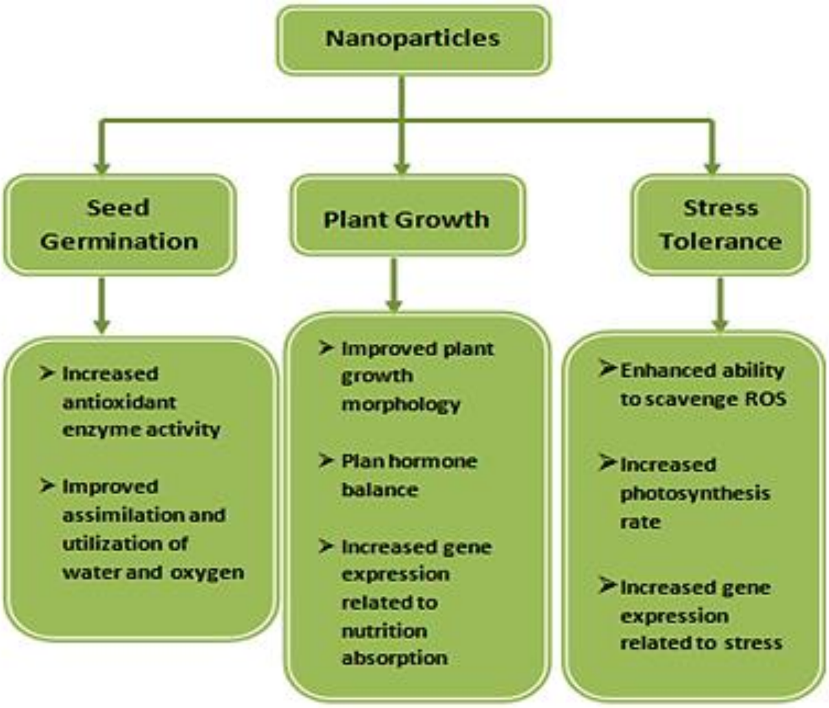

Fig 5: Nanotechnology in Plant growth and Seed germination

The pre-sowing procedure known as "seed priming" modifies the seed's physiology to speed up germination. By boosting plants' tolerance to biotic and abiotic stressors, it also increases crop activity. Priming is the process of preparing seeds in advance of planting by applying conventional techniques like coating and pre-soaking. It has been demonstrated that nano-priming, or priming using nanoparticles, is more promising than conventional priming techniques for attaining realistic agricultural yields. The phrase "priming" refers to the development of stress tolerance under moderate and repeated stress, and nano-priming makes use of nanoparticles (NPs) smaller than 100 nm[12].

Utilization of Nanotechnology in controlling Plant Diseases

Two methods exist for using nanoparticles to protect plants:

(a) The nanoparticles themselves offer crop protection, and;

(b) The nanoparticles act as carriers for pesticides already in use or other actives, like double-stranded RNA (dsRNA), and can be sprayed on seeds, foliar tissue, or roots.

As carriers, nanoparticles can offer a number of advantages, including

(i) Increased shelf-life.

(ii) Better solubility for pesticides those isn’t very soluble in water.

(iii) Decreased toxicity.

(iv) Increased site-specific absorption by the intended pest.

An enhancement in the activity and stability of the nanopesticides against environmental stresses (sunlight and rain) is another potential advantage of nanocarriers. This might lead to a major decrease in the number of applications, which would lower their toxicity and lower their costs.

In addition to revolutionizing current pest management systems, nanotechnology can offer solutions for agricultural uses. The following benefits of using nanoparticles as carriers:

- Better solubility for pesticides that is poorly soluble in water.
- Increased bioavailability and efficacy of pesticides when loaded onto nanoparticles and reduced pesticide toxicity.
- The improvement of the lifespan and controlled absorption of actives.
- Nanoparticles as carriers to enhance the formulations' UV stability while slowing down the decomposition of active chemicals.
- Nanopesticides to boost their selective toxicity and combat pesticide resistance[13].

Relevance of Nanotechnology in Genome Editing

With the application of genome editing (GE) technology, plants with increased resistance to pests, diseases, and herbicides have been produced with increased yields and nutritional value. Recently, a number of GE tools have been created, such as the adaptable and effective clustered regularly interspaced short palindromic repeats (CRISPR) with nucleases technique.

Compared to traditional biomolecular methods, nanoparticle-mediated gene delivery is better because it increases the transformation efficiency for both temporary (transient) and permanent (stable) genetic alterations in different plant species. Most nations can employ CRISPR approaches for permanent GM-free GE through transient expression, according to nanotechnologies that allow force-independent DNA supply without integrating transgenes. Introducing transgenes or CRISPR/Cas9 into plants using particular gene delivery systems is one of the primary steps in genetic engineering[14].

The remarkable specificity of Cas nucleases and low off-target base-pairing rates of guide RNAs have made the CRISPR-Cas platform suitable for targeted knock-in of marker-free DNA into specified endogenous genomic locations for optimal expression. CRISPR-Cas systems have become an effective tool for increasing crop yields and resilience to stress. Using an aerosol-mediated foliar spray, which involves spraying carbon nanoparticles like fertilizer, is another method of introducing CRISPR cargo. In a controlled laboratory environment, this holds particular promise for non-commercial uses like genome-wide organism screening.

Since leaves are the usual route of uptake for nanoparticles in plants, further improvements will necessitate careful optimization of the nanoparticle suspension formulations to increase wettability with leaf surface (smaller contact angle between leaf-suspension interface) and retention on leaf surface under field environment (sunlight, microbes, temperature, pH, nucleases, organic matter, and rain). Additionally, this would raise the intrinsic activity of the nanoparticles, or the reported transformation efficiencies adjusted by the amount of loaded reagent and exposed surface area[15].

Conclusion:

With its wide range of uses in plant breeding, disease prevention, fertilizer application, and precision agriculture, nanotechnology has the potential to completely transform the agricultural system. By enabling researchers to get through plant cell walls and cell membranes and by mitigating the drawbacks of existing transgene delivery techniques, nanoparticle-mediated gene transformation has advanced quickly. Without the need for chemicals or biological assistance, many nanoparticle-mediated gene transformation techniques can even carry foreign DNA or siRNA to particular organelles (such the mitochondria and chloroplasts).

These novel approaches to plant genetic engineering will result in stable genetically modified seedlings and ground-breaking discoveries. The combination of genome editing, nanotechnology, and de novo regeneration has the potential to speed up crop breeding and enhance crop quality and yield, as genome editing technology plays a significant role in enhancing crop quality and yield. CRISPR-Cas9 genome editing tools hold great potential for both agricultural and scientific research.

Additionally, efforts in the direction of commercializing applications based on nanoparticles are required. This can be accomplished by screening and fine-tuning nanomaterials for various crop applications. By adjusting their consistency and qualities, such optimized nanomaterials can have their efficiency increased. As a result, new nanotechnology technologies must be created that are extremely effective in absorbing agricultural components, improving stability, and facilitating the targeted transportation of fungicides, insecticides, and fertilizers. Moreover, combining innovative nanotools and devices with current bioremediation procedures can increase their effectiveness.

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NANOTECHNOLOGY FOR SUSTAINABLE DEVELOPMENT:
A PATH TO A GREENER FUTURE

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Abstract:

Nanotechnology refers to any technology that operates at the nano-scale and has a wide range of practical uses. As it is a general term that epitomizes humanity's insatiable thirst for knowledge with application. Development and application of chemical, physical, and biological systems at scales from individual molecules or atoms to submicron dimensions, as well as integrating the resulting nanomaterials into larger systems, is meant to be encompassed within the arena of nanotechnology. As a result, a comprehensive overview covering the various uses of nanotechnology in modern organizations is provided. This study demonstrates that nanotechnology is widely used across several industries, not just in research labs or small-scale nanotechnology production facilities. Organizations all over the world are currently looking to use nanotechnology to enhance the productivity and foundation of their ideas in terms of working, designing, and structuring. An additional area where the application of nanotechnology has only recently started to gain momentum and continues to show promise is Artificial Intelligence. The convergence of nanotechnology and the IoT holds great promise for enhancing and augmenting numerous applications. By facilitating the development of more compact, effective and adaptable sensors, antennas, and CPUs, nanotechnology can improve the functionality and performance of IoT devices. These innovative technologies have the potential to entirely change the way companies operate and increase their efficacy and productivity. This chapter provides an overview of the work that has been done so far and explores future possibilities for the development of nanomaterials and technologies that will have a substantial social and economic impact. The following primary fields—medical, food science and environmental—are employed to categorize operations that most benefit from nano-technological advances.

Keywords: Nanotechnology, Nanomaterials, Artificial Intelligence, IoT, Sensors.

Introduction:

The fundamentals of the biological, physical, and chemical sciences are combined in the process of nanotechnology. Globally, nanotechnology has gradually but firmly taken over several industries[1]. One of the most exciting major enabling technologies of the twenty-first century is nanotechnology. Rather than gradually enhancing current technologies, nanotechnology presents revolutionary, game-changing discoveries and breakthroughs that can deliver prompt answers and solutions to benefit our community, the environment, and the planet[2]. The world's problems with global sustainability can now be addressed on a variety of levels thanks to nanotechnology. Important physicochemical characteristics of nanomaterials make them particularly appealing as functional materials for environmentally friendly technologies[3].

There are four generations of nanomaterials that have surfaced and are employed in multidisciplinary scientific domains: general nanosystems, small-scale molecular nanosystems, active and passive nano-assemblies, and nanosystems. As science and technology progress, the scientific community embraces products and technologies that are safer, more affordable, and environmentally friendly than those of the past. In addition, they worry about the financial viability of technology because the world's natural resources are depleting too quickly. Thus, nanotechnology offers a means to approach this issue. Compared to earlier bulking and heavy gear, this method is more transparent, less polluting, and more reasonably priced.

The most recent sophisticated uses of nanotechnology in a variety of industries—primarily in the food, cosmetics, environment, healthcare, artificial intelligence (AI), and IoT will be discussed in this chapter.

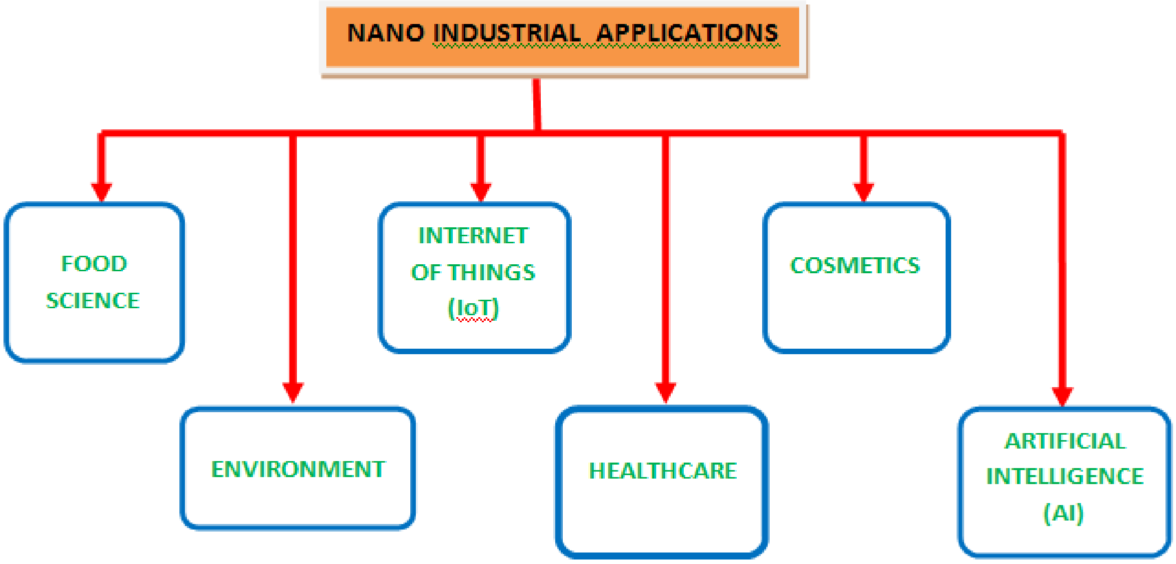

Fig. 1: Applications of Nanotechnology

Role of Nanotechnolgy in various fields

1. Food Science

Food systems are seeing an increase in the use of nanotechnology-based goods, such as bioactives, pharma foods, nutraceuticals, and functional foods [4].

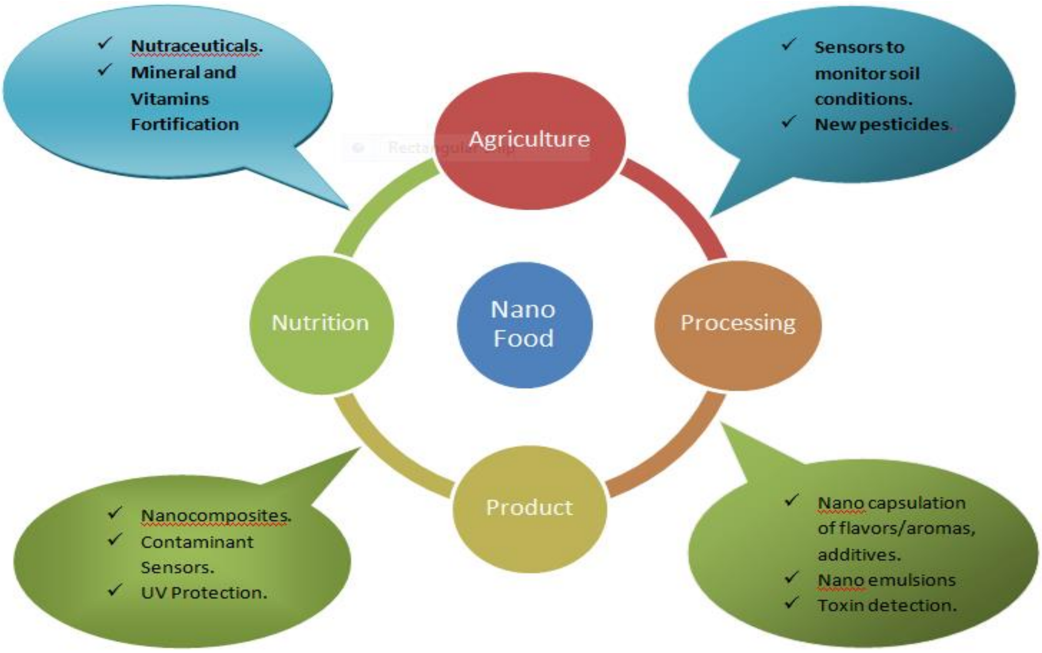

Fig. 2: Applications of Nanotechnology in various fields

Certain meals contain components at the nanoscale that are different from those made by artificial means. Synthetic nanostructured materials found in food mostly consist of polymeric/biopolymeric nanoparticles (protein), nanoemulsions, liposomes, and nanocomposites containing various forms of nano colloidal particles, including:

(i) Nanoparticles (20–200 nm)—usually made of biodegradable polymers for antioxidant release or long-term medicine.

(ii) Liposomes, which are synthetic vesicles of 100–400 nm and primarily composed of lipid bilayers, are small, spherical organelles.

(iii) Micelles (10-100 nm): amphiphilic particles that self-assemble and can contain medications that are lipophilic or lipophobic while being stabilized by surfactants.

(iv) Nanocapsules (10–1000 nm): these small pills can hold substantial amount of pharmaceuticals and nucleic acids, such as DNA, microRNA, siRNA, and shRNA.

(v) Nanoconjugates are polymers that have been covalently linked to pharmaceutical compounds.

(vi) Monodisperse macromolecules called dendrimers, which range in size from 3 to 20 nm, can be utilized to encapsulate or covalently conjugate drugs, imaging agents, and targeting molecules[5].

While maintaining the food items' sensory and physical qualities, nanotechnology can enhance food packaging to deliver safer, healthier, and higher-quality foods with longer shelf lives.

Fig. 3: NanoTechnology in food sector

Using nanocapsules as nutritional supplements or food additives can help improve the distribution of insoluble additives and mask or disguise unwanted flavors or tastes without the need for additional emulsifiers or surfactants.

Physical quantities are transformed into signals by nanosensors so that they may be quickly recognized and examined. In addition to monitoring time, temperature, and oxygen indicators, this method is utilized to identify any undesirable taste or smell, food borne pathogens, food spoilage, toxins, vitamins, and pesticides.

The safety of food contact surfaces and the quality and safety of food products themselves are enhanced by the discovery that nano-engineered surfaces with antimicrobial coatings are among the most effective antimicrobial agents against biofilms. Surface disinfection in the food sector is achieved through the application of nano-coatings, such as ZnO, TiO_2, and tiny silver. Moreover, it was discovered that UV-C ultraviolet light-activated TiO_2 was useful in reducing bio-contamination problems in chicken farming, food processing, and food transportation[6].

2. Cosmetics

The market for individual consideration is rapidly developing, and cosmeceuticals are currently one of the personal care industry's fastest-growing categories. Due to their increased benefits over conventional cosmetic products, nanomaterials are gaining popularity in this field. It is one of the projects that are growing most rapidly, requiring more research, investigation, and applications in the field of nano-cosmeceuticals. All ages find satisfaction in cosmetics, which have been utilized by humans for a very long time, mostly for restorative causes. They can be characterized as preparations that are usually applied externally and made from one or more ingredients derived from natural or synthetic sources[7].

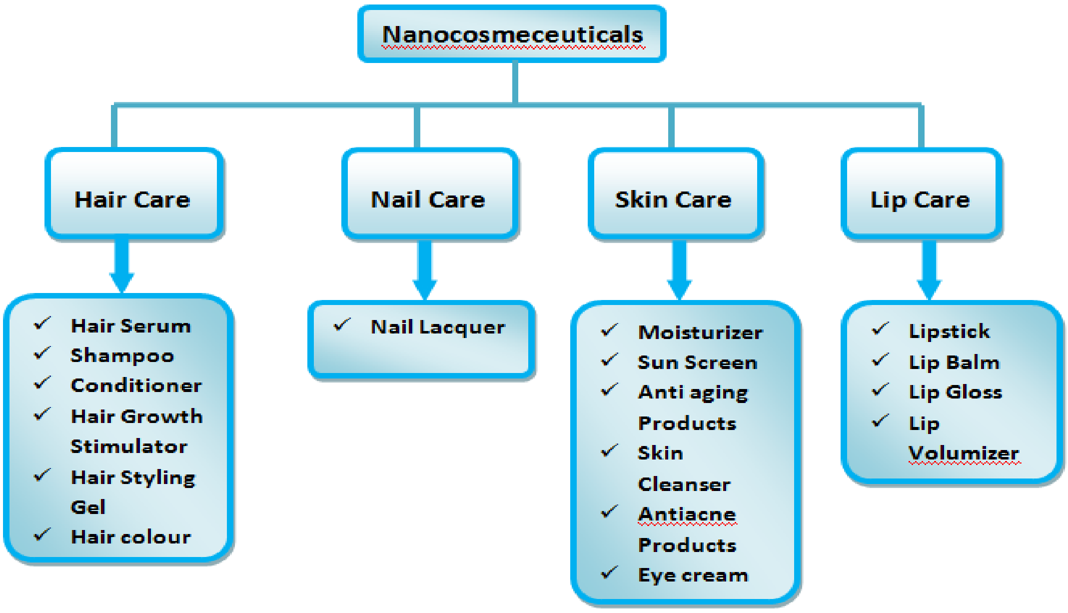

Fig. 4: Application of Nanotechnology in cosmetics

2006 saw the introduction of "NanoParticles" into the NanoMarket by the massive cosmetics company Estee Lauder. In addition to having patented the usage of numerous "nanosome particles," L'Oreal, the largest cosmetics firm in the world, is dedicating roughly $600 million of its $17 billion in revenue to Nano-patents. In terms of US nanotech patent holders, it comes in at number six[8].

Fig. 5: Positive Aspects of cosmeceuticals

Fundamental of nanotechnology in cosmetics is the application of such tiny structures that promote better absorption and dispersion of active ingredients. These minuscule particles, which usually have a size of one to one hundred nanometers, have unique chemical and physical properties that can significantly increase the efficacy of cosmetics. In order to provide better UV protection, deeper skin penetration, long-lasting effects, improved color, and higher finish quality, cosmetic producers use variants of chemicals that are nanoscale.

A new era of skincare products that are not only more effective but also customized to each individual's needs is possible because to the noteworthy advancement of nanotechnology integration in cosmetics.

3. Healthcare

Products incorporating nanotechnology have shown growing utility in the medical field, resulting in the development of innovative nanosystems for the detection, imaging, and management of an extensive variety of illnesses, including cancer, as well as conditions affecting the heart, eyes, and central nervous system. Biomedical devices can effectively include nanomaterials since most biological systems are nanoscale in nature[9].

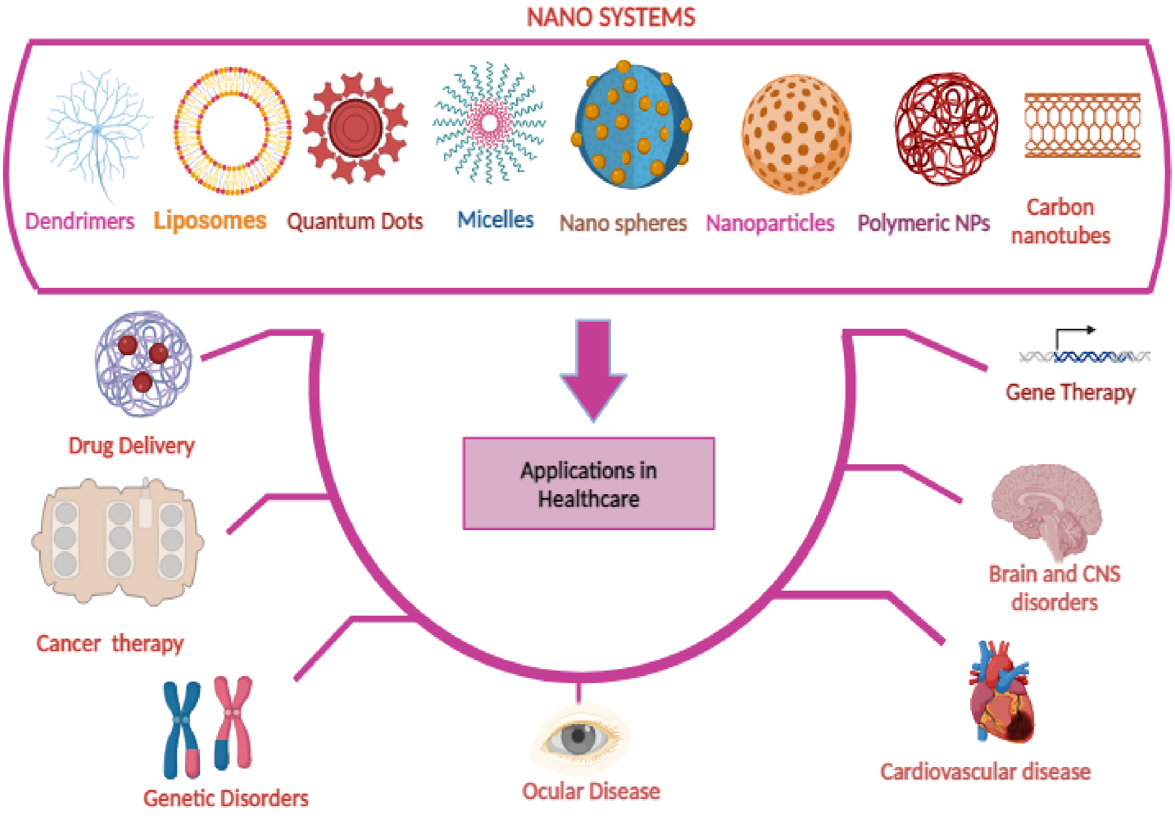

Fig. 6: Applications of Nanotechnology in Healthcare

Nanomedicine is the application of nanotechnology and related nanocarriers/nanosystems to medical care. Broadly speaking, nanomedicine is a branch of science and technology that integrates several medical application areas, including pain management, disease prevention, diagnosis and treatment, human health enhancement, trauma injury prevention, and disease treatment options. Therefore, under the cover of the extensive field of nanomedicine, an interdisciplinary approach is being used to apply the results of biotechnology, nanomaterials, biomedical robotics, and genetic engineering.

In addition to contemporary medications and therapies like liposomal formulations, polymeric nanoparticles, modern diagnostic kits based on nanotechnology include nanosensors, nanoparticle-based imaging agents, nanoparticle-based PCR Assays, and Lab-on-a-Chip devices. Commercialization of nanomedicines, nanotechnology in gene therapy, vaccines based on nanoparticles, antimicrobial compounds, etc. for use in research and clinical settings is underway[10].

Compared to traditional methods, drug delivery with nanosystems allows for more accurate drug delivery to target tissues or organs, as well as regulated release and longer retention times. Among the most effective nanosystems for targeted drug delivery that are being developed to treat different forms of cancer and cardiovascular illnesses are nano-liposomes. The primary three applications of nano-liposomes are for medication distribution to target tissue, high biocompatibility, and bloodstream drug flow regulation.

4. Environment

In order to address the effects of global warming and climate change, nanotechnology has the power to shift technology into clean, green, and sustainable alternatives. Due to their special qualities—such as greater surface area, more surface functional groups, greater pore volume, and superior mechanical, optical, and electrical properties—nanomaterials perform better in a variety of environmental remediation techniques. Researchers have created nanoparticles for use in waste management, environmental cleanup, and the production of effective, sustainable energy solutions, like solar cells based on nanomaterials.

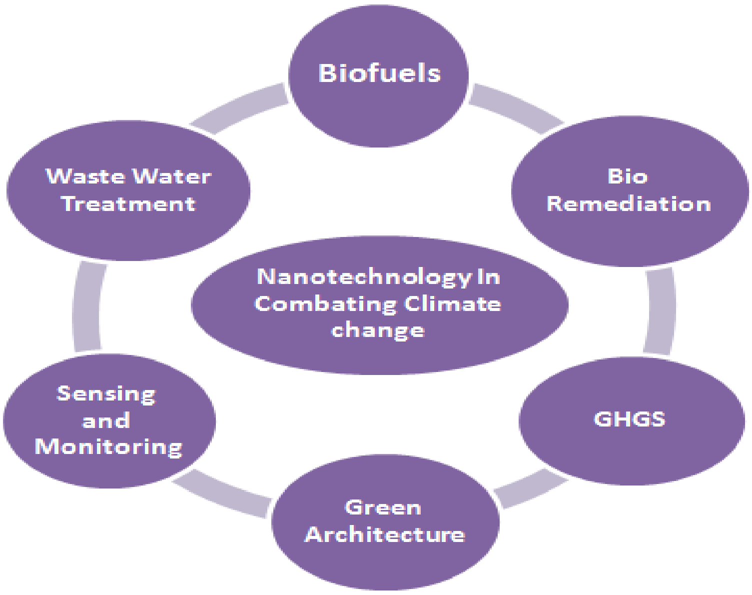

Fig. 7: Different Roles of Nanotechnolgy in Environment

Applying nanotechnology to environmental applications has a lot of advantages. Carbon nanotubes (CNTs), zeolites, silver nanoparticles, and nanoparticles of zero valent iron (ZVI) are a few types of nanoparticles that can be utilized for the remediation of water. For the treatment of water in buildings, workplaces, and commercial spaces, a different method called nanofiltration can be employed. For energy-efficient water desalination, molybdenum disulphide (MoS2) nonporous membranes are utilized, which filter five times more than traditional ones[11].

Immobilized enzymes have been utilized for increased efficiency in the manufacture of biofuels, while nanomaterials are often utilized to accelerate the hydrolysis of lignocellulosic biomass. Magnetized nanoparticle or metal oxide-based matrices have been used to immobilize enzymes such as cellulases, laccases, hemicellulases, and others. These combinations of nanomaterials and enzymes, known as nanocatalysts, are known for their increased efficiency.

5. Artificial Intelligence

The domains of artificial intelligence and nanotechnology have played a pivotal role in achieving the objective of precision medicine, which is to customise the optimal course of treatment for individual cancer patients. The recent merging of these two domains is facilitating enhanced patient data collection and nanomaterial design for precision cancer treatment.

AI is also beneficial for the design of nanomedicine, since it may optimize material properties based on how they are expected to interact with target drugs, biological fluids, the immune system, vasculature, and cell membranes, all of which can alter the effectiveness of treatment.

Better nanotechnology design for diagnosis and therapy can be achieved by utilizing AI algorithms' capacity to analyze massive datasets and identify intricate patterns. The optimization of nanomedicine formulations can be aided by the prediction of nanoparticle interactions with the target drug, biological media, and cell membranes, as well as drug encapsulation efficiency and release kinetics. Additionally, patients can be classified according to their health status and the effectiveness of their medications can be predicted using pattern recognition and classification algorithms. Given the complexity of cancer, these analytical skills are particularly important[12].

6. Internet of Things (IoT)

The Fourth Industrial Revolution is seen to have been greatly aided by the internet of things (IoT) paradigm, which has the potential to completely change the way we live. However, the addition of nanotechnology is expected to increase its impact even further. The convergence of nanotechnology and the Internet of Things holds great promise for enhancing and augmenting numerous applications. By facilitating the development of more compact, effective, and adaptable sensors, antennas, and CPUs, nanotechnology can improve the functionality and performance of Internet of Things devices. Healthcare, industrial monitoring and environmental sensing are just a few of the fields where these advancements may result in increased precision, energy economy, and adaptability.

The term "Internet of Nano-Things" refers to the integration of all or part of these nanodevices into the current IoT framework. The implications of the Internet of Nanotechnology (IoNT) extend far beyond its simple distinction, despite it being usually portrayed as merely a tiny version of the Internet of Things.

A revolution in the sensor area has been brought about by the emergence of nano-enabled wearable sensors for the internet of things (IoT), which enable easy identification of various pollutants, diseases, toxins, etc., regardless of time or location[13].

Conclusion:

In a short amount of time, nanotechnology has dominated every scientific discipline, including chemistry, biology, and physics. Due to the obvious and established advantages of micro scaling, it is now anticipated to have a significant impact on manufacturing technology. Currently, nanotechnology is creating entirely new industries in every sector of the economy, including computing, information technology, engineering, medicine, agriculture, and food.

Nanocomputer, nanoengineering, nanoinformatics, nanobiotechnology, nanomedicine, nanoagriculture, and nanofood industries are the well-known names for these sectors. In the materials and mechanical sciences, the most innovative and affordable technologies are being launched, while the most spectacular discoveries are being made in the field of nanomedicine.

Additionally, climate change is a pressing issue that has to be addressed. In lieu of traditional techniques that contribute to pollution and global warming, sustainable technology should be used to prevent the effects of climate change. In conclusion, one of the technologies that have the potential to offer long-term fixes and substitutes for more traditional options is nanotechnology. A variety of useful and safe tools can be used to preserve the environment, including functionalized nanomaterials, metal organic frameworks (MOFs), carbonaceous materials, nanozeolites, nano silica, nanosensors, nanocoatings, nanolubricants, nanometals, nanocatalysts, nanopackaging, nanocomposites, and nanopackaging.

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NANOTECHNOLOGY FOR A SUSTAINABLE FUTURE: NANO FERTILIZERS

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Abstract:

Nanotechnology represents a specialized branch of science focused on developing materials at the nanoscale. This technology increases properties of the materials i.e. high strength, exceptional thermal and electrical conductivity of the material. Nanotechnology is creating novel materials, innovating devices and applications, refinement and optimization of nanomedical tools. These unique properties are already finding practical applications in various industries, from electronics to medicine and in agricultural. A new field, nanotechnology, acts an important role in various branches of sciences as in medical sciences, agriculture sciences, environmental sciences, sustainable development in water treatment plant and in energy production. In agricultural field, fertilizers play a vital role. These fertilizers may be environmentally friendly, applied regularly in small amounts. Conventional fertilizers can be created in modified forms with the use of nanotechnology.

Introduction:

Any material of whether natural or synthetic, that can be used to promote plant growth, is called fertilizer. Nitrogen (N), Phosphorus (P), and Potassium (K) are essential macronutrients for farming, readily available from sources such as animal manure, human manure, and compost. Nowdays, synthetic fertilizers are predominantly used in farming, with urea being the most widely used due to its high nitrogen content. Thus, in order to increase production of crop and to reduce the adverse effects, nano-materials are used to synthesize nanofertilizers.

Nanofertilizers are nutrients that are coated or encapsulated with in nano material in order to enable controlled release and its subsequent slow diffusion into the soil. Fertilizers, commmonly known as plant nutrients, are substances that provide elements or minerals necessary for plant growth. In order to supply the rising population's nutritional needs agricultural production must rise by using nano fertilizers. In addition to lowering soil toxicity, minimizing the possible negative effects of overusing chemical fertilizers and decreasing the frequency of fertilizer applications, nano fertilizers boost the efficiency with which plant nutrients are used. In order to boost crop output and nutrients, nano fertilizers are used to increase efficiency in agriculture. These fertilizers may be environmentally friendly, applied regularly in one or more macro and micronutrients. With the use of nanotechnology, conventional fertilizers can be created in new or modified forms, or bulk materials. Fertilizers can be extracted from various vegetative or reproductive plant parts using various techniques. Nano fertilizers is used to increase the production of crop, increases the fertility of soil and also increases the quality of products.

The particles in nanofertilizers are smaller and offer greater surface area to support various metabolic processes in the plant system, more photosynthets are produced. This is the fundamental reason for the larger surface area of nanofertilizers. The small size and larger surface area of nanofertilizers show strong reactivity with other chemicals. Beside this, nanofertilizers are highly soluble in various solvents. Thus it is said that the use of nanofertilizers is an environment-friendly process and a good alternative to chemical fertilizers. For a sustainable agriculture, various nanoenabled products are used due to their smaller size and larger surface area [1]. It has been reported that the production and quality of crops has been significantly increased by the use of nanofertilizers[2] as they could supply nutrients to plants more effectively. Nanofertilizers have the capability to improve the existing food production to larger extent. It is due to the increased surface area to volume ratio and better plant nutrient absorption.

Nanotechonology in Sustainable Agriculture

Incorporating nanotechnology into agronomy is vital for advancing sustainable development. Nanotechnology shows significant promise in enhancing sustainable agriculture through precise monitoring of environmental factors and implementing targeted interventions as required. Nano-tools like nano-fertilizers, nano-pesticides, nano-sensors, and nano-herbicides are employed as intelligent delivery systems to promote sustainability in the agricultural sector. The use of agrochemicals such as fertilizers and pesticides enhances sustainable crop production and effectiveness. Conventional methods used to produce agrochemicals often result in issues such as water pollution and environmental contamination. Nano-materials created using environmentally friendly and biodegradable methods have the potential to improve agricultural practices. Agrochemical production methods include both the bottom-up and top-down approaches. The applications of nanotechnology in agriculture include:

1. Nano-formulations of nano-tools: use of fertilizers and pesticides for better production of crop.
2. The use of nano-sensors can protect crops by detecting crop diseases and residues of agrochemicals.
3. Nanotechnology can increase agricultural production.
4. Nanotechnology is used in food packaging.

Chemical Fertilizers and its Demerits

Traditionally, fertilizers provide nutrients to plants in chemical forms that are difficult for them to absorb. The majority of the macronutrients that these chemical fertilizers add have very little soil solubility, which results in relatively low consumption. This means that these chemical fertilizers must be applied repeatedly. Farmers must apply more chemical fertilizers due to rising food demand, which has an impact on the health of the soil and the ecosystem. Irreversible damage to the mineral cycles and soil structure is observed by the extra use fertilizers. Furthermore, the application of fertilizer in excess and disproportionately damages plants, soil microorganisms, and ultimately food chains in ecosystems, resulting in hereditary mutations that affect subsequent generations. The primary human cause of the global eutrophication issues has been determined to be agricultural fertilizers containing phosphorus and nitrogen[3]. Using chemical fertilizers lowers a farmer's profit margin. Furthermore, extended use of chemical fertilizers had detrimental effects on the ecosystem all over the world, including soil degradation, chemical burning, eutrophication of water, groundwater contamination and air pollution [4,5]. Conventional fertilizers have a detrimental effect on crops' nutrient usage efficiency due to their high rates of nutrient release, as well as the fact that these nutrients are not available to plants [6,7].

Challenges and considerations faced by farming community are:

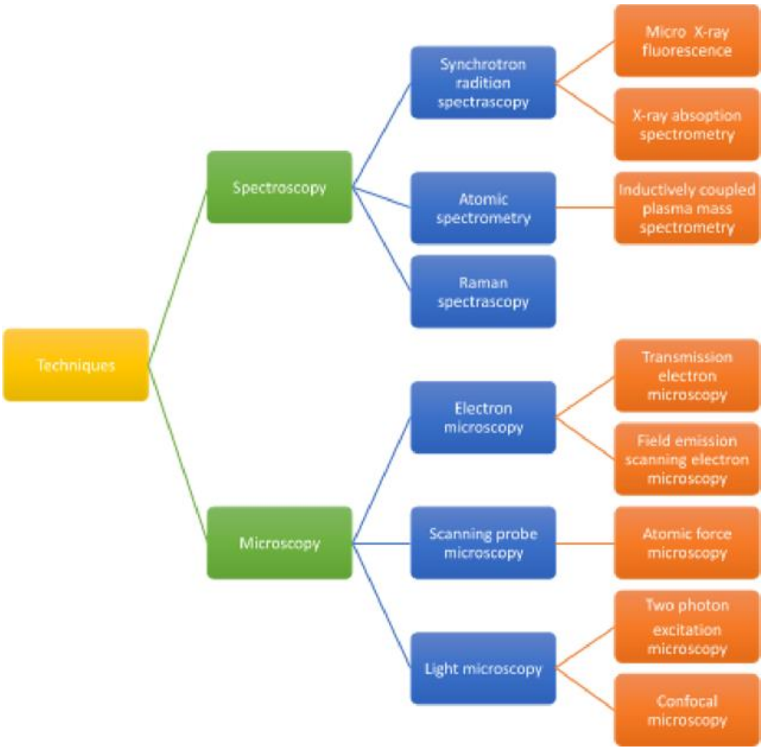
- Cost effective: The production and application of nanofertilizers can be more expensive than traditional fertilizers.
- Protecting the environment, safety and regulation: There is a need for comprehensive studies on the safety of nanofertilizers for human health and the environment. Regulatory frameworks are still evolving.
- Public acceptance: Farmers and consumers may be cautious about adopting new technologies until their benefits and safety are well established.
- Unsustainable farm management
- Feeding a growing population

Benefits of Nanofertilizers: Necessity of Time

The productivity of agriculture has increased to fulfill the requirements of billions of people, population boom, particularly in developing nations. Deficits in soil nutrients result in substantial reductions in the amount and quality of grain available for human and animal consumption, as well as substantial financial losses for farmers [8] Hydroponics is one technology that can be utilized for the better production but it is found that these methods are not economical good. Therefore, in order to increase agricultural productivity by lowering resource consumption and supply nutritional supplements, it is a requirement for economical and sustainable technologies, consumption as well as fertilizer application. The application of fertilizer is traditionally done with unnecessarily more fertilizer but the nanotechnological technique places more emphasis on using less fertilizer. Due to advances in nanotechnology, it is now feasible to produce nanoparticles from essential metals. These can be incorporated into fertilizer formulations to enhance uptake in plant cells and preserve nutrients. Moreover, nanofertilizers can enhance nutrient utilization efficiency and take environmental concerns associated with excessive fertilizer use by reducing nutrient losses. [9]. With targeted distribution and regulated release mechanisms, nanostructured fertilizers can enhances nutrient's efficiency. They may precisely release their active components in response to biological and environmental demands. Furthermore, by accelerating the rates of germination of seed, growth of seedling, protein and carbohydrate synthesis and nitrogen metabolism, nanofertilizers have been shown to improve the production in agricultural [8] and various improvements are found as the result of using nanofertilizers:

1. Improve crop yield
2. Improve shelf life
3. Improve stability
4. Reduce toxicity

Techniques used for the detection of particles size of nano-fertilizers



Nanofertilizer can be produced using bulk fertilizer ingredients, conventional fertilizers or by encasing or coating other plants in nanomaterials. The particles of nano-fertilizers are in the range of 1- 100 nanometers. The most important application of this size is the development of alternative and environmentally friendly nanofertilizers. Nanoparticles have a big surface area and the capacity to retain a lot of nutrients, which they then release gradually. The crop can then absorb nutrients in accordance with its demands without experiencing any of the negative side effects associated with conventional fertilizers. [10].

Nanofertilizers facilitate various metabolic reactions in plants due to their increased surface area, which enhances photosynthesis and boosts productivity. By delivering nutrients directly to plants, nanofertilizers reduce ecotoxicity and minimize nutrient loss to soil or groundwater [11]. Whether applied to soil or leaves, nanofertilizers promote deeper penetration of nanoparticles into plants. Smaller nanoparticles, smaller than the pore sizes of leaves and roots, are more likely to diffuse into crops from their surfaces, enhancing uptake efficiency [12]. Nanofertilizers significantly improve photosynthesis, nutrient absorption, nutrient translocation, and resistance to pests and pathogens.

There are various microscopic and spectroscopic techniques used for the detection of nano particles as shown in figure.

Types of nanofertilizers

Various types of nanofertilizers exist depending on the nutrient type and carrier, including those based on macronutrients, micronutrients, and carbon-based, polymer-based, zeolite-based, trace elements based and nano-biofertilizers.

1. Macronutrient-based nanofertilizers

Nanomaterials have been utilized to combine macronutrients like nitrogen, phosphorus, potassium, magnesium, sulfur, and calcium, aiming to deliver precise nutrient quantities to crops while reducing bulk requirements. This approach also offers the added advantage of lowering expenses related to purchase and transportation. The three primary macronutrients are potassium (K), phosphorus (P) and nitrogen (N). Nitrogen is a nutrient that is necessary for protein synthesis, metabolism of energy and for the growth of plants. Despite making up over 78% of the atmosphere, nitrogen cannot be used by plants in its atmospheric state. Plants can absorb certain chemical forms of nitrogen (N) such as nitrate (NO_3^-) and ammonium (NH_4^+). Nitrate, which carries a negative charge, is insufficiently absorbed in soil because it has low affinity for soil particle surfaces. Combining it with hydroxylapatite and zeolite in soil enhances nitrogen uptake and slows down nitrogen release. Negatively charged nitrate is inadequate in the soil because it has low affinity for soil particle surfaces. Combining it with hydroxylapatite and zeolite in soil enhances nitrogen uptake and slows down nitrogen release[10]. Another important element, phosphorous is as important as nitrogen for energy storage and transportation, photosynthesis, root development, flowering, and the synthesis of organic molecules [13]. Potassium is essential for many different processes, including ionic equilibrium, protein synthesis, photon translocation, stomata regulation, water uptake and enzyme activation in plants.

Among the three elements magnesium (Mg), sulphur (S), calcium (Ca) and calcium-based nanofertilizers are most important for stabilizing cell walls, transferring minerals, storing minerals in the soil, neutralizing toxins and forming seeds. On the other hand, magnesium is essential for plant growth because it occupies the core of chlorophyll molecules and activates enzyme. Sulphur improves the effectiveness of nitrogen and strengthens the production of chlorophyll.

2. Micronutrient-based nanofertilizers

Micronutrients contain the elements B, Fe, Cu, Mn, Zn, Mo, and Cl [14]. Iron, especially heme proteins, is needed for the electron transport system, chlorophyll production and some enzyme activities. Zinc is needed by a variety of metabolic enzymes for a variety of catalytic functions and processes including photosynthesis, tryptophan synthesis, protein synthesis, cell division, membrane potential and structure maintenance. The limited bioavailability of zinc in plant-based diets makes zinc insufficiency a common global health issue [15]. Boron controls the cell cycle, the synthesis of nucleic acids, elongation of cell and function of membranes[16]. Plant nitrate reductase is molybdenum-dependent. Mo is also a crucial component of nitrogenase, an enzyme that legume crops need to fix nitrogen. Copper is involved in several physiological processes, including hormone signaling, protein trafficking, cellular transport, antioxidative action and mitochondrial respiration.

3. Polymer-based banofertilizers

Polymers like chitosan, albumin, and alginate can transport nanoparticles. Chitosan is a cheap, cationic biopolymer that is used to increase agricultural output, photosynthetic rate, nutrient uptake, seed germination of seed and plant growth. Studies reports that chitosan has antibacterial characteristics [17,18]. When applied foliar, Zn-chitosan nanoparticles can stimulate wheat plant development [19]. Cu-Chitosan nanoparticles may help tomato and corn plants development [20,21].

4. Zeolite-based nanofertilizers

Zeolite-based nanofertilizers improve the crops accessibility to nutrients during their growth cycle by releasing nutrients to the plant. During the process of denitrification, leaching, volatilization and nitrogen fixation, it is seen that nutrients loss is less from the soil Designing nanofertilizers has made extensive use of nanozeolites and their mixtures because of their huge surface area and capacity to control nitrogen release [22]. It is reported that zeolite-based composite fertilizers improve lettuce plants nitrogen uptake efficiency and stimulate growth in maize yield [23-25].

5. Carbon-based nanofertilizers

Carbon is an essential element for life on earth. Carbon nanomaterial with remarkable physicochemical and bistability features is called a carbon nanotube. Plants grown in carbon nanotube enriched nutritional mix exhibited enhanced shoot length and seed germination. Carbon nanotubes have the ability to pierce the tomato seed coat, increasing the seeds internal water intake and influencing their rates of germination and growth [26]. Treatment with carbon nanotubes increased the rate at which tobacco cells grew [27]. In a similar manner, date palm callus, embryogenesis, germination were recorded. The findings showed that the carbon nanotube treatment had an impact on the culture process[28].

6. Trace elements based nanofertilizers

There are fourteen trace elements i.e. iron, copper, lead, chromium, cobalt, vanadium, zinc, arsenic, cadmium, strontium, molybdenum, selenium, manganese, rubidium and lead. Living tissues contain very minute levels of trace metals while some of these are not necessary for proper nourishment [29,30]. Nanoparticles sourced from trace elements are considered safer and have a wide range of uses, including serving as supplements in poultry feed [31,32], human feed and medicine [33, 34].

7. Nano-bio fertilizers

Nano-biofertilizers are formed through the combination of nanoparticles and biofertilizers. The process includes encapsulating biofertilizers with appropriate nanoparticles to control the release of nutrients into the soil, aiming to minimize environmental impacts. Nanobiofertilizers also incorporate one or more microorganisms to improve soil fertility by fixing atmospheric nitrogen and solubilizing phosphorus. Several factors in nano-biofertilizer development include their involvement in slow or controlled release, support for microbial growth, and prolonged effectiveness. By combining nanoparticles with natural biofertilizers like Pseudomonas fluorescens, Bacillus subtilis, and Paenibacillus elgae has demonstrated excellent growth promotion in vitro.[35]. Researchers reported that plant growth-promoting rhizobacteria combined with gold nanoparticles have beneficial effects. However, the addition of silver nanomaterials with biofertilizers was found to be less effective, as it negatively impacted the natural activity of microorganisms.[36]. Improving the average life of traditional biofertilizers is essential, and incorporating nanoparticles has been highly effective in enhancing their durability against heat and UV degradation.[37].

Benefits of nanofertilizers over the traditional chemical fertilizers

Nanofertilizers have recently become available to farmers and gardeners as a novel type of fertilizer. It provide many benefits over traditional chemical fertilizers to increase the health and productivity of the plants as well as soil fertility. The main advantage of nanofertilizers is its increased capacity to supply nutrients straight to plant cells. By this, extra nutrients are prevented from entering the soil or flowing into neighboring lakes, streams and other bodies of water, which could harm the ecosystem by contaminating the water with too much phosphorus or nitrogen. Nanofertilizer technology enables meeting specific and specialized nutritional requirements of plants. Researchers can now develop slow-release formulations that reduce leaching risks while ensuring optimal plant nutrition during crucial growth stages like flowering and fruiting. When compared to conventional fertilizers, nanofertilizers offer several advantages: they reduce costs and boost profits, enhance soil fertility, improve crop yield and quality characteristics of the crop. They are nontoxic and less damaging to persons and the environment.

Nanofertilizers reduce the expenses associated with environmental protection while optimizing the utilization of nutrients. Both the nutritional value and flavour of crops have increased, maximum iron utilization and increased protein content in wheat grains, increase plant growth by making them resistant to disease and increase plant stability by preventing bending and establishing deeper crop roots. Nanofertilizers can readily enter seeds and increase the amount of nutrients available to developing seedlings, resulting in healthy seedlings with longer roots and shoots. Nanofertilizers can be used in various agricultural fields including:

- **Field Crops**: Such as wheat, rice and maize, where improved nutrient efficiency can significantly impact yield and quality.
- **Horticulture**: For fruits, vegetables, and ornamental plants, enhancing growth and reducing the environmental footprint.
- **Gardening**: Both for amateur and professional gardeners looking to maximize the health and productivity of their plants.

Nano fertilizers offer several potential benefits in agriculture and environmental sustainability:

1. **Improved Nutrient Efficiency**: Nano fertilizers can enhance nutrient uptake efficiency by plants, reducing the amount of fertilizer needed.
2. **Reduced Nutrient Loss**: They can minimize nutrient leaching and runoff, thus reducing environmental pollution.

3. **Enhanced Crop Yield**: Nano fertilizers can promote better crop growth, leading to increased yield per unit area.
4. **Controlled Nutrient Release**: They provide controlled and sustained release of nutrients, optimizing plant nutrient availability.
5. **Enhanced Nutrient Delivery**: Nano particles can deliver nutrients directly to plant cells, ensuring efficient uptake.
6. **Lower Environmental Impact**: They reduce the environmental impact of conventional fertilizers by lowering the amount needed and minimizing runoff.
7. **Improved Soil Fertility**: Nano fertilizers can enhance soil fertility and structure over time.
8. **Resistance to Pests and Diseases**: Some nano fertilizers can improve plant resistance to pests and diseases.
9. **Adaptability to Different Soil Types**: They can be tailored to suit different soil types and plant species.
10. **Water Use Efficiency**: Nano fertilizers can improve water use efficiency in plants, reducing overall water consumption.
11. **Enhanced Seed Germination**: They can improve seed germination rates and early seedling growth.
12. **Stress Tolerance**: Nano fertilizers can enhance plant tolerance to environmental stresses such as drought and salinity.
13. **Bioavailability**: They improve the bioavailability of nutrients to plants, ensuring they are utilized effectively.
14. **Longer Shelf Life**: Nano fertilizers often have a longer shelf life compared to traditional fertilizers.
15. **Reduced Labor Costs**: They can reduce labor costs associated with frequent application and handling of fertilizers.
16. **Potential for Use in Organic Agriculture**: Some nano fertilizers can be used in organic farming practices.
17. **Customizable Formulations**: They can be formulated with specific nutrients and additives tailored to crop needs.
18. **Compatibility with Modern Farming Techniques**: Nano fertilizers are compatible with modern farming techniques such as precision agriculture.
19. **Sustainable Agriculture**: They contribute to sustainable agricultural practices by reducing resource inputs and environmental impact.
20. **Research and Development**: Continued research in nano fertilizers can lead to further innovations and benefits in agriculture.

These benefits highlight the potential of nano fertilizers to improve agricultural productivity while minimizing environmental degradation and resource use.

Future perspectives of nano agrochemicals

Nanotechnology is pivotal in agriculture for enhancing crop production and reducing nutrient loss, sparking greater interest in bulk fertilizers at the nano-scale. Nano-fertilizers are developing as a new, emerging product for agriculture. The application of nano-fertilizers to plants reduces the quantity of fertilizer. They are non-toxic and eco-friendly.

So, nano-fertilizers represent a promising boon for agriculture in the future. It is important to stimulate industry interest in adopting nanotechnology for fertilizer production to enhance large-scale manufacturing of nano-fertilizers[38]. Emerging nano-tools such as nano-fertilizers, nano-pesticides, nano-biosensors, nano-biofertilizers, and nano-biopesticides represent novel products in the industry. Nano-agrochemicals like nano-fertilizers and nano-pesticides are known for their ability to improve plant growth and nutrition, protect crops from pests, and ultimately boost crop yields. Yet, there are still research gaps in the field of agrochemicals. The small size of nanoparticles allows them to penetrate crop leaves easily, posing potential risks to humans who consume the resulting crops. Recent research indicates that nanoparticles synthesized via biological processes are less harmful than those produced using chemical and physical methods.The environmental impacts of these nanoparticles remain uncertain. Therefore, additional research is needed to explore the realm of nano-agrochemicals, aiming to enhance nanoparticle effectiveness while minimizing their environmental toxicity.

Conclusion:

The continued research and development in nanotechnology promise further advancements in nanofertilizers, potentially leading to more sustainable and productive agricultural practices. Integrating nanofertilizers with other technologies, such as precision agriculture and smart farming, could revolutionize the way to approach crop nutrition and soil health.

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ROLE OF NANOTECHNOLOGY IN HUMAN GENETIC ENGINEERING

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Abstract:

Nanotechnology and human genetic engineering go hand in hand, as nanotechnology has a significant impact on human genetic engineering. The use of nanoparticles allows for the delivery of genetic materials into cells. Nanotechnology has significantly improved drug and gene delivery, enabling them to be delivered to targeted cells and organs. It has also facilitated the development of novel therapeutic agents. In this chapter, we will discuss the delivery of gene editing tools like CRISPR-CAS 9 and their role in the treatment of diseases like Down syndrome. The use of nanotechnology is necessary to deliver these gene editing tools to specific sites. Furthermore, we will discuss the role of nanoparticles in gene therapy and next-gen sequencing technology.

Introduction:

One technology that offers enormous promise in the twenty-first century is nanotechnology. The theory of nanoscience can be applied to practical situations by measuring, modifying, assembling, and creating matter at the nanoscale level. The role of nanotechnology in human genetic engineering goes back to the 20th century, but its role in molecular biology came into existence when Paul Rothemund developed the “scaffolded DNA origami” in 2006. "It is possible to generate sequences of oligomeric nucleic acids, which will preferentially associate to form migrationally immobile junctions, rather than linear duplexes, as they usually do," stated Nadrian Seeman in 1982, laying the conceptual groundwork for DNA nanotechnology (Seeman, 1982). As targeted and site-specific nanomedicine increases the effectiveness of chemotherapy, the field of nanotechnology also plays a larger role in the treatment of advanced cancer.

Such materials and technologies can be engineered to interact at the molecular level with a high degree of functional specificity with cells and tissues for applications in medicine and physiology, thus opening hitherto unattainable levels of technological and biological system integration. (Siddhartha srivastava, 2009). As nanotechnology in human genetics is a relatively new and developing field, research is being conducted on its potential uses in human health and genetics. Recent advancements in the field have brought attention to the potential use of gene editing techniques, such as CRISPR CAS 9, in treating disorders, such as Down syndrome.

Nanoparticles for gene delivery

Implementing gene delivery entails introducing external genetic components, such as deoxyribonucleic acid (DNA) or ribonucleic acid (RNA), into host cells in order to facilitate gene expression. This process is crucial in gene therapy for the introduction or silencing of genes to promote their therapeutic effects. Gene therapy has attracted the attention of many biologists, as it can be used to treat many genetic disorders. However, genes cannot be delivered without a vector. Therefore, the question arises as to how to effectively deliver genes into the target tissue.

Viral vectors are used to deliver genes into target cells, and genes are expressed, especially for *in vitro* applications such as stem cells. While these methods have certain limitations, mainly stemming from safety and inflammatory response concerns, as well as their high cost, they remain valuable tools in the field. Scientists have discovered non-viral vectors as safe alternatives to counter the concerns related to viral vector gene delivery.

Nanoparticles, with a size of approximately 100 nanometers, possess the ability to encapsulate nucleic acid molecules and are capable of readily penetrating cell membranes due to their diminutive dimensions. Extensive research has been done on modifying these nanoparticles to enhance their systemic stability and increase their potential as gene-delivery vehicles. However, the majority of these nanoparticles are not suitable for systemic distribution due to their rapid enzymatic breakdown by serum nucleases. This concept describes nanoparticles as gene carriers. The types of nanocarriers used are shown in Figure 1. The application of nanotechnology in gene delivery has witnessed significant advancements in recent times, encompassing biodegradable nanocarriers, stimulus-responsive polymeric nanocarriers, and targeted ligand-mediated nanocarriers.

1. Biodegradable Nanocarriers

The primary function of biodegradable polymers is to release the DNA in a controlled manner. Naturally occurring biopolymers are nontoxic, biodegradable, and possess adequate flexibility for use in the production of nanoparticles. These particles can be employed to encapsulate or embed drugs and other compounds, thereby enhancing their bioavailability. The quest for biodegradable nanomaterials is a dynamic area of study (Xingran kou, January,2021).An example of such a nanocarrier is poly (β-amino ester), poly(α-(4-aminobutyl)-l-glycolic acid) (PAGA).

2. Stimulus-responsive polymeric nanocarrier

Stimulus-responsive nanocarriers are commonly referred to as intelligent. Nanocarriers are capable of producing either physical or chemical changes after exposure to external signals. Temperature-sensitive nanocarriers have a greater role to play in gene delivery as they show lower critical solution temperature in aqueous solution below which the nanocarriers are water-soluble and above which they are water-insoluble (Hinrichs, August,2019). Magnetic-sensitive nanocarriers are also one of the types of stimulus-responsive polymeric nanocarriers whose roles are currently being investigated in gene delivery. An example of such a nanocarrier is poly(N-isopropylacrylamide) (PNIPAAm).

3. Targeted ligand-mediated nanocarrier

Targeted ligands have different structures, advantages, and disadvantages. Examples of these ligands include folic acid, carbohydrates, peptides, aptamers, and antibodies. These are essential for differentiating between healthy and diseased tissues. By selectively binding to receptors expressed on tumor cells, these ligands reduce the harm caused by cytotoxic medicines to healthy cells. (Shuxin Yan, Feb,2024)

Targeted drug delivery systems can be developed by functionalizing small-molecule medications and nanoparticles to identify targeting ligands in cancer cells. With the use of this technology, medications can be specifically delivered to cancer cells, greatly increasing therapeutic efficacy and reducing toxicity. (Zongmin Zhao, 2020)

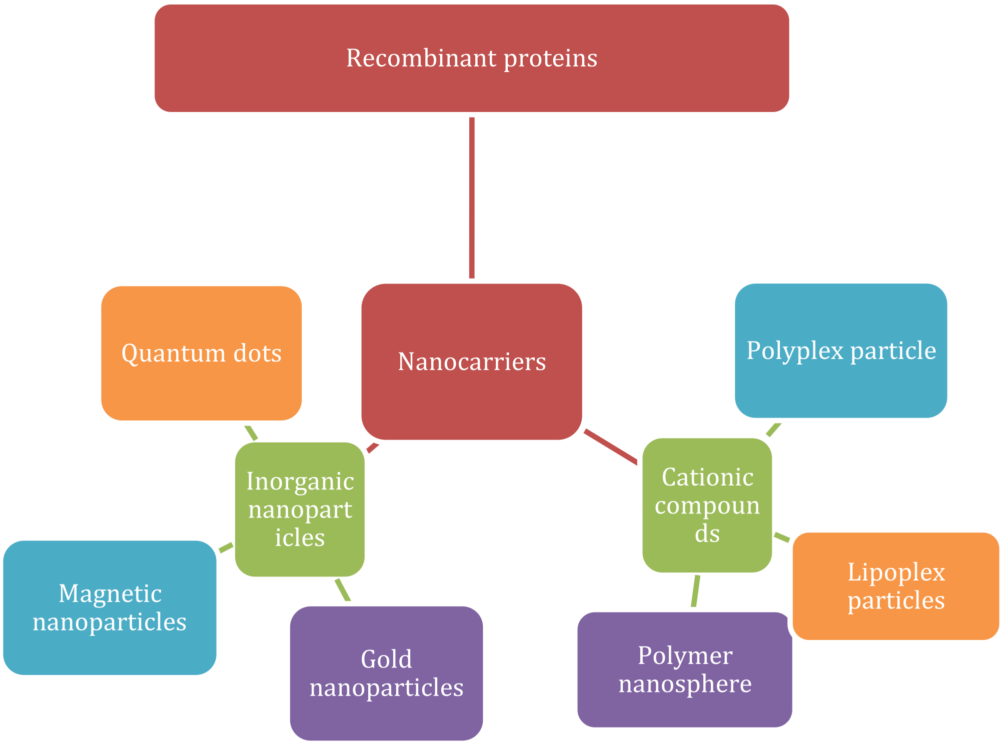

Fig. 1: Types of nanocarriers

Site-specific and targeted delivery using nanodrugs

Nanodrugs have revolutionized drug delivery systems by enabling precise targeting and site-specific delivery. Nanoparticles utilize various targeting techniques, including passive and active targeting, to deliver medications to specific parts of the body. Passive targeting, known as enhanced permeability and retention (EPR), involves integrating therapeutic drugs into macromolecules or nanoparticles to passively target cancers (Lillard, June,2009). In contrast, active targeting requires specific ligands that bind to receptors overexpressed on target cells, enhancing the delivery of therapeutic drugs or carrier systems (Lillard, June,2009). Additionally, nanoparticles can be modified with proteins that bind to specific receptors on target cells, increasing cytotoxicity against tumors while reducing systemic adverse effects (Yang sun, April,2023).

Furthermore, nanoparticles offer a promising solution for delivering medications across biological barriers. Many medications struggle to penetrate the Blood-brain barrier (BBB), limiting their effectiveness in treating conditions like brain tumors. Nanoparticles, however, can bypass this barrier, offering a potential avenue for delivering therapeutic drugs over an extended period. For example, hyper-osmotic mannitol has been shown to open tight junctions in the BBB, facilitating the passage of nanoparticles and potentially improving treatment outcomes in challenging brain disorders (Lillard, June,2009). Nano drugs hold immense potential for advancing drug delivery by enabling targeted delivery, overcoming biological barriers, and minimizing systemic adverse effects, thereby enhancing therapeutic efficacy.

Increased bioavailability using nanodrugs

Nanotechnology has several mechanisms by which it enhances the bioavailability of nanomedicine. Reducing drug size increases their surface area, which improves solubility and permeability (shu wang, April,2014). Surface modification enhances the stability, circulation time, and target specificity of nanoparticles. For instance, the surface of nanoparticles can be altered using PEG (polyethylene glycol) to improve stability and circulation and to increase target specificity by adding target ligands, such as short peptides, antibodies, or receptor-binding chemicals. Improved solubility is another way in which nanotechnology enhances the bioavailability of nanomedicine. Nanoparticles made of biocompatible and biodegradable materials, such as liposomes, Nanoemulsions, lipid nanocarriers, and PLGA nanoparticles, can increase drug stability and prevent degradation. In addition, nanoparticles facilitate drugs' cellular absorption, which is important for both bioavailability and therapeutic benefits. Hence, nanotechnology enhances the bioavailability of nanomedicine through various mechanisms, such as reducing drug size, modifying surface properties, improving solubility, increasing stability, enhancing target specificity, and promoting cellular uptake. These developments will have a significant impact on the pharmaceutical sciences, leading to the creation of new therapeutic, diagnostic, and preventative agents (shu wang, April,2014).

Nanotechnology and gene editing tools

Nanotechnology has grown its influence in gene editing with time. Targeted gene modification has never been easier or more precise because of cutting-edge technologies like prime editing, base editing, and CRISPR-Cas9 nucleases. The effort to maximize gene therapy has found a valuable ally in nanotechnology. More targeted and less immunogenicity are possible with nanoparticles that have been precisely tailored at the nanoscale to deliver genes to selective cells. Recent research indicates that certain types of nanomaterials, including polymer, lipid-based, porous, and gold nanoparticles, can effectively facilitate gene editing while simultaneously enhancing DNA stability, shielding the target gene from nuclease degradation, and boosting the safety and efficacy of gene therapy. (Shao wei hu, June,2023). The CRISPR/Cas9 system, which has recently emerged and advanced, offers a programmable platform for precise genome editing, and delivery of gene therapy tools via nanoparticle vectors. The stability and effectiveness of the CRISPR-Cas9 components can be increased by using nanoparticles to encapsulate and shield them from the body's deterioration. This safeguard makes sure the gene editing instruments don't break until they arrive at the intended cells. Getting editing tools, such CRISPR-Cas9 components, into target cells safely and effectively is one of the hurdles in gene editing. A variety of delivery mechanisms, including nanoparticles and nanocarriers, are available thanks to nanotechnology, and they can both help distribute and shield the CRISPR components from deterioration inside the cells. (Chen & Chen, 2013)

Nanotechnology for gene expression and regulation

Nanotechnology holds enormous promise for regulating and expressing genes, and it provides fine control over cellular functions at the molecular level. This is one area where nanotechnology can be used:

1. Gene Editing: The effectiveness and specificity of gene editing methods such as CRISPR/Cas9 can be enhanced by nanotechnology. Target cells can be precisely targeted by functionalized nanoparticles to deliver CRISPR components, reducing off-target effects and optimizing editing accuracy.
2. Gene Silencing: Nanoparticles can be used to deliver antisense oligonucleotides and siRNA to quiet particular genes implicated in disease processes. These delicate molecules are shielded from deterioration and have an easier time entering target cells thanks to nanoparticles.
3. Delivery: Gene-regulating agents like small interfering RNA (siRNA), microRNA (miRNA), and gene-editing instruments like CRISPR/Cas9 can be delivered using nanoparticles. These nanoparticles target certain tissues or cells, improve cellular absorption, and shield the payload from destruction.
4. Biosensor: Real-time gene expression level monitoring is made possible by nanotechnology-based biosensors, which offer important new understandings of cellular functions and disease processes. These biosensors can be made to precisely and highly selectively identify particular gene products or nucleic acid sequences.
5. Monitoring: Gene expression patterns in living things can be seen using imaging methods

made possible by nanotechnology, such as using gold nanoparticles or quantum dots. This feature makes it possible to monitor disease progression and therapeutic responses non-invasively, which supports personalized medicine strategies.

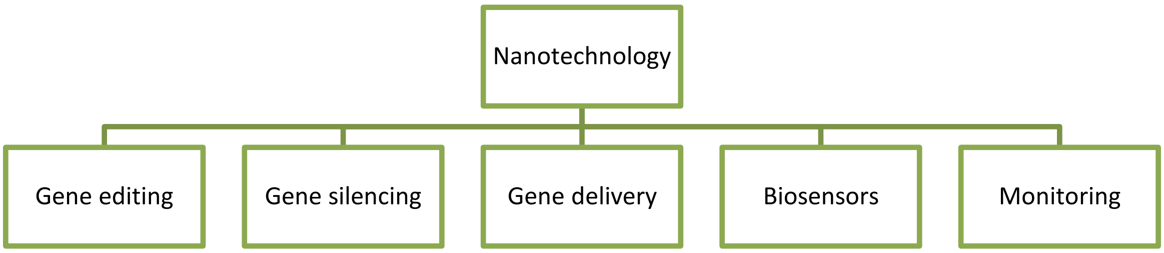

Fig. 2: Uses of nanotechnology

Therefore, nanotechnology offers strong tools for accurately controlling gene expression and has enormous potential to transform healthcare by providing individualized and targeted therapeutic interventions. Toxic effects of nanoparticles, immunogenicity, and scalability, among other issues, must be resolved before gene treatments based on nanotechnology may be widely used in medicine.

Nanotechnology in disease diagnosis and treatment

Nanotechnology has been increasingly recognized as a promising field with significance in the diagnosis and treatment of various diseases. The unique properties of nanomaterials, such as their high surface area-to-volume ratio, allow for the development of nanodiagnostic platforms capable of detecting diseases rapidly and in real-time using small volumes of patient samples. Due to its unparalleled precision and efficacy, nanotechnology has completely changed the diagnosis and treatment of disease.

1. Molecular Imagining

MI is a significant area of study in biomedical science that deals with the molecular analysis of illness or body functioning. High sensitivity and specificity imaging techniques make it simple to interpret, characterize, and quantify the events of interest in the body. One of the most important requirements for interrogating particular molecular targets in biological systems is target identification and verification using high-affinity probes, which can be accomplished by employing MI. MI's specificity is increased with the use of contrast signals known as probes. (MFH Schocke, 2002)

In general, a few important requirements must be satisfied in order to photograph certain molecules in vivo.

1. The availability of appropriate pharmacodynamics and high-affinity probes
2. These probes' capacity to get beyond biological delivery obstacles such as cell membranes, arteries, and interstitial spaces.

3. Using chemical and biological amplification techniques
4. The accessibility of quick, sensitive, high-resolution imaging methods

For in vivo imaging at the molecular level to be successful, all four requirements are typically satisfied (Ralph weissleder, 2001). According to a prior study, oligopeptide nanoparticles (NPs) have the potential to function as activatable probes due to their capacity to generate fluorescence when stimulated by the low pH of the tumor microenvironment. Furthermore, it has been demonstrated that targetable probes can be transported across the BBB using PS-80-coated PBCA dextran polymeric NPs (Ying zhao, 2014). Additionally, a recent study shows that by binding to the highly expressed class. A scavenger receptor, sulfated dextran-coated IO NPs can effectively improve bioimaging of the inflammation in the brain caused by activated microglia. (Tang Tang & pettit, 2018)

2. Biomarker Detection

A biomarker is a parameter that can be tested and assessed objectively to determine if it represents pathologic or normal processes, or whether it indicates how a treatment will work. Biomarkers can vary quantitatively (expression level) or qualitatively (mutation(s)) (Satish balasaheb nimse, 2016). Unfortunately, the full potential of biomarkers is not being realized due to a variety of technical issues with existing technology for biomarker identification (Olga golubnitschaja, 2007).

Biomarkers are more challenging to identify since they are frequently present in very low amounts along with distinct proteins. It can be challenging and time-consuming to identify biomarkers at very low concentrations in various situations. It is significant to remember that early-stage disorders usually have the best chance of recovery after treatment. Some of the techniques used in biomarker detection are colorimetric assay, electrochemical assay, mass-sensing BioCD protein array, surface plasmon resonance (SPR), gel electrophoresis, enzyme-linked immunosorbent assay (ELISA), surface-enhanced Raman spectroscopy (SERS), and fluorescent approaches.

3. Drug delivery

The need to introduce nanotechnology in drug delivery system arises to counter the conventional drug delivery system, their dispersion was haphazard, their absorption was reduced, unaffected regions suffered harm, and the recovery process was protracted. Numerous obstacles, including their enzymatic breakdown, pH imbalance, mucosal barrier, off-target action, and elevated blood toxicity upon instant release, made them less effective (Alshamari, 2022). Due to all such reasons, there was a need for nanotechnology in drug delivery.

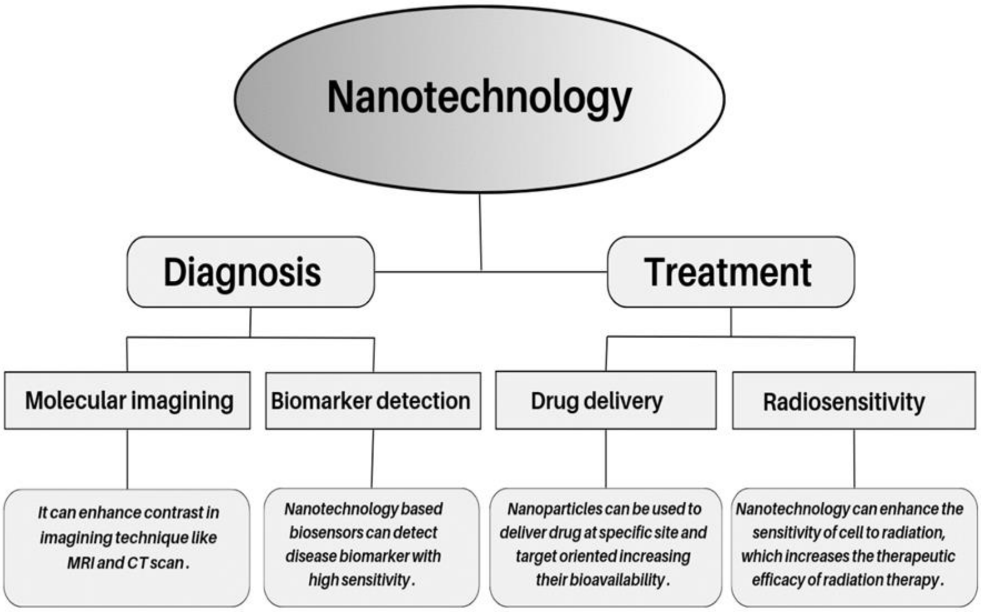

Fig. 3: Nanotechnology in disease diagnosis and treatment

Table 1: Cancer Biomarkers and their samples

Cancer	Biomarker	Sample	Reference
Breast cancer	Estrogen and Progesterone receptor	Tissue	(Henderson, 1998)
Thyroid cancer	Thyroglobulin	Serum, Tissue	(Pacini & Pinchera, 1999)
Lung cancer	Carcinoembryonic Antigen	Blood	(Molina, *et al.*, 2008)
Lymphomas	B2M	Serum	(Federico, *et al.*, 2007)
Pancreatic	Carbohydrate Antigen 19-9	Blood	(Zhenhua, Ma, & Wang, 2009)
Ovarian cancer	Cancer Antigen 125	Blood	(Ozaksit, *et al.*, 1995)
Multiple Myelomas	Monoclonal Immunoglobulin	Blood, Urine	(Cordoba, *et al.*, 2000)

Table 2: List of nanodrugs approved by FDA (Yuanchao jia & He, 2023) (Francisco rodriguez & Fuente, June,2022)

Types of nanoparticles	Features	Benefits	Approved drug manufacturers
Denderimer	• They provide a lot of surface area for interaction because of their highly branched shape. • Dendrimers have a hollow core that effectively enclose medicinal molecules	• They are useful in pharmaceutical applications. • They can improve medication solubility, stability and targeted administration	1. Arborols 2. Cascade molecules 3. PAMAM Dendrimers
Liposome	• Liposomes are an efficient way to release of drugs by encapsulating both hydrophobic and hydrophilic parts. • To distribute drugs, it has been thoroughly investigated especially in cancer treatment	• It can reduce drug clearance by the immune system. • To improve efficacy and target injured cell selectively, ligands can be added to it.	1. Vyxeos 2. Doxil 3. Onivyde 4. Visudyne
Polymer Nanoparticles	• PNPs are solid particles with sizes between 10 and 1000 nm that are useful for encapsulating drugs. • Low immunogenicity and toxicity.	• Protein and other labile molecules are stabilized by PNPs. • It can distribute drugs precisely and covertly by adding ligands.	1. Plegridy 2. Eligard 3. Neulasta 4. Pegasus
Micellar nanoparticles	• Micelles are made up of molecules that have two distinct affinities for water, forming amphiphilic colloidal formations.	• Target distribution via selective functionalization can increase therapeutic potential and decrease toxicity	1. Abraxane

4. Radiosensitivity

Using nanoparticles as a radio sensitizer is a viable technique to boost radiation therapy effectiveness. Given that radiation treats more than 50% of cancer cases, researchers are very interested in finding substances that could lessen the effects of radiation therapy. nanoparticles to effectively enhance the sensitivity of cells to radiation, it's crucial to ensure they are specifically delivered to certain cell types or organelles within cells. Targeting helps maximize their effectiveness while minimizing potential side effects on healthy tissues (Tatjana paunesku, 2015). By boosting oxidative stress, localizing within tumor cells, and increasing radiation absorption, nanoparticles can improve the efficacy of radiotherapy. Particularly high atomic number materials like gold can function as radiosensitizers in nanoparticles to increase the therapeutic efficacy of radiation therapy for cancer (Soraia rosa, 2017). According to the search results, radio sensitization based on nanoparticles is not capable of 100% selectively targeting cancer cells over healthy cells. (Behnaz Babaye Abdollahi & Azar, Feb,2021)

Conclusion:

Nanotechnology is crucial to human genetic engineering because it offers new techniques for gene transfer and modification. Nanoparticles are non-viral vectors used in gene therapy that can carry genetic resources such plasmid DNA, mRNA, and siRNA and transport them to specific cells, tissues, or organs. Through interactions with biological components, these nanoparticles can precisely control the release of their cargo, in addition to enhancing targeted delivery and perhaps overcoming current barriers in gene transport efficiency. (Sofía Mirón-Barroso & Trigueros, 2021)

Nanotechnology enables the synthesis of unique properties in nanoparticles, which is essential for solving issues such as potential toxicity and low transfection efficiency in gene delivery systems. Moreover, nanotechnology-based genome editing techniques can enhance genetic engineering processes, promote the dispersion of genetic materials in plants, and help stabilize genetic materials. Overall, the field of nanotechnology has great promise for the future of human genetic engineering since it provides methods for precise and efficient gene transport, modification, and therapeutic applications (Kexin wu & li, 2023).

Future Prospects

In recent years, there has been a lot of enthusiasm and anticipation surrounding the science and technology of nanomaterials. Because it deals with extremely small particles in the nanometer regime, the topic is extremely interesting to academics by definition. But there is much more to be done in the field of gene delivery, crossing the biological barrier without adverse effects and gene manipulation for the treatment of genetic disorders. Nanotechnology offers creative ways to overcome problems including potential toxicity and low transfection efficiency, as well as enhancing the efficacy of gene delivery devices. Research is being done on the possible applications of nanomaterials, particularly DNA nanostructures, in biomedicine. These applications include the building of structures of different sizes and shapes, as well as two- and three-dimensional nanostructures. (Sofía Mirón-Barroso & Trigueros, 2021) Scientists are investigating the potential uses of nanomaterials in biomedicine, especially DNA nanostructures. These applications include the creation of various-sized and shaped objects, as well as two- and three-dimensional nanostructures.

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NANOSCALE WONDERS OF CHEMISTRY IN MEDICAL SCIENCE

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Abstract:

The fast-developing expanse of nanotechnology controls the matter in the atomic and molecular scale. The chemical compounds exhibit unique chemical properties compared to their bulk counterparts. Various fields like drug delivery, energy storage, and environmental remediation, celebrate its applications. A review of its application particularly in medical fields like pharmacy dentistry and neuroscience is highlighted to understand the new way of the overhaul. The drug delivery method becomes effective due to its small size and large surface area since it exhibits increased solubility. Selective drug accumulation in the target location and absorption through tight junctions of endothelial cells and crossing over the blood-brain barrier adds value to its application in the medical field. Types of pharmaceutical Nano systems like carbon nanotubes, Quantum dots, Nanoshells, Nanobubbles, Niosomes, Liposomes, etc. were discussed. Dental implants, polishing of enamel surface, Dental filling, prevention of caries, and teeth whitening are a few areas where dentistry joins hands with nanoparticles. The usage of hydroxy apatite, iron oxide, zirconia, silica, titanium, and silver in the field of dentistry was investigated. The functional and structural features of the nanoplatforms like gold nanoparticles, iron oxide, Quantum dots, etc, and their possible applicability in neuroscience were explored.

Keywords: Nanochemistry, Pharmacy, Dentistry, Neuroscience, Quantum Dots.

Introduction:

Nanomaterials in the form of nanotubes, nanowires and nanoparticles do wonders in varied fields including science, engineering, and medical science. The current chapter reviews the application of nanochemistry in medical science. Pharmacy, dentistry, and neural science are the specific areas selected under medical science for the current review. Nanoparticles are efficient medication delivery methods. Nanoparticulate medicine delivery systems have various applications, including radiation, AIDS, cancer, and gene therapy. It can also function as vesicles to transport proteins, medications, and vaccines across the blood-brain barrier. Dentistry, as a field, has always been at the forefront of adopting innovative technologies to enhance patient care. With the advent of nanotechnology, dentistry has witnessed a paradigm shift in the way oral healthcare is approached. The outcome of a thorough review is portrayed in the present chapter.

Role of Nanotechnology in Pharmaceutical Science

Several nano-systems have been developed, including paramagnetic nanoparticles, carbon nanotubes, nano-emulsions, and dendrimers. The biological performance and physical stability of drug-containing nanoparticles are greatly influenced by particle size, surface charge, surface hydrophobicity, and drug release. Nanodrugs are frequently used in clinical settings for diagnostic and therapeutic purposes and are now being studied in clinical studies for various medical disorders. Nanoparticles are used in the treatment of kidney problems, tuberculosis, skin ailments, Alzheimer's disease, many types of cancer, and in the creation of COVID-19 vaccines.

Classification of Pharmaceutical Nanosystems

Carbon nanotubes

The first carbon nanotubes were identified in 1991. They are formations made of cylinders of carbon. The length of the tubes ranges from 1 to 100 nm and are made of graphite cylinders sealed at one or both ends with buckyballs. Two popular designs in recent times are single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Standard configurations are frequently encountered in C60-fullerenes. They come in various graphite cylinder configurations and are known for being hollow and cage-like, like fullerenes and nanotubes. They are suitable for drug encapsulation due to their size, fundamental physical features, and surface characteristics. The diameter of a single-walled carbon nanotube (SWNT) is twice that of a DNA helix. The number of walls in a multi-walled carbon nanotube's (MWNT) structure determines its diameter, ranging from a few nm to tens of nm. The processes of burning, electric arc discharge, and chemical vapour deposition are the most widely used to produce carbon nanotubes and fullerenes [1]. The robustness and stability of these structures make them suitable for use as dependable drug transporters. Endocytosis or direct insertion via the cell membrane are the two ways that nanotubes enter cells. The intracellular targeting of fullerenes was demonstrated by their shapes in tissues and mitochondria. It was found that they possess antibacterial and antioxidant qualities additionally.

Quantum dots

Semiconductor structures ranging in size from 2 to 10 nm make up quantum dots (QDs). The CdSe-based inorganic semiconductor core of the nanocrystals is encased in an organic shell coated with ZnS to improve their optic characteristics. When exposed to light, they are designed to emit light. Quantum dots become more soluble in aqueous buffers when a cap is added. The diameter of the particle is between 2 and 10 nanometers [2]. Extended tracking of intracellular activity, imaging biological processes in a controlled setting, and continuous real-time observation have all been associated with various features. Several features include strong fluorescence, broad UV excitation, good photostability, and restricted emission. Quantum dots, or QDs, are used in various diagnostic and therapeutic applications, including immunoassays, DNA hybridization, cell labeling, cancer treatment carriers, biomolecule detection, gene therapy, non-viral vector development, and biological and non-biological agent transport.

Nanoshells

With a silica core and a metal outer layer, nanoshells are modified structures intended for medication delivery. At present, Nanoshells have attracted a great deal of interest. These particles can have their properties altered by varying the ratio between the shell and the core. Currently, it is feasible to produce these nanostructures with certain dimensions and forms. Because all the components cannot be produced in the proper forms, nanoshells are used to create new systems with a variety of morphologies. To achieve the desired morphology, distinct-shaped particles could be covered with a thin shell. Because it is possible to combine inexpensive cores with valuable materials, these shells are economical. As a consequence of this, less precious material is used to synthesizenanoshells. Immunological techniques can be used to target nanoshells [3]. An illustration of this tactic is the application of antibodies to the outer gold surface of gold nanoshells to enhance their targeting of cancer cells. Chemical stabilization of colloids, improving luminescence characteristics, and drug delivery are just a few of the many applications for nanoshells.

Nanobubbles

On the surface of lipophilic materials in liquid settings, nanobubbles are minuscule particles that resemble bubbles and are formed at the nanoscale. They mix to form stable microbubbles that don't change even at room temperature when heated to body temperature. Gas nucleation on the hydrophobic surface causes air trapping and the formation of air bubbles in supersaturated liquids. These nanoparticles fall into four categories: bulk, oscillating, plasmonic, and interfacial nanobubbles. When exposed to ultrasound, the medications used in cancer treatment were able to more efficiently target tumour tissues and improve tumour cell absorption thanks to the particles' excellent encapsulation [4].

- Polymeric nanoparticles provide complete drug protection, are biocompatible and biodegradable, and have a size range of 10 to 1000 nm. Medicines are released gradually and under control using polymeric nanoparticles as carriers.
- Dendrimers are tiny molecules made by carefully regulated polymerization that are less than 10 nm in size. These are intricate polymer structures with numerous identically sized branches. Dendrimers are used to administer drugs precisely to deliver specific drugs to the liver and macrophages.
- Metallic nanoparticles are colloids of silver and gold that are smaller than 100 nm. They have a huge surface area, good stability, and excellent bioavailability, which makes them appropriate for use as pharmaceuticals. They are employed in the delivery of drugs and genes, accurate diagnostic testing, thermal ablation, and enhanced radiotherapy.

- Polymeric micelles are very capable of ensnaring drugs and exhibiting biological stability. Their usual size falls between 10 and 100 nm. They are used for accurate drug administration by active and passive targeting and have good diagnostic value.

Applications of Pharmaceutical Nanotechnology

- **Drug delivery methods**: Pharmaceuticals address the drawbacks of conventional drug delivery systems, which include poor patient compliance, high metabolic rate, cytotoxicity, large dose requirements, and lack of selectivity.
- **Diagnostics**: Biological activities in animals, including gene expression, protein interactions, signal transmission, cellular metabolism, and transport within and between cells, are analyzed and measured by molecular imaging.
- **Medication Discovery**: By improving the solubility and bioavailability of active pharmaceutical ingredients and excipients, pharmaceutical nanotechnology plays a major role in medication development and discovery.

Role of Biopolymeric nanoparticles in diagnostic, detection, and imaging purposes

Theranostic, the combination of therapy and diagnostics, is widely used in cancer treatment. Theranostic nanoparticles aid in illness diagnosis, locating the disease, determining its stage, and assessing treatment response. Moreover, these nanoparticles can transport a therapeutic substance to the tumour, delivering the required amounts by molecular or environmental triggers [5,6]. Chitosan is a biopolymer known for its unique features, such as biocompatibility and the existence of functional groups. It is utilised to encapsulate or coat distinct nanoparticles, creating diverse particles with multiple functions for possible applications in detecting and diagnosing various ailments.

According to Lee *et al.* oleic acid-coated FeO nanoparticles in oleyl-chitosan to study the accumulation of these nanoparticles in tumour cells using the enhanced permeability and retention (EPR) effect in vivo for analytical purposes through near-infrared and magnetic resonance imaging (MRI). Both methodologies demonstrated significant signal strength and enhancement in tumour tissues due to increased EPR effect following intravenous administration of cyanine-5-attached oleyl-chitosan nanoparticles (Cyanine 5) during in vivo evaluations.

Yang *et al.* [7] developed potent nanoparticles to detect colorectal cancer (CC) cells using light. The nanoparticles are created by combining alginate with folic acid-modified chitosan, resulting in enhanced 5-aminolevulinic (5-ALA) release in the cell lysosome, making the cancer cells visible. It was demonstrated by the findings that the modified nanoparticles were incorporated into the CC cells through the process of endocytosis that was mediated by the folate receptor. The positively charged 5-ALA was transported into the lysosome as a result of the weak attraction that exists between 5-ALA and chitosan, which was made possible by the presence of deprotonated alginate. It was because of this that protoporphyrin IX (PpIX) accumulated in the cells, which made it possible for photodynamic detection to take place. According to the findings of this research, nanoparticles made from chitosan, when coupled with alginate and folic acid, are ideal carriers for the targeted delivery of 5-ALA to cervical cancer cells for the purpose of endoscopic fluorescence detection. Because it is abundant in the regions surrounding cells where cancer spreads to other parts of the body, cathepsin B (CB) is an essential component in the process of determining whether or not metastasis has occurred. Cathepsin B is strongly associated with the spread of cancer to other parts of the body. Through the combination of a self-assembled CB-CNP with a fluorogenic peptide that was attached to the tumor-targeting glycol chitosan nanoparticles (CNPs) on its exterior, Ryu *et al.* were able to develop a CB-sensitive nanoprobe, which they referred to as a CB-CNP. In the presence of living circumstances, the fluorescence of the nanoprobe was completely extinguished. The nanoprobe was constructed as a sphere with a diameter of 280 nanometers and a spherical structure.

Role of Nanotechnology in Neuroscience

Blending nanochemistry with neural science results in the research of new materials and technology for a better understanding of neurological diseases [8]. Henceforth a novel therapeutic method Neuronanotechnology in neuroscience was developed to control and repair the damaged neural structure on the atomic, molecular, and cellular scale [9].

Neuronanotechnology

Neuroscience is the scientific study of the functions and disorders of the nervous system comprising the brain, spinal cord, and peripheral nervous system. The brain and its impact on behaviour and cognitive functions were focused by the neuroscientist. In the development of advanced materials and techniques for understanding the brain at the nanoscale level nanochemistry and neuroscience intersect in various ways.

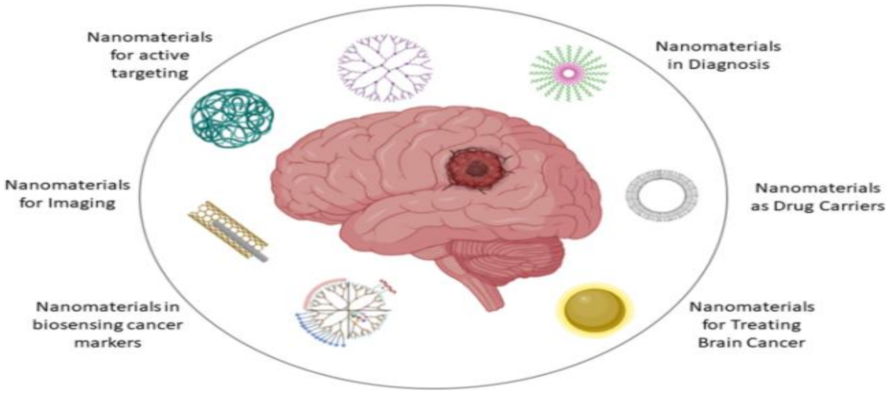

Fig. 1: Nanomaterial as diagnosing and treating tools

Nanotechnology plays a special role in the development of brain-specific imaging, diagnosis and drug delivery. Fig 1 [10]. Nanoparticles such as dendrimers and quantum dots of high specificity and multifunctionality, deliver the therapeutics, imaging agents, and diagnostic molecules to the brain across the blood-brain barrier (BBB).This enables the proper understanding of CNS diseases and their treatment [11].

Blood-Brain Barrier

A selective semi-permeable membrane between the interstitium of the brain and the blood is called the blood-brain barrier (BBB). It regulates the movement of molecules and ions between the blood in the cerebral blood vessels and the brain. It is composed of endothelial cells (ECs), pericytes (PCs), capillary basement membrane, and astrocyte end feet. Its function is to shield the brain from toxic substances, filter harmful compounds from the brain to the bloodstream, and supply brain tissue with nutrients [12]. A defective blood-brain barrier fails to transport the Amyloid-β peptide commonly known as A-beta from the brain to the peripheral circulation. The accumulation and deposition of this compound in the brain results in Alzheimer’s disease [13].

The presence of the same BBB becomes challenging and at times even complicated for delivering drugs into the brain due to its selective permeability, which restricts the passage of most molecules from the bloodstream into the brain. To achieve brain-targeted drug delivery several techniques have been developed. A simple technique of incorporating drugs through nanocarriers capable of penetrating this BBB was identified. Due to the bio-compatibility and easy penetration of the BBB carbon family nanomaterials find their utility as the efficient drug carriers into the brain [14].

Nano Electrodes as a Neural Interface

Microelectrode arrays are coated with Carbon nanotube (CNT) films for studying neuronal networks. Stimulation of brain tissue and in vivo recording are done with Intracortical nanoelectrode arrays. To control neurite outgrowth the Composite nanomaterials and nano scaffolds are assembled on the same interface. Intracellular electrical recordings are done with flexible nanowire field effect transistors.Fig 2[15]

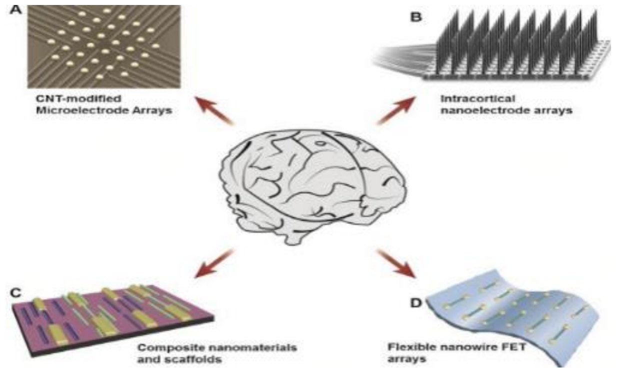

Fig. 2: Nanoscale devices that interact with the nervous system to record brain physiology

Characteristics of Nanoelectrode

- Miniaturization: The nanoscale size of CNT or conducting polymers allows high spatial resolution and precise interfacing with small neuronal populations or individual neurons.

- Biocompatibility: Nanoelectrodes use biocompatible Nanomaterials, which means that biological systems tolerate them and do not create significant immune responses or any tissue damage. This supports long-term neural recording which requires chronic implantation within the brain or nervous system.
- Enhanced sensitivity: Electrical signals from neurons, synaptic current and action potentials are detected with high sensitivity due to the high surface-to-volume ratio of nanoelectrodes. This provides insights into neuronal communication and network dynamics enabling the study of neural activity.
- Functionalization: Nanoelectrodes target specific neuronal populations and enhance stability and biocompatibility by surface modification through various coatings. To promote cell adhesion or selective neural interfacing and tissue integration functionalization involves the immobilization of biomolecules such as antibodies and enzymes.
- Neural recording: Researchers use nanoelectrodes to monitor the electrical signals generated by neurons in real time through extracellular recording. Invaluable investigations regarding the brain function, neural activity and the mechanisms leading to neurological disorders are analysed. Nanoparticles functionalized with specific ligands target particular brain regions, enabling researchers to visualize the neuronal activity
- Neural stimulation: Electrical or optogenetic stimulation of neurons is done by nanoelectrodes. This manipulates the neural circuits by enabling precise control over neuronal activity.Neural stimulation with nanoelectrodes is applied in deep brain stimulation, neuroprosthetics, and the treatment of epilepsy and Parkinson's disease.
- Brain-machine Interface: BMIs provide communication pathways between the external devices or computers and the brain. Nanoelectrodes become an essential component to provide this brain-machine interface.

Nanomaterials in Neuroimaging

Neuroimaging techniques such as magnetic resonance imaging (MRI), positron emission tomography (PET), and fluorescence imaging use contrast agents and imaging probes developed using nanomaterials. MRI, photoacoustic imaging, and near-infrared fluorescence imaging utilize functionalized carbon nanotubes (CNTs) as contrast agents.

Contrast agents

During CT scans Contrast agents are administered via injection or orally thereby enhancing the effects of the image and helping to identify the soft tissue abnormalities by increasing the contrast between lesion tissues or tumor and normal tissues, resulting in high-contrast CT images that enhance the disease diagnosis [16].

- MRI contrast agent: The intrinsic magnetic properties possessed by CNTs contribute to their potential as MRI contrast agents. The magnetic properties can be utilized to modulate the relaxation times of surrounding protons, which in turn changes the MRI signal intensity. By altering the relaxation times of nearby water molecules, the functionalized carbon nanotubes can enhance contrast in MRI.
- Photoacoustic Imaging contrast agent: In photoacoustic imaging, upon absorption of pulsed laser light a photoacoustic signal is generated. Functionalized carbon nanotubes, due to their strong optical absorbance in the near-infrared region have been identified as Photoacoustic image contrast agents. CNTs convert light energy into heat when irradiated with near-infrared light. This leads to an increase in the local temperature and generates acoustic waves. High-resolution images of biological tissues are generated by detecting this acoustic signal.
- Near IR Fluorescence Imaging Contrast Agent: By attaching quantum dots or fluorescent dyes to the surface of CNTs, researchers achieved enhanced fluorescence emission in the near-infrared region. Compared to visible light fluorescence imaging near IR Fluorescence Imaging provides reduced background autofluorescence and deeper tissue penetration. Functionalized CNTs can be targeted to specific biomolecules or tissues of interest, enabling sensitive and specific imaging in biological systems.

Drug Delivery

Neurological disorders can be treated with therapeutic drugs using polymeric nanoparticles as carriers. Drugs can be encapsulated within the nanoparticles or conjugated to their surfaces, allowing for controlled release and sustained drug delivery to the brain while minimizing systemic side effects. Recent studies show that the Surface charge of nanoparticles can be one of the most important factors affecting the ability of nanoparticles to penetrate cells[17]

Targeting ligands: Polymeric nanoparticles can be surface-functionalized with targeting ligands such as antibodies, peptides, or small molecules that have an affinity for receptors or biomarkers overexpressed in specific regions of the brain or on certain cell types. This allows for precise targeting of the nanoparticles to desired locations within the brain.

Encapsulation of contrast agents: Polymeric nanoparticles can encapsulate various types of contrast agents, including superparamagnetic iron oxide nanoparticles (SPIONs) for MRI, fluorophores for fluorescence imaging, or radioactive tracers for positron emission tomography (PET) imaging. By encapsulating these contrast agents within biocompatible polymer matrices, the nanoparticles can protect the agents from degradation, prolong their circulation time in the bloodstream, and enhance their accumulation in the targeted brain regions.

Blood Brain Barrier penetration: One of the key challenges in brain drug delivery is overcoming the blood-brain barrier (BBB), which restricts the entry of many drugs and contrast agents into the brain. Polymeric nanoparticles can be engineered to bypass or transiently open the BBB through various mechanisms, such as receptor-mediated transcytosis, adsorptive-mediated transcytosis, or physical disruption. This enables efficient delivery of nanoparticles and their payloads to the desired brain region.

Role of Nanotechnology in Dentistry

Nanochemistry, the branch of nanotechnology dealing with the synthesis and manipulation of nanoscale materials, has paved the way for groundbreaking advancements in various facets of dentistry. This chapter explores the pivotal role of nanochemistry in revolutionizing oral healthcare, encompassing applications ranging from restorative materials to diagnostic tools.

Nanomaterials in Restorative Dentistry

Nano-structured materials have garnered significant attention in restorative dentistry owing to their unique properties such as enhanced mechanical strength, improved biocompatibility, and superior antibacterial activity. Nanocomposites, composed of nanoparticles dispersed within a polymer matrix, exhibit excellent aesthetic properties and mechanical characteristics, making them ideal for dental restorations. Furthermore, the incorporation of nanoparticles, such as silver or zinc oxide, imparts antimicrobial properties to these materials, mitigating the risk of secondary caries and enhancing longevity.[18]

- ➢ Dental Implants: Nanomaterials are also being explored for dental implant coatings to improve osseointegration—the process by which the implant fuses with the surrounding bone. Nano-scale surface modifications, such as nano-structured titanium surfaces or bioactive nano-particle coatings, can accelerate bone growth and enhance the stability and longevity of dental implants.
- ➢ Bioactive Materials: Nanotechnology has facilitated the development of bioactive materials for restorative dentistry applications. These materials release bioactive ions (e.g., calcium, phosphate) at the restoration-tooth interface, promoting remineralization and preventing secondary caries formation. Incorporating nanoscale hydroxyapatite or other bioactive nanoparticles into restorative materials can mimic the natural remineralization process of teeth, enhancing their therapeutic effects.[19]
- ➢ Antimicrobial Agents: Nanomaterials are being investigated for their antimicrobial properties in restorative dentistry. Silver nano particles, for example, exhibit potent antimicrobial activity against a broad spectrum of oral pathogens. Incorporating silver nano particles into dental materials can help inhibit bacterial growth, reducing the risk of secondary caries and improving the longevity of restorations.[20]

- Sensitivity Reduction: Certain nanomaterials, such as nanohydroxyapatite particles, have been shown to reduce dentin hypersensitivity. These particles can occlude dentinal tubules, effectively blocking the transmission of stimuli that cause sensitivity, providing relief to patients with sensitive teeth.[19]

Nanostructured Biomaterials for Bone Regeneration

In implant dentistry, the integration of nanostructured biomaterials has revolutionized bone regeneration strategies. Nanoscale surface modifications of implant materials promote osseointegration by enhancing cellular adhesion and proliferation. Additionally, nanostructured scaffolds, fabricated using techniques like electrospinning, provide a three-dimensional microenvironment conducive to tissue regeneration, thereby facilitating the restoration of damaged bone tissue with enhanced efficiency and precision.[20]

- Enhanced Surface Properties: Nanostructured biomaterials can be engineered to have specific surface topographies, such as nanotopographies or nanopores, which can promote osteoblast (bone-forming cell) adhesion and proliferation. These surface modifications increase the surface area available for cell attachment and improve the osseointegration of implants.[21]
- Osteoconductive Nanomaterials: Nanomaterials, such as nanohydroxyapatite (nHA) and nanostructured calcium phosphates, closely resemble the mineral composition of bone. When incorporated into scaffolds or coatings, these materials provide a bioactive substrate that enhances osteoconductivity, allowing for better integration with the surrounding bone tissue.[22]
- Controlled Drug Delivery: Nanostructured biomaterials can serve as carriers for growth factors, proteins, or small molecules that promote bone regeneration. Nanoparticles or nanofibers loaded with bioactive molecules can be designed to release these factors in a controlled manner, providing sustained stimulation to cells at the defect site and promoting tissue regeneration.
- Stem Cell Therapy: Nanostructured scaffolds can provide an ideal microenvironment for stem cell adhesion, proliferation, and differentiation. By mimicking the nanoscale features of the ECM, these scaffolds can direct stem cell behavior towards osteogenic differentiation, facilitating the formation of new bone tissue at the defect site.[23]

Nanoencapsulation for Targeted Drug Delivery

Nanochemistry plays a pivotal role in the development of novel drug delivery systems tailored for oral healthcare applications. Nanoencapsulation techniques enable the targeted delivery of therapeutic agents to specific oral sites, thereby optimizing treatment efficacy while minimizing systemic side effects. Nanocarriers, such as liposomes and polymeric nanoparticles, protect encapsulated drugs from degradation and facilitate controlled release kinetics, offering a promising avenue for the management of oral infections, periodontal diseases, and oral cancer.[24]

- Improved Bioavailability: Nanoencapsulation can protect drugs from degradation in the body and enhance their solubility, allowing for improved absorption and distribution to the target tissues. This is particularly beneficial for poorly water-soluble drugs, as nanocarriers can increase their dispersibility and bioavailability, leading to more effective therapeutic outcomes.[25]
- Protection of Labile Drugs: Nanoencapsulation offers protection to labile drugs, such as peptides, proteins, or nucleic acids, from enzymatic degradation and premature clearance in the body. Encapsulation within nanocarriers shields these fragile molecules from harsh biological environments, maintaining their structural integrity and bioactivity until they reach their target site.[26]
- Enhanced Penetration: Nanocarriers can penetrate biological barriers more efficiently than free drugs, allowing for enhanced delivery to sites that are typically difficult to access. This is particularly advantageous for crossing physiological barriers, such as the blood-brain barrier or tumor microenvironment, where conventional drugs may have limited efficacy.
- Diagnostic Imaging: Nanoencapsulation can be combined with contrast agents or imaging probes to facilitate diagnostic imaging alongside therapeutic drug delivery. This allows for real-time monitoring of drug distribution, pharmacokinetics, and therapeutic response, enabling personalized medicine approaches and optimizing treatment regimens.

Diagnostic Applications of Nanotechnology

Nanotechnology has revolutionized diagnostic methodologies in dentistry, enabling early detection and personalized treatment planning. Nanosensors, capable of detecting minute concentrations of biomarkers in saliva or gingival crevicular fluid, provide valuable insights into the onset and progression of oral diseases. Moreover, nanomaterial-based imaging contrast agents enhance the resolution and sensitivity of diagnostic imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI), facilitating accurate disease localization and treatment monitoring.[27]

- Biosensors: Nanotechnology-based biosensors utilize nanomaterials such as nanoparticles, nanowires, or nanotubes to detect biomolecules associated with specific diseases. These biosensors can provide real-time, label-free detection with high sensitivity and selectivity. They are used for detecting various biomarkers, including proteins, nucleic acids, and small molecules, enabling early diagnosis of diseases such as cancer, infectious diseases, and cardiovascular disorders.[28]
- Point-of-Care Testing (POCT): Nanotechnology has enabled the development of miniaturized, portable diagnostic devices for point-of-care testing. These devices, often

referred to as lab-on-a-chip or microfluidic platforms, integrate nanomaterial-based sensors, microfluidics, and other components to perform rapid and accurate diagnostic tests outside of traditional laboratory settings. POCT devices are particularly useful for resource-limited or remote settings, allowing for timely diagnosis and treatment monitoring.[28]

- Molecular Imaging: Nanotechnology-based contrast agents and probes are used for molecular imaging techniques such as magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET). These contrast agents, typically composed of nanoparticles or nanoscale materials, enable non-invasive visualization of molecular and cellular processes in vivo. Molecular imaging provides valuable insights into disease progression, treatment response, and personalized medicine approaches.[29]
- Nanopore Sequencing: Nanopore sequencing is a cutting-edge DNA sequencing technique that utilizes nanoscale pores embedded in a membrane. As DNA molecules pass through the nanopores, changes in electrical signals are detected and used to decipher the DNA sequence. Nanopore sequencing offers several advantages over traditional sequencing methods, including real-time sequencing, single-molecule detection, and portability. It has applications in genomics, personalized medicine, and infectious disease diagnostics.
- Nanoparticle-Based Theranostics: Theranostics combines diagnostic and therapeutic functionalities within the same nanoparticle platform. Nanoparticle-based theranostic agents enable simultaneous imaging and targeted therapy, allowing for personalized treatment strategies and real-time monitoring of therapeutic response. These multifunctional nanoparticles hold great promise for precision medicine, cancer therapy, and theranostic applications.[30]

Challenges and Future Perspectives

Looking ahead, continued interdisciplinary collaboration between materials scientists, bioengineers, and dental clinicians holds the key to overcoming these challenges and unlocking the full potential of nanochemistry in oral healthcare. With ongoing advancements in nanomaterial synthesis, characterization techniques, and targeted delivery strategies, the future of dentistry is poised for transformative innovation, ultimately empowering clinicians to deliver personalized, minimally invasive, and patient-centric oral healthcare solutions.

Conclusion:

It is important to mention that nanotechnology is relevant in the fields of biomedicine and medicine. When it comes to making improvements in the pharmaceutical and agriculture industries, nanomaterials are helpful instruments. They are utilized in a wide variety of applications, including biosensors, the administration of pharmaceuticals, the protection of plants, and many others. Despite the wide variety of activities that have been demonstrated, it is necessary to investigate the nanotoxicological effects. It is possible that the harmful effects of nanomaterials could be different based on a variety of different scenarios. Consequently, research is necessary to solve problems that are associated with knowledge and concerns.

Nanochemistry and neuroscience are two distinct but interconnected fields of study that intersect in various ways, particularly in the development of advanced materials and techniques for understanding the brain at the nanoscale level. Nanochemistry contributes to the development of nanoelectrodes and nanomaterial-based neural interfaces for recording and stimulating neural activity with high spatial and temporal resolution. It also contributes to the development of contrast agents and imaging probes for various neuroimaging techniques. Nanomaterials penetrate the blood-brain barrier for targeted drug delivery.

Nanochemistry represents a cornerstone of innovation in modern dentistry, offering unprecedented opportunities to enhance the efficacy, safety, and precision of oral healthcare interventions. From the development of advanced restorative materials to the design of targeted drug delivery systems and diagnostic platforms, nanotechnology continues to reshape the landscape of dentistry, ushering in an era of personalized and regenerative oral healthcare. Embracing the principles of nanochemistry promises to catalyze a new era of dental practice characterized by improved patient outcomes, enhanced treatment modalities, and a brighter future for oral health worldwide.

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IMPLEMENTATION OF NANOTECHNOLOGY ON GREEN SYNTHESIS AND ITS APPLICATIONS

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Abstract:

Nanotechnology plays a vital role in promoting green chemistry, thereby contributing to a more sustainable and eco future. By utilizing the capabilities of nanoparticles, scientists are able to devise inventive solutions that minimize the utilization of hazardous chemicals and mitigate environmental pollution. One promising area where Nanotechnology has demonstrated remarkable potential is in the development of catalysts for green chemical reactions. These nano catalysts have the ability to enhance the efficiency of reactions while reducing energy requirements and eliminating the need for toxic solvents. Moreover, Nanotechnology facilitates the creation of materials with enhanced properties such as improved stability, selectivity, and reactivity. This opens up new avenues for the production of environmentally friendly products and processes across diverse industries including pharmaceuticals, energy generation, and waste management. The nanoscale size of these materials also grants better control over their behavior and properties, resulting in increased precision and effectiveness in green chemistry applications. Additionally, by harnessing Nanotechnology, it is possible to optimize resource utilization, minimize waste generation, and achieve significant energy savings. Overall, the integration of Nanotechnology in green chemistry holds immense potential in addressing the urgent environmental challenges we face today, while paving the way for a more sustainable future.

Keywords: Nano Catalyst, Green Chemistry, Eco Friendly

Introduction:

Employing environmentally conscious substances and methods to synthesize chemical compounds with an objective of minimizing the consumption of hazardous materials and lowering the formation of causing harm byproducts is known as "green synthesis." The three main tenets of green synthesis are efficiency, safety, and sustainability. The potential of green synthesis to solve major environmental issues while advancing technological developments and sustainable economic practices makes it an essential tool in contemporary chemistry and industry[1]. Green synthesis encourages responsibility towards the environment and minimizes the adverse effects of chemical manufacturing on ecosystems and human health by decreasing the need for hazardous chemicals and solvents, minimizing waste production, and effectively utilizing the resources that exist. A culture of innovation is also promoted by adopting green synthesis, which propels the creation of materials, catalysts, and synthetic methods that are both more effective and clean. This strategy supports international initiatives to reduce pollution, climate change, and resource depletion while also making industry more competitive. Green synthesis ultimately has a significant impact on the development of a future that is more durable and sustainable, one in which chemical processes advance societal well-being without endangering the planet's health. The most recent developments in green technology included a broad range of inventions meant to tackle urgent environmental issues. In science, engineering, and medicine, nanotechnology—which works at the scale of individual atoms and molecules—has become a game-changer with a wide range of applications [2]. Through the manipulation of matter at the nanoscale, which generally spans from 1 to 100 nanometers, nanotechnology facilitates the creation and manufacturing of materials, apparatuses, and systems possessing distinct characteristics and abilities. Nanotechnology presents previously unheard-of chances for innovation and progress in fields ranging from energy storage and environmental remediation to nanoelectronics and nanomedicine. It makes it easier to create nanomaterials with customized features, fine-grained control over chemical interactions, and improved performance attributes. Nanotechnology's influence on technology, healthcare, and society is expected to increase as researchers continue to realize its potential. This will accelerate the transition to a future that is more efficient, connected, and sustainable. Also Green synthesis and nanotechnology interact in a number of ways, providing viable paths for the manufacture and use of environmentally benign and sustainable nanomaterials. In green synthesis reactions, nanoparticles can act as highly effective catalysts and also Excellent photocatalytic properties can be found in nanostructured materials, such as nanoporous materials, nanotubes, and quantum dots. Furthermore, it is employed in green synthesis methods that produce fine chemicals, medicines, and materials for renewable energy sources. Integrating green synthesis techniques with nanotechnology is a possible way to achieve environmentally friendly production processes that are sustained [3].

Synthesis involved in Green Nanotechnology

One of the main aspects of green nanotechnology is the development of environmentally conscious methods for the synthesis of nanomaterials. This involves utilizing less or no harmful chemical use, as well as sustainable materials and energy sources [4].

1. **Biological Methods:**
   To create nanomaterials, biological agents like microbes, plants, or enzymes are used in biological synthesis. These biological systems have the ability to function as stabilizers, reducing agents, or nanoparticle production templates. Since biological synthesis frequently occurs in moderate environments, less energy is used and less hazardous waste is produced.
2. **Plant-Mediated Synthesis:**
   When synthesizing nanoparticles, plant extracts or phytochemicals can be utilized as stabilizing and reducing agents. Bioactive chemicals found in various plant components, including leaves, stems, roots, and fruits, have the ability to promote the reduction of

metal ions and the creation of nanoparticles. Plant-mediated synthesis is an economical, environmentally friendly method that frequently yields well-dispersed, precisely sized, and shaped nanoparticles.

3. **Microbial Synthesis:**

   The environmentally conscious synthesis of nanoparticles has made use of microorganisms like bacteria, fungus, and algae. These microbes have metabolic pathways and enzymes that facilitate the reduction of metal ions into nanoparticles. Benefits of microbial synthesis include scalability, specificity, and the capacity to produce nanoparticles in ambient environments.

4. **Bioinspired Synthesis:**

   To produce nanomaterials with desired features, bioinspired synthesis replicates natural processes. Biomolecules, including DNA, peptides, and proteins, can serve as scaffolds or templates to enable the precise construction of nanoparticles. Bioinspired synthesis is a technique that uses biomolecules' self-assembly and recognition skills to create complex nanostructures.

5. **Green Chemical Methods:**

   To create nanoparticles, environmentally safe chemicals and solvents are used in green chemical synthesis. This strategy focuses on limiting waste production, lessening environmental effect, and substituting safer reagents for hazardous ones. The employment of non-toxic reducing agents, natural extracts, and green solvents are examples of green chemical processes [5].

6. **Microwave and Ultrasound-Assisted Synthesis:**

   By using microwave and ultrasound radiation, one can increase the rate and efficiency of the synthesis of nanoparticles while using less energy. These methods provide for quick heating and effective mixing, which reduce reaction times and increase yields. Green principles can be integrated with microwave and ultrasound-assisted synthesis through the use of environmentally friendly solvents and reducing agents.

Applications in Green Nanotechnology

1. **Biomedical Applications**
   (a) Drug Delivery: Since green-synthesised nanoparticles can contain therapeutic substances and target certain tissues or cells, they are being extensively studied for drug delivery. Examples of these nanoparticles include liposomes, polymeric nanoparticles, and metallic nanoparticles. Green synthesis techniques guarantee the safety and biocompatibility of nanoparticles intended for use in medicine.
   (b) Theranostics: Targeting ligands and imaging agents can be functionalized into nanoparticles produced using environmentally friendly technologies to allow for simultaneous therapy and diagnostics. Personalized medical techniques are made

possible by these theranostic nanoparticles, which enable real-time monitoring of disease development and therapy efficacy.

(c) Tissue Engineering: Hydrogels, nanofibers, and nanoparticles—all of which are obtained by green synthesis—are used as scaffolds in tissue engineering applications. By providing structural support for cell growth, proliferation, and differentiation, these scaffolds imitate the extracellular matrix and aid in tissue regeneration and organ repair.

2. **Environmental Remediation:**
   (a) Water Purification: To remove pollutants from water sources, green-synthesised nanoparticles like iron oxide nanoparticles or carbon-based nanomaterials are used. Water quality can be enhanced by these nanoparticles' ability to adsorb, break down, or catalyze the transformation of contaminants, such as emerging pollutants, heavy metals, and organic pollutants.

   (b) Air Filtration: For the capture of fine particles, volatile organic compounds (VOCs), and airborne pathogens, air filtration systems use nanoparticles that are manufactured using environmentally friendly methods. These nanoparticles can improve indoor air quality by increasing the surface area and adsorption capacity of air filters, hence improving their efficacy.

   (c) Soil Remediation: Contaminated soils are remedied by using green-synthesised nanoparticles, such as nanoclays or zero-valent iron nanoparticles. Pesticides, hydrocarbons, and heavy metals are just a few of the contaminants that these nanoparticles can immobilize or break down to lessen their bioavailability and environmental impact [5].

3. **Energy Harvesting and Storage:**
   (a) Solar Cells: To improve light absorption and charge separation, green-synthesised nanoparticles, such as quantum dots or perovskite nanoparticles, are included into solar cells. By boosting the conversion of sunlight into electricity, these nanoparticles increase the efficiency of solar cells and aid in the production of renewable energy.

   (b) Fuel Cells: Greenly produced nanoparticles operate as catalysts in fuel cell reactions, such as the oxidation and reduction of hydrogen. The kinetics of electrochemical reactions are increased by these catalyst nanoparticles, improving fuel cell performance and energy conversion efficiency.

   (c) Battery Electrodes: To improve energy storage capacity and cycling stability, battery electrodes include green-synthesised nanomaterials like graphene or silicon nanoparticles. These nanomaterials make it possible to create high-performance batteries with longer cycle lives and higher power densities, which helps with energy storage for electric cars and portable electronics [6].

4. **Food and Agriculture:**
   - (a) Food Packaging: To enhance barrier qualities, prolong shelf life, and avoid microbiological contamination, green-synthesised nanoparticles, like nanocellulose or silver nanoparticles, are added to food packaging materials. These nanoparticles lessen food waste and their negative effects on the environment while improving the safety and quality of packaged food goods.
   - (b) Crop protection: Eco-friendly insecticides and fertilizers for agricultural purposes are made from nanoparticles manufactured by green methods, such as chitosan nanoparticles or essential oil-loaded nanoparticles. These nanoparticles reduce the need for conventional chemical inputs, promote agricultural output and plant growth, and mitigate environmental pollution in addition to controlling pests, diseases, and weeds [7].
5. **Consumer Products:**
   - (a) Cosmetics and Personal Care: To provide benefits like UV protection, skin hydration, and antibacterial qualities, green-synthesised nanoparticles, including zinc oxide or lipid nanoparticles, are added to cosmetics and personal care products. These nanoparticles ensure customer safety and sustainability while improving product performance.
   - (b) Textiles: To give textiles features like stain resistance, antibacterial qualities, and increased durability, nanoparticles made using environmentally friendly processes are added. By enhancing the longevity and functionality of textile goods and lowering the need for regular washing and chemical treatments, these nanoparticles help the textile industry become more sustainable.
6. **Waste Management:**
   - (a) Recycling: To recover valuable materials from waste streams, green-synthesised nanoparticles, such as magnetic or photocatalytic nanoparticles, are used in recycling processes. By making it easier to separate, purify, and recover metals, polymers, and other recyclable materials, these nanoparticles help reduce waste and conserve resources.
   - (b) Biodegradable Materials: To improve the qualities and performance of biodegradable materials, such as bioplastics or compostable packaging, nanoparticles produced sustainably are added. By enhancing the mechanical strength, barrier qualities, and rate of disintegration of biodegradable materials, these nanoparticles support environmentally friendly substitutes for traditional plastics and packaging materials [8-10].

Recent Trends in Green Nanotechnology

Metal nanoparticles can be utilized to remove contaminants because of their enormous surface area, strong adsorption, and high reducibility. All metal nanoparticles made by green synthesis is capable of eliminating contaminants from the environment. According to a literature, after 15 days, the COD and BOD removal efficiencies of NZVI produced by Spinacia oleracea (spinach) were 73.82% and 60.31%, respectively. Numerous studies unequivocally state that copper nanoparticles were an effective antiviral drug. By using the plate titration assay, the green production of copper nanoparticles with a size of around 160 nm revealed their antiviral properties against the swine influenza virus [11-13]. Depending on the size and structure of the nanoparticles, the heavy metal can be removed from the polluted solution using plant-mediated selenium nanoparticle production. Furthermore, studies have shown that elemental mercury may be removed from soil and air using green synthesized selenium nanoparticles, as well as heavy metals (zinc, copper, and nickel) from the soil. For the treatment of pesticides, azo dyes, alkaline-earth metals, malachite green, nitrate, monochlorobenzene, antibiotics, and the conversion of certain metals like chromium, cobalt, and copper, the green synthesis approach was crucial in creating zero-valent iron nanoparticles. By using both in vitro and in vivo techniques, extracts from European cranberries (Viburnum opulus) bush fruit that synthesize silver nanoparticles were found to have an anti-inflammatory response. These silver nanoparticles are being utilized to improve the potential therapeutic analysis for the treatment of inflammation. Numerous disorders were identified, diagnosed, and healed by the gold nanoparticle. An essential instrument for biomedical applications is the au nanoparticle [14-15].

Conclusion:

Research on nanomaterials is still ongoing, and its area and applications are growing. Due to the use of hazardous reagents and high energy requirements, traditional methods of synthesizing nanomaterials, such as Sol-Gel, chemical vapor deposition, laser ablation, flame spray pyrolysis, ultrasound, and hydrothermal, are detrimental to the environment. Given their adverse effects on the environment during the current rise in climate change, the use of these technologies is both negligent and ignorant. Green synthesis techniques are just as effective as traditional synthesis techniques and cause little to no harm to the environment or the people who work on them. Green nanotechnology synthesis research will let us to build new supercomputer conductors, produce more useful medical equipment, and use revolutionary sensors to explore space, the last frontier. Once everything is considered, identifying the key molecules involved in the environmentally friendly synthesis of nanomaterials paves the way for ongoing improvements and modification of the chemical and physical characteristics of nanomaterials that benefit the larger scientific community. As the globe continues to adapt to climate change, it is critical that green nanomaterial synthesis continue to advance in order to protect the environment, energy, and scientific research ethics.

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CO-PRECIPITATION METHOD SYNTHESIS OF COBALT MOLYBDATE ($CoMoO_4$) FOR SUPERCAPACITOR APPLICATION

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Abstract:

The synthesis of hybrid materials has emerged as a pivotal avenue for enhancing the performance of energy storage devices and catalytic systems. In this chapter, we delve into the synthesis methods employed to create the activated carbon-$CoMoO_4$ hybrid material, a promising candidate for advanced supercapacitor applications. This section outlines the fundamental approaches, techniques, and considerations involved in the fabrication of this hybrid material. The precursor materials and their significance in influencing the final characteristics of the hybrid material. We elucidate the rationale behind the choice of activated carbon and CoMoO4 as fundamental constituents, highlighting their individual attributes that contribute to the synergistic performance of the hybrid material. The subsequent sections delve into the stepwise synthesis processes, including precursor preparation, mixing techniques, and reaction kinetics. co-precipitation method, a top-down approach renowned for its precision. Within this methodology, we craft two distinct nanomaterials, beginning with the creation of CoMoO4 (CMO) as the foundation. Subsequently, we elevate this synthesis by infusing activated carbon, culminating in the birth of the activated carbon- CoMoO4 hybrid (AC-CMO)

Keywords: Activated Carbon, CoMoO4, Hybrid Material, etc.

Introduction:

To achieve precise control over the final morphology and properties of the activated carbon- CoMoO4 hybrid material, a comprehensive overview of synthesis techniques is provided. Physical and chemical methods are used to synthesis of activated carbon- CoMoO4, emphasizing their unique advantages and challenges with experimental conditions that govern the synthesis, including factors such as temperature, reaction time, precursor ratios, and solvent choices.

The synthesis methods that have been previously utilized in the fabrication of $CoMoO_4$. These methods are extensively examined, shedding light on their individual intricacies and nuances. Subsequently, a subsequent section provides a detailed and comprehensive analysis of our experimental synthesis approaches. This comprehensive exposition encompasses a thorough discussion of the experimental conditions, highlighting their specific merits, and delves into additional contextual details that contribute to a more holistic understanding of the synthesis process.

The synthesis methods employed in the creation of activated carbon-CoMoO4 hybrid material. By amalgamating diverse synthesis techniques with advanced characterization methodologies, we seek to unravel the intricate interplay of components, mechanism and properties that underscore the superior electrochemical performance of this hybrid material in energy storage applications.

Types of Synthesis Methods

Within the realm of material synthesis, a diverse array of methodologies exists, each offering distinct avenues to engineer and tailor materials with targeted properties. In this chapter, we embark on a comprehensive exploration of the various synthesis methods employed in the creation of CoMoO4 and related hybrid materials. This section serves as a crucial foundation to navigate the intricacies of material preparation.

Synthesis methods can be broadly categorized into two principal classifications: physical methods and chemical methods. These categories represent fundamental approaches that harness distinct mechanisms to assemble and structure materials at the nanoscale. The ensuring section will delve into each category, presenting an array of some synthesis methods under their respective umbrellas.

1. Physical Methods

Physical synthesis methods encompass a range of techniques that manipulate and engineer materials through physical processes, without involving chemical reaction [1] These methods leverage physical properties such as vapor phase, template-assisted growth, and mechanical forces to create materials with specific structures and properties.

- **Vapor Deposition:** Vapor deposition techniques involve the condensation of vaporized precursor materials onto a substrate, forming thin films or coatings. Techniques like chemical vapor deposition (CVD) and physical vapor deposition (PVD) enable precise control over film thickness, composition, and crystallinity, making them suitable for producing uniform and high-quality materials [2].
- **Template-Assisted Synthesis:** This method employs porous templates or scaffolds as substrates, guiding the growth of materials into desired structures. It offers a versatile approach to create materials with well-defined shapes and sizes. An example is the use of nano-porous templates to synthesize nanowires or nanotubes [3].

Mechanical Methods:

Mechanical synthesis involves the application of mechanical forces to create materials. Techniques like ball milling and attrition milling crush and blend precursor materials, resulting in fine powders or composite materials. These methods are particularly useful for achieving homogeneous mixing and enhancing solid-state reactions.

Physical Synthesis Advantages:

Physical methods provide several advantages, including precise control over material dimensions, minimal chemical contamination, and the ability to fabricate unique structures that may be challenging to achieve through chemical means. These methods are suitable for producing thin films, nanomaterials, and complex nanostructures.

While physical methods offer exceptional control over material properties, they may require specialized equipment and controlled environments. Researchers often choose these methods based on the desired material characteristics and the scalability of the synthesis process. The utilization of physical synthesis methods in the creation of comoo4 and related hybrid materials contributes to the development of tailored energy storage solutions with enhanced performance.

3. Chemical methods

Chemical synthesis methods encompass a diverse array of techniques that rely on chemical reactions to create materials with tailored properties and structures. These methods offer precise control over composition, morphology, and crystallinity, making them indispensable for engineering materials for specific applications [4].

- **Hydrothermal synthesis**: Hydrothermal methods involve the reaction of precursor materials in a high temperature, high pressure aqueous environment. This controlled reaction environment allows the formation of crystalline materials with controlled particle sizes and shapes. Hydrothermal synthesis is particularly advantageous for producing nanoparticles and nanocrystalline materials. Di Guo *et al.* synthesized CoMoO4 nanoplate arrays via hydrothermal route and observed electrochemical performance with a specific capacitance of 1.26 F/cm2 [5].
- **Co-precipitation:** Co-precipitation involves the simultaneous precipitation of multiple precursor ions from a solution, resulting in the formation of solid particles. This method enables the controlled formation of homogeneous mixtures and the production of materials with well defined compositions. Co-precipitation is widely used for creating metal oxides, hydroxides and composite materials [6].

The co-precipitation method is n a chemical synthesis technique that empowers us to create the activated carbon- CoMoO4 hybrid material. This method, operating at room temperature, brings forth its distinct advantages as we unravel its nuances and uncover its potential. Our experimental approach stands poised to offer a novel perspective on the synthesis process, yielding insights into the interplay of variables, the intricate dance of precursor interactions, and the birth of a hybrid material with promising prospects.

Experimental

In the pursuit of tailored nanomaterials with advanced energy storage capabilities, within this methodology, we craft two distinct nanomaterials, beginning with the creation of CoMoO4 (CMO) as the foundation. Subsequently, we elevate this synthesis by infusing activated carbon, culminating in the birth of the activated carbon- CoMoO4 hybrid (AC-CMO), a potent union poised to unlock new energy storage horizons.

The co-precipitation method was judiciously chosen as our synthesis approach due to its exceptional versatility, allowing precise control over material composition and properties. Its capacity for homogeneous integration of activated carbon within the CoMoO4 matrix ensures a harmonious synergy of components. Moreover, the method's scalability, practicality, and room temperature operation align seamlessly with our goal of crafting an efficient and feasible energy storage solution. This method stands as the ideal conduit to engineer the activated carbon-CoMoO4 hybrid, empowering us to unlock its full potential for enhanced supercapacitor performance.

Chemicals used for the synthesis of both CMO and AC-CMO are as follows Ammonium Molybdate (NH4)2MoO4, Cobalt Chloride CoCl2, Sodium Boro-hydrate NaBH4, NMP/ N-Methyl-2-Pyrrolidone (C5H9NO), PVDF/Polyvinylidene Fluoride (C2H2F2).

The synthesis of CoMoO4 (CMO) and the activated carbon- CoMoO4 hybrid (AC-CMO) was achieved through a facile co-precipitation method, meticulously executed to ensure the precise creation of these materials. Beginning with CMO, the synthesis involved a sequential process. Initially, 1mmol of ammonium molybdate (NH4)2MoO4, was introduced into 50 ml of distilled water, followed by continuous stirring at room temperature for 30 minutes using a magnetic stirrer. Subsequently, 1mmol of Cobalt Chloride CoCl2, was introduced into the same solution, with consistent stirring maintained under identical conditions. Finally, the addition of 30mmol of NaBH4 into a 50 ml mixture of ammonium molybdate and cobalt chloride completed the chemical reaction. This resultant aqueous solution was further subjected to continuous stirring for an additional 30 minutes. The synthesis process for AC-CMO mirrored that of CMO, with the inclusion of 200 mg of activated carbon into 50 ml of distilled water as the initial step.

After each variant's three-step synthesis process, the reaction solutions were left undisturbed for 12 hours, facilitating the formation of precipitates. Following this, the separation of supernatant and precipitate was achieved through a decanting process, meticulously repeated six times for both material variants.

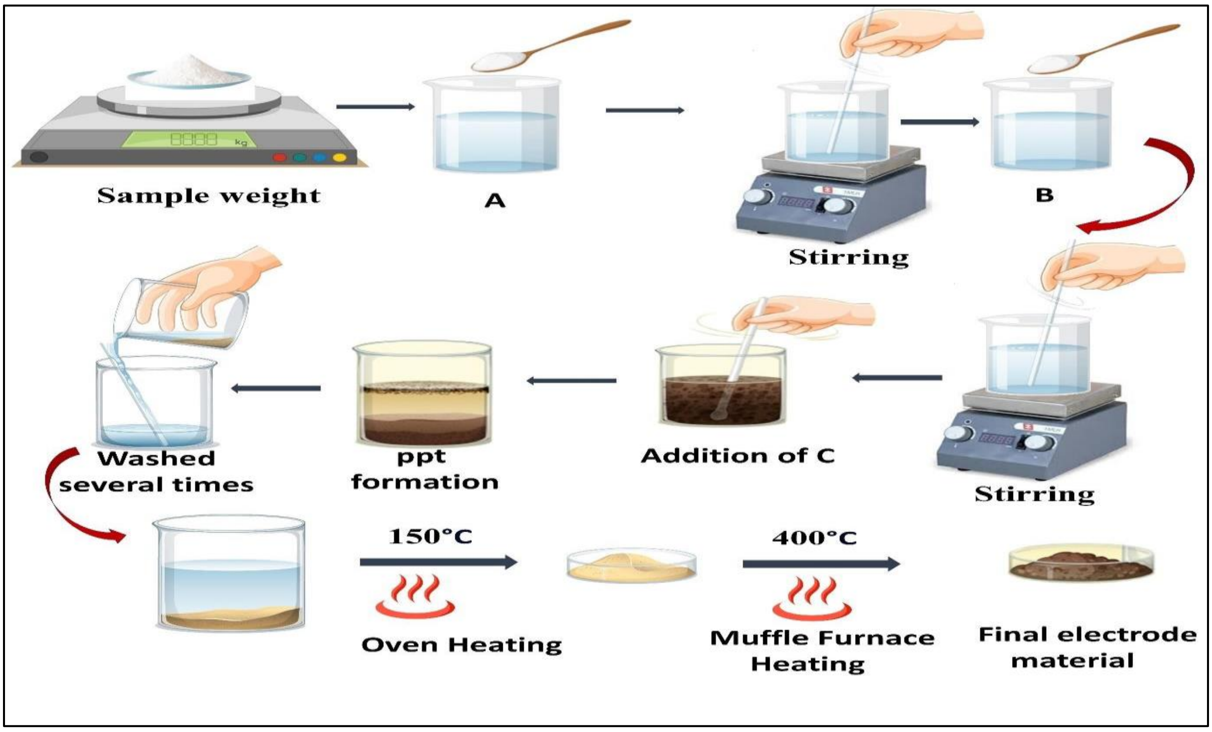

Fig. 1: Schematic representation of Co-precipitation experimental method for CMO (A)-addition of (NH4)2MoO4, (B)-addition of CoCl2, (C)-addition of NaBH4

Once excess water-soluble byproducts were eliminated, the resulting precipitate was isolated by draining excess supernatant. This precipitate was then subjected to heating in a hot air oven at 150°C for a duration of 12 hours, effectively eliminating any residual moisture content. The material was subsequently cooled and further crushed using mortar and pestle, refining the particle size into the nanoscale range.

The subsequent step involved transferring the material into an alumina boat (specimen holder), which was then positioned in a muffle furnace and subjected to a temperature of 400°C for a duration of 4 hours. Upon completion of this heat treatment, the material was allowed to cool down before undergoing further grinding using mortar and pestle. The resultant powdered material emerged from this process, poised for subsequent stages of electrode preparation and comprehensive material characterization.

Electrode Formation

Electrode formation is a vital bridge between synthesized materials and energy applications. Our focus now shifts to the technique of slurry coating, a versatile method that transforms synthesized materials into functional electrodes. By crafting a precisely balanced slurry and coating it onto a carbon paper substrate, we lay the foundation for comprehensive electrochemical analysis. This section unveils the art of slurry coating, unrevealing its pivotal role in harnessing the potential of our materials for enhanced energy storage and conversion.

Substrate Preparation: The process commences by preparing a carbon paper substrate, ensuring an area of 10 x 5 cm. The pristine substrate is weighed to ascertain its initial weight before the application of the slurry.

Material Proportions and Slurry Formation:

The synthesized materials, complemented by PVDF (Polyvinylidene fluoride) and activated carbon, are proportioned in an 8:1:1 ratio. These components are then meticulously weighed and combined within a mortar and pestle. Gradually, the minimum requisite amount of NMP (N-Methyl-2-pyrrolidone) is introduced to initiate slurry formation. Grinding and comminution persist until a uniform, dense slurry is achieved, reflecting the culmination of this preparatory stage.

Slurry Coating:

The ensuing step involves the application of the slurry onto the designated area of the carbon paper substrate. With precision and care, the slurry is skilfully coated onto the substrate, laying the groundwork for subsequent electrochemical analyses.

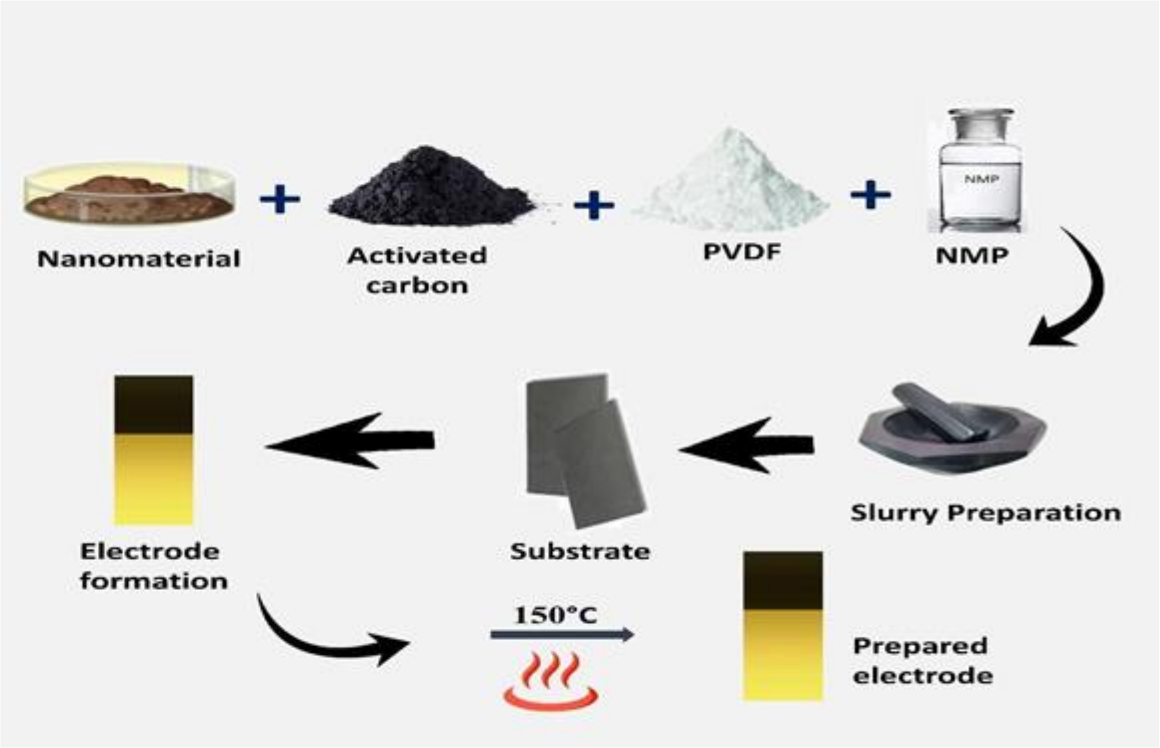

Fig. 2: Schematic representation of electrode preparation

Drying and Heating:

A pivotal aspect of electrode preparation entails the drying and curing process. The freshly coated electrodes are placed within a hot air oven, subjected to a temperature of 150 degrees Celsius for a duration of 4 hours. This controlled environment serves to consolidate the slurry, enhancing its structural integrity. Post-Treatment and Readiness for Analysis: After the prescribed heating period, the electrodes are carefully retrieved from the oven, allowing them to cool. These electrodes are again weighed for getting the actual attached material's mass. These finely crafted slurry-coated electrodes now stand primed and poised for rigorous electrochemical analyses, including Cyclic Voltammetry (CV), Galvanostatic Charge-Discharge (GCD), and Electrochemical Impedance Spectroscopy (EIS). As we delve into the realm of electrochemical analysis, the efforts invested in electrode preparation and slurry coating serve as the cornerstone of our quest to unlock the energy storage potential of our synthesized materials.

Conclusion:

The above parameters of electrode preparation play vital role in deciding the final electrochemical performance. According to same parameters, electrodes of CMO and AC-CMO has been synthesized.

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NANO REVOLUTION: TRANSFORMING CONSTRUCTION FOR A SUSTAINABLE TOMORROW

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Abstract:

Nanomaterials can improve the physical as well as mechanical properties of Ordinary Portland cement. The goal of this work is to improve the mechanical and durability qualities of Ordinary Portland Cement (OPC) by mixing in nanoscale silicon dioxide (nano SiO_2) and titanium dioxide (nano TiO_2). The impact of these nanomaterials on OPC's compressive strength and setting time was studied. Because of the inclusion of nano TiO_2, the initial and final setting times decreased, and more water was needed to maintain a standard consistency. On the other hand, SiO_2 lengthens OPC's initial and final setting times. By combining OPC with both nanomaterials—nano SiO_2 and nano TiO_2—the mortar's compressive strength was increased. The experimental findings show that nano SiO_2's size and content effects are clearly visible. The compressive strength of cement paste may be considerably increased by using small particles and a high concentration of nano SiO_2. Nevertheless, compared to nano SiO_2, the size effect of nano TiO_2 is substantially smaller, and the content effect of nano TiO_2 is only noticeable at a young age. Regarding the compressive strength at a late age, the inclusion of nano SiO_2 and nano TiO_2, according to the results, helps to refine the cementitious microstructure, which improves the mechanical characteristics.

Keywords: Nano SiO_2, Nano TiO_2, Nanoparticles, Ordinary Portland Cement (OPC), Nanomaterials, Construction Materials, Concrete Manufacturing

Introduction:

The incorporation of nanotechnology into construction materials has attracted considerable interest in recent years, since it has the potential to fundamentally transform the performance and characteristics of conventional construction materials. Extensive study has been conducted on the upgrading of Ordinary Portland Cement (OPC), a key ingredient in concrete manufacturing, by using nanoparticles. Nanoparticles, such as silicon dioxide (nano SiO_2) and titanium dioxide (nano TiO_2), are being used as additives to enhance the mechanical strength and longevity of OPC-based products [1-2].

The main aim of this study is to examine the impact of adding nano SiO_2 and nano TiO_2 on the mechanical and durability properties of OPC [3-4]. The research intends to give useful insights into the potential of these nanoparticles as additives in cementitious systems by analysing their influence on OPC's compressive strength and setting time. By using nanoscale additives, it is possible to customise the characteristics of OPC to meet specific application needs. Prior studies have demonstrated that nano SiO_2 and nano TiO_2 have a substantial impact on the performance of cementitious materials. It has been noted that the addition of nano TiO_2 reduces both the initial and final setting durations of OPC. However, this comes at the cost of using more water to maintain uniformity. In contrast, nano SiO_2 has been discovered to extend the setting durations of OPC, indicating divergent impacts between these two nanomaterials [5-6].

Moreover, the use of both nano SiO_2 and nano TiO_2 has shown a synergic impact on improving the compressive strength of OPC-based mortars. The experimental results emphasize the specific influence of both the size and content of nano-SiO_2 on the compressive strength of cement paste, emphasizing the significance of particle size and concentration in optimizing mechanical performance [7-8]. In addition, although the impact of nano TiO_2 on size is not as significant as that of nano SiO_2, its influence becomes more evident in accelerating strength development in early-age [9-10].

Furthermore, the addition of nano SiO_2 and nano TiO_2 has been demonstrated to enhance the structure of the cement, resulting in advancements in mechanical properties at both the initial and later stages. This improvement indicates the possibility of increased durability and long-term performance of OPC- based materials [11].

The incorporation of nanotechnology into construction materials is a state-of-the-art method designed to enhance the performance and characteristics of conventional building components. Ordinary Portland Cement (OPC), which is widely used in concrete, has been a major focus of research efforts aimed at harnessing the potential advantages provided by nanomaterial additions. Specifically, nanoparticles like silicon dioxide (nano SiO_2) and titanium dioxide (nano TiO_2) have received considerable interest due to their ability to affect the mechanical properties and long-lasting nature of OPC-based matrices on a nanoscale level[12]. This study aims to investigate the complex interactions between nano SiO_2 and nano TiO_2 and their impact on the mechanical characteristics and durability of OPC. It clarifies the detailed processes that make nano-additives effective in cementitious systems by carefully examining their effects on compressive strength and setting time.

Modifying the microscopic structure of ordinary Portland cement by adding very small particles allows for the creation of custom building materials that have improved performance qualities. This represents a significant change in the approach to develop construction materials. Prior studies have emphasized the significant impact that nano SiO_2 and nano TiO_2 have on the properties and performance of cement-based materials [13]. Significantly, nano TiO_2 has been demonstrated to cause a significant decrease in both the beginning and end of OPC solidification, however it requires an increased amount of water to maintain the required level of thickness. In contrast, nano SiO_2 has shown a tendency to extend the duration of setting periods, suggesting that these two nanomaterials have different impacts [14].

In addition, the combined inclusion of nano SiO_2 and nano TiO_2 has resulted in synergistic effects, leading to potential improvements in the compressive strength of OPC-based mortars. The experimental results emphasize the noticeable influence of the size and concentration of nano-SiO_2 particles on the compressive strength of cement paste, highlighting the crucial function of these factors in optimizing mechanical performance [15-16]. The impact of nano TiO_2 on size is less pronounced compared to nano SiO_2, but it becomes more noticeable during the early stages of development, indicating possible advantages for accelerating strength development in nascent phases [17].

Furthermore, incorporation of nano SiO_2 and nano TiO_2 has been proven to cause a reduction in size within the cement structure, resulting in enhancements in mechanical properties throughout different time periods. This improvement has significance for strengthening the durability and long-term resilience of materials based on Ordinary Portland Cement, hence increasing their lifespan and improving sustainability.

Use of SiO_2 in construction

Silicon dioxide (SiO_2) is often used in construction due to its distinct features and adaptability. SiO_2, also known as silica, is widely present in the natural environment and may be obtained from a variety of raw materials including sand, quartz, and silica fume. The use of this substance into construction materials can have a wide range of positive impacts, including strengthening mechanical qualities and improving durability and sustainability [18]. SiO_2 is often known as silicon dioxide, this has significant applications in the field of construction. Some notable applications of construction include:

1. Concrete and Cementitious Systems: Nano SiO_2 particles, which are extremely small SiO_2 particles, have been extensively used as additives in concrete and cementitious systems. By distributing these nanoparticles throughout the cement matrix, several beneficial outcomes can be attained. Nano SiO_2 functions as a filler substance, diminishing pore diameters and augmenting the compactness of cementitious composites, consequently raising their mechanical properties and durability. In addition, nano SiO_2 can engage in pozzolanic processes, resulting in the creation of extra binding phases and enhancing the overall strength and durability of concrete.

2. Improved Mechanical Properties: The addition of SiO_2 nanoparticles to concrete mixes can greatly boost their mechanical properties, such as compressive strength, flexural strength, and resistance to abrasion. The nano SiO_2's high surface area-to-volume ratio enables a strong interface with the cement matrix, which enhances load transmission and improves the structural performance of concrete elements [19].

3. Enhancement of Durability: SiO_2-based additions can improve the durability of concrete constructions by reducing the impact of several degradation processes. Nano SiO_2 particles function as a protective shield against absorption of moisture and chemical substances, therefore diminishing the probability of corrosion in reinforced concrete construction. In addition, the compaction of the cement structure aided by SiO_2 nanoparticles can improve resistance to freezing and thawing cycles, alkali-silica reaction (ASR), and sulphate assault.

4.Self-Healing Concrete: SiO_2 nanoparticles have demonstrated potential in the advancement of self-healing concrete systems. Fractures in the concrete matrix can be repaired by the reaction between SiO_2 nanoparticles, moisture, and calcium ions. This reaction forms insoluble calcium silicate hydrate (C-S-H) gel, which seals the fractures and restores the material's integrity.

5.High- Performance Coatings and Sealants: Silica-based coatings and sealants are frequently employed to improve the durability and weather resistance of concrete surfaces, resulting in high-performance outcomes. These coatings offer a safeguard against the infiltration of moisture, the impact of UV radiation, and the effects of chemical exposure. As a result, they extend the lifespan of concrete buildings and decrease the need for maintenance.

6. Nanotechnology in Construction: In addition to traditional applications, current research in nanotechnology is investigating novel applications of SiO_2 nanoparticles in the field of construction materials. These include the development and creation of self-cleaning and photocatalytic substances, sophisticated insulation systems, and novel construction techniques with the aim of enhancing energy efficiency and promoting environmental sustainability [20].

Use of TiO_2 in construction:

Titanium dioxide (TiO_2) is widely used in construction due to its exceptional characteristics, such as remarkable durability, photocatalytic activity, and adaptability. The incorporation of this substance into different building materials enhances their performance, sustainability, and environmental quality. Below are many notable applications of TiO_2 in the field of construction:

1. Self- Cleaning Surfaces: TiO_2 is widely used in the production of self-cleaning coatings for the exteriors of buildings, pavements, and glass surfaces. Titanium dioxide (TiO_2) experiences photocatalytic reactions when it is exposed to sunlight. These processes result in the decomposition of organic pollutants, dirt, and microbiological contaminants present on the surface. This self-cleaning system aids in preserving the visual appeal of buildings and minimising maintenance expenses [21-22].

2. Air Purification: TiO_2-based photocatalytic materials are used in air purification systems to eliminate pollutants, volatile organic compounds (VOCs), and odours from both indoor and outdoor settings. By using the photocatalytic properties of TiO_2, these materials have the ability to break down dangerous compounds into non-toxic byproducts, resulting in enhanced indoor air quality and decreased health hazards.

3. Anti-Microbial Applications: TiO_2 nanoparticles has antibacterial characteristics and are integrated into construction materials to prevent the proliferation of bacteria, fungus, and algae. By integrating TiO_2 into paints, varnishes, and concrete surfaces, the growth of microorganisms and the creation of biofilms may be reduced, resulting in enhanced cleanliness and longevity of construction materials [23].

4. UV Protection: TiO_2 is frequently employed as a UV-blocking ingredient in coatings, paints, and construction materials to safeguard surfaces against deterioration induced by ultraviolet (UV) radiation. Titanium dioxide (TiO_2) aids in the prevention of discoloration, degradation, and cracking of external surfaces by dispe rsing and absorbing ultraviolet (UV) radiation. This, in turn, extends the lifespan of construction components.

5. Improved Durability: By integrating TiO_2 nanoparticles into construction materials like concrete, mortar, and asphalt, their longevity and capacity to withstand environmental effects may be enhanced. Titanium dioxide enhances the mechanical characteristics of these substances, including compressive strength, flexural strength, and abrasion resistance, while also reducing deterioration processes such as carbonation, sulphate attack, and chloride penetration.

6. Cool Roofing Systems: TiO_2-coated roofing materials, such as tiles and membranes, are used in cool roofing systems to reduce heat absorption and minimize heat transfer into buildings. By reflecting solar radiation and lowering surface temperatures, TiO_2-coated roofing materials help reduce cooling energy demands, mitigate urban heat island effects, and improve occupant comfort in buildings.

7. Light- Transmitting Concrete: Translucent concrete panels are enhanced with the addition of TiO_2 nanoparticles to improve their light-transmitting capabilities. These panels, commonly employed in architectural facades and interior design applications, enable the infiltration of natural light into structures while simultaneously preserving structural integrity and aesthetic attractiveness.

Understanding the influence of nano SiO_2 and nano TiO_2 on the setting time of Ordinary Portland Cement is important for comprehending their impact on cement hydration kinetics and workability [24]. Setting time is the period of time it takes for cement paste to go from a plastic to a rigid easy to deal with condition hardened state. The presence of nano SiO_2 and nano TiO_2 can have significant impact on this process as a result of their high surface area, reactivity, and interactions with cementitious phases.

Effects of Nano SiO_2 and Nano TiO_2 on Setting Time

Nano TiO_2 Setting Time:

Adding nano TiO_2 to OPC has been found to expedite the setting time, resulting in decreases in both the initial and ultimate setting times. This phenomena can be ascribed to many factors:

1.High Surface Area: Nano TiO_2 particles have a large surface area per unit mass because of their small size at the nanoscale level, the greater surface area facilitates the formation and expansion of hydration products, leading to a faster overall hydration process[25].

2. Catalytic Activity: Nano TiO_2 demonstrates catalytic activity, which can promote the formation of hydration products and facilitating the advancement of cement hydration processes. The catalytic effect increases the reactivity of cementitious phases, resulting in accelerated setting times.

3. Seed Effect: Nano TiO_2 particles serve as 'nucleation sites' for the precipitation of hydration products, such as calcium silicate hydrate (C-S-H) gel and calcium hydroxide (CH). Nano TiO_2 enhances the development of hydration products by providing nucleation sites, resulting thereby an accelerated setting process.

4. Particle Size Distribution: The particle size distribution of nano TiO_2 can influence its effects on setting time. Smaller particles have a greater effect since they have a larger surface area and are more reactive leading to faster setting times compared to coarser particles [26]. Incorporating nano TiO_2 into OPC leads to an accelerated setting process, which is marked by decreased initial and final setting times. The increased rate of setting time can have implications for construction practices, as it affects the ease of working and handling and managing of fresh concrete.

Nano SiO_2 and Setting Time:

Unlike nano TiO_2, the inclusion of nano SiO_2 in OPC has a tendency to extend the duration of the setting process. Nano SiO_2 particles have an inhibitory impact on the process of cement hydration, causing delays in the timeframes for both the initial and ultimate setting of the cement. Multiple variables contribute to this phenomenon:

1.High Reactivity: Nano SiO_2 particles have a high level of reactivity as a result of their tiny dimensions and extensive surface area [27]. The particle's high reactivity causes water molecules to be adsorbed on its surface, which in turn limits the availability of water for cement hydration processes.

2. Surface Charge: Nano SiO_2 particles possess an electric charge on their surface, which can influence their interactions with cementitious phases. The electrostatic repulsion between negatively charged nano SiO_2 particles and negatively charged cement particles hinders the clumping and clustering of cement particles, thereby causing a delay in the hydration process.

3. Pore Filling Effect: The pore filling effect of nano SiO_2 particles involves the filling of empty spaces between cement particles. This process reduces the movement of water molecules and slows down the diffusion of ions that participate in hydration processes. This pore-filling effect contributes to the delay in setting time observed with the addition of nano SiO_2.

4. Adsorption Products of Hydration: Nano SiO_2 particles have the ability to adsorb hydration products, such as C-S-H gel and CH, on their surface. This adsorption phenomenon decreases the availability of hydration products for additional reactions, resulting in a slower advancement of cement hydration and extended setting times[28].

Understanding the efficiency of nano SiO_2 and nano TiO_2 in boosting the mechanical properties of Ordinary Portland Cement, it requires evaluating their effects on the compressive strength of the cement. The compressive strength of concrete is a crucial mechanical property that directly determines the ability of concrete constructions to withstand loads and maintain their durability over time. The incorporation of nanoparticles can influence compressive strength through various mechanisms including nucleation and growth of hydration products, refinement of microstructure, and modification of hydration kinetics.

Impact on Compressive Strength

Nano SiO_2 for Compressive Strength:

It has been shown that the inclusion of nano SiO_2 in OPC improves the compressive strength, especially when employing smaller particle sizes at higher concentrations. Several mechanisms contribute to this improvement:

1. Pozzolanic Reaction: It occurs when nano SiO_2 particles combine with calcium hydroxide (CH) which is released during cement hydration. This reaction results in the formation of more calcium silicate hydrate (C-S-H) gel. [29]. The pozzolanic reaction enhances the compaction of the cementitious matrix and the formation of additional binding phases, resulting in increasing compressive strength.

2. Filling Effect: The presence of nano SiO_2 particles can fill the voids and interstitial spaces within the cement paste, resulting in a compact microstructure. The pore-filling action decreases the porosity of the cementitious matrix and strengthens the bonding between particles, leading to an increase in compressive strength. [30].

3. Seed Effect: Nano SiO_2 particles serve as sites for the formation of hydration products, such as C-S-H gel. Nano SiO_2 speeds up the synthesis of hydration products and helps them spread evenly throughout the cementitious matrix, resulting in improved compressive strength. This is achieved by introducing more nucleation sites.

4. Strength Enhancement in Final Stages: The addition of nano SiO_2 promotes the development of a finer and more compact cementitious microstructure, leading to a progressive increase in strength as time passes. The incorporation of nano SiO_2 in concrete leads to enhanced compressive strength over time, demonstrating the concrete's long-lasting durability. Incorporating nano SiO_2 in OPC results in enhanced compressive strength through the stimulation of pozzolanic processes, the refinement of microstructure, and the provision of nucleation sites for the creation of hydration products.

Nano TiO_2 for Compressive Strength:

Nano TiO_2 also affects the compressive strength of OPC, but to a smaller degree than nano SiO_2. The impact of nano TiO_2 on compressive strength is predominantly noticeable during the first stages and is governed by parameters such as particle size and concentration. Important mechanisms include:

1. Enhanced Hydration: Nano TiO_2 expedites the hydration process by facilitating the formation and expansion of hydration products. This rapid hydration results in the early formation of compressive strength, especially during the initial phases of concrete curing.

2. Pore Refinement: Nano TiO_2 particles contribute to the refinement of the cementitious microstructure by filling voids and reducing pore sizes. This pore refinement enhances interparticle bonding and increases the density of the cementitious matrix, thereby improving compressive strength [31].

3. Synergistic Effects: When combined with nano SiO_2, nano TiO_2 can exhibit synergistic action that enhances the compressive strength. The coexistence of both nanomaterials concurrently amplifies the pozzolanic reactivity, refinement of microstructure, and acceleration of hydration kinetics, leading to more substantial improvements in compressive strength in comparison to either nanomaterial alone.

Nano TiO_2, albeit less influential than nano SiO_2, enhances compressive strength, especially in the context of of early-age strength development and microstructural refinement. The addition of nano SiO_2 and nano TiO_2 to OPC results in significant improvements in compressive strength due to processes such as pozzolanic reactions, refinement of the microstructure, and acceleration of hydration kinetics [32]. Nano SiO_2 largely affects compressive strength through pozzolanic processes and refining the microstructure. On the other hand, nano TiO_2 contributes to the development of strength at an early stage and refines the pores. The simultaneous utilisation of nanoparticles can lead to synergistic outcomes, further enhancing compressive strength and overall performance of cementitious materials. These findings highlight the potential of nanotechnology to enhance the mechanical properties and longevity of concrete structures, thereby enabling the adoption of sustainable and resilient construction methods.

Durability Enhancement

The incorporation of nano SiO_2 and nano titanium dioxide nano TiO_2 into Ordinary Portland Cement boosts both its mechanical properties and durability. The durability of concrete is a crucial factor in its performance, as it facilitates the structures to endure climatic and operational circumstances throughout their lifespan. Nano SiO_2 and nano TiO_2 increase durability through various mechanisms such as pore refinement, reduction of harmful processes, and alteration of microstructural characteristics.

Pore Refinement and Permeability Reduction:

One of the primary mechanisms by which nano SiO_2 and nano TiO_2 improve durability is by refining the microstructure of the cementitious material. The nanoparticles occupy voids and interstitial spaces within the cement paste, leading to a more condensed and solid structure. This process of pore refinement reduces the linked pore network, resulting in a reduction in the permeability of concrete to hazardous elements such water, chloride ions, and sulphates. The decreased permeability restricts the entry of harmful substances, thereby reducing the occurrence of degradation processes such as chloride ion infiltration, sulphate assault, and alkali-silica reaction (ASR). As a result, improving the long-term resilience of concrete structures are improved [33].

Mitigation of Carbonation and Corrosion:

Nano SiO_2 and nano TiO_2 contribute in reducing carbonation-induced corrosion in concrete structures. Carbonation is the chemical reaction between atmospheric carbon dioxide and calcium hydroxide (CH) in concrete, resulting in the formation of calcium carbonate (CaCO3). This process causes a decrease in pH and subsequent corrosion of the reinforcing steel. The addition of nano SiO_2 and nano TiO_2 enhances the compaction of the cementitious matrix, hence decreasing the permeation of carbon dioxide and restricting the extent of carbonation. In addition, nano TiO_2 possesses photocatalytic capabilities that enable it to actively break down organic contaminants and decrease the occurrence of carbonaceous deposits on concrete surfaces. This, in turn, helps prevent carbonation-induced corrosion.

Alkali-Silica Reaction (ASR) Mitigation:

Nano SiO_2 is essential in reducing alkali-silica reaction (ASR), a harmful chemical reaction between alkalis in cement and reactive silica in aggregates. This reaction results in the creation of expanding gel, leading to the subsequent cracking and degradation of concrete. The addition of nano SiO_2 helps in the absorption of excessive alkalis and diminishes the presence of reactive sites for ASR, therefore alleviating the potential for expansion and harm in concrete structures.

Self-Cleaning and Photocatalytic Activity:

Nano TiO_2 exhibits self-cleaning properties and photocatalytic behaviour, hence enhancing the long term durability of concrete surfaces. Nano TiO_2 particles, when exposed to ultraviolet (UV) light, act as catalysts for the oxidation of organic pollutants and airborne contaminants. This process helps to maintain the cleanliness of concrete surfaces and reduces the buildup of dirt and pollutants. The self-cleaning function of concrete not only improves its visual appeal but also preserves its surface qualities and extends the lifespan of structures [34].

Incorporation of nano SiO_2 and nano TiO_2 into OPC has the potential to greatly improve the longevity of concrete structures. These nanomaterials enhance the quality and durability of concrete infrastructure by refining pores, reducing permeability, mitigating carbonation and corrosion, mitigating ASR, and providing self-cleaning qualities. Nano-enhanced cementitious materials solve durability concerns and improve the long-term performance of concrete, leading to more sustainable and long-lasting concrete infrastructure. This eventually results in infrastructure with an extended service life and reduced maintenance costs. Additional investigation and advancement in this field are crucial to fully harness the advantages of nanotechnology in improving the longevity of concrete structures.

Challenges and opportunity:

The use of nanoparticles in construction poses both difficulties and possibilities, highlighting the intricate interaction among scientific advancement, regulatory factors, and market dynamics. In this article, we will explore some of the main obstacles and advantages related to the use of nanomaterials in the construction sector:

Challenges:

1. Safety Concerns: One of the primary challenges associated to nanomaterials is ensuring their safe handling, disposal, and control of exposure. There are apprehensions over the possible health and environmental risks presented by nanoparticles, which include risks of inhalation, hazards associated with skin contact, and ecological impacts. Thorough risk evaluation, regulatory oversight, and implementation of safety protocols in the workplace are crucial for effectively reducing these hazards.

2. Regulatory Challenges: The regulations governing nanoparticles in construction are constantly evolving but remains are currently fragmented and complex. Regulatory authorities encounter difficulties and challenges in establishing precise and uniform nanomaterial terminology, procedures for characterising them, and safety criteria. The lack of clarity surrounding regulatory compliance and liability concerns might hinder the mainstream use of nanoparticles in the construction industry.

3. Cost and Scalability: The production and incorporation of nanomaterials in costruction products sometimes involve elevated expenses in comparison to traditional materials. Scaling up manufacturing processes while ensuring constant quality and performance poses technical and economic difficulties. The broad adoption of cost-competitive nanomaterial-based solutions that provide concrete advantages is still a challenge.

4. Durability and Long-Term Performance: Although nanomaterials show potential for improving the durability and performance of construction materials, their long-term behaviour and stability in real-world situations remain incompletely understood. The durability and longevity of nanomaterial-enhanced products may be influenced by factors such as nanoparticle aggregation, degradation processes, and environmental interactions. Assessment of their performance requires conducting long-term investigations and field testing.

Opportunities:

1.Performance Enhancement: Nanomaterials possess distinct features and functions that can greatly augment the performance of construction materials. Their elevated surface area-to-volume ratio, adjustable qualities, and multifunctionality facilitate enhancements in mechanical strength, longevity, thermal insulation, and other key characteristics. Nanotechnology-based materials can meet changing performance needs and contribute to the advancement of high-performing, environmentally-friendly sustainable infrastructure.

2.Innovative Applications: Nanotechnology allows for the creation of new avenues for innovation in construction, noval materials, and construction techniques, leading to innovative applications in the field of construction. Nanomaterials enable the development of intelligent and versatile structures that possess features such as self-cleaning, self-repair, and energy generation. Nanocoatings, nano-enhanced concrete, and nanosensors are innovative applications that provide effective solutions for many issues in the construction industry.

3.Sustaiability and Resource Efficiency: Nanomaterials are crucial in promoting sustainability and resource efficiency in construction. Nanotechnology allows for the creation of environmentally friendly and resource-efficient construction solutions by optimising material qualities and lowering resource usage. Nanomaterials have the potential to enhance energy efficiency, reduce carbon footprint, and minimise waste at every stage of the construction process.

4.Customization: Nanotechnology provides the ability to precisely manipulate material properties and performance characteristics, allowing for customized solutions that meet specific application needs. Nanomaterials can be tailored in terms of dimensions, composition, and surface chemistry to fulfil diverse needs in construction. Thus capacity to customise allows for opportunities for optimisation of material design, functionality, and performance in wide range of applications.

Conclusion:

Overall, the incorporation of nano SiO_2 and nano TiO_2 into Ordinary Portland cement has great potential in enhancing the performance, durability longevity, and sustainability of concrete constructions. Through a comprehensive investigation of nano materials effects on OPC, it is clear that these nanoparticles exert substantial effects on various aspects of cementitious materials, such as setting time, compressive strength, and durability.

The incorporation of nano SiO_2 and nano TiO_2 affects the setting time of OPC, with nano TiO_2 expediting the process and nano SiO_2 prolonging it. The observed effects are attributed to the nanoparticles' surface area, reactivity, and interactions with cementitious phases, highlighting the intricate nature of their influence on cement hydration kinetics.

In addition, the presence of nano SiO_2 and nano TiO_2 in Ordinary Portland Cement increases its compressive strength by facilitating pozzolanic processes, refining the microstructure, and accelerating the hydration kinetics. The use of nano SiO_2, specifically, has a significant impact on compressive strength, particularly when employing tiny particle sizes and greater concentrations. Nano TiO_2 enhances the development of strength at an initial stage and improves the refining of pores, but to a smaller degree than nano SiO_2.

Moreover, nano SiO_2 and nano TiO_2 play crucial roles in improving the longevity of concrete constructions. They aid in the reduction of pore size, decrease in permeability, prevention of carbonation, corrosion, and alkali-silica reaction (ASR), and also possess self-cleaning and photocatalytic characteristics. These properties collectively enhance the durability and strength of concrete, resulting in a longer lifespan and less need for maintenance.

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COMPREHENSIVE VIEW OF NANOTECHNOLOGY IN DETECTION, DIAGNOSIS, AND MAPPING

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Abstract:

The development of novel treatments will be covered in this chapter, along with advancements in nanotechnologies that pertain to disease analysis, diagnosis, treatment, and detection. The objective of this chapter is to illustrate the many interpretations of nanomedicine and how they affect the conversion of fundamental science research in nanotechnology into practical uses in medicine. The creation of new medicines using nanotechnologies will be discussed, including techniques that could enable more precise and effective drug delivery as well as logically created, targeted medications. It has been demonstrated that nanotechnology can improve sensitivity and selectivity and reduce the cost of diagnosis by allowing the modification of materials at the nanoscale. The field of nanomedicine involves the use of constructed nanodevices and nanostructures to monitor, repair, construct, and control human biological systems at the molecular level. It has a significant impact on a variety of medical fields, including bioengineering, biophysics, molecular biology, cardiology, ophthalmology, endocrinology, oncology, and immunology. The development of nanotechnology presents opportunities for treating neurodegenerative diseases like Alzheimer’s and Parkinson’s, as well as for treating tuberculosis and using nanotechnology in surgical dentistry. It is anticipated that numerous innovative nanoparticles and nanodevices will be employed in the future, greatly improving human health. A few of these areas are highlighted, with a focus on the use of nanoparticles for drug delivery, screening, diagnostics, and mapping.

Keywords: nanotechnology, nanomedicine, nanoparticle, nanodevice

Introduction:

The term "nanotechnology" refers to fields of science and technology where structures, devices, systems, and materials are designed, characterized, manufactured, and used in ways that involve phenomena happening at nanoscale dimensions. In 1959, physicist Richard Feynman gave a talk on creating objects at the atomic and molecular levels that established the idea of nanotechnology[1].

For numerous years, people have searched for miracle cures to ease the pain of illness and injuries. A lot of experts believe that using nanotechnology in medicine can be crucial to accomplishing this. Using engineered nanotechnology devices and nanostructures that operate at the molecular level, these applications cover complete biological human system monitoring, administration, development, maintenance, and protection. Nanotechnology has the potential to significantly change medical research and open up new avenues for human advancement[2].

By using molecular devices and a molecular comprehension of the human body, advances in technology and science have been employed to diagnose illnesses, cure and prevent trauma, relieve pain, and preserve and improve human health. The majority of the commercial applications of nanotechnology in medicine today focus on drug delivery. Existing pharmaceutical chemicals are more bioavailable and more precisely targeted, and new mechanisms of action might be introduced[3].

The relevance of nanoscale science to the development of nanotechnology will be demonstrated by an overview of the links between the creation of model systems and the hunt for nanosystems tailored to specific applications. We define nanotechnology as the use of science to create practical systems and technologies using a fundamental knowledge of the properties of matter at the nanoscale, which is consistent with a previous definition. This view of our field implies that our study will have a major influence on the direction of technology and that there is still a great deal to learn about the behavior of nanoscale materials. Evaluating our understanding of the behavior of nanoscale materials, outlining a set of current key principles and concepts, and defining the most important research frontiers are all critical steps towards better aligning model system development with its anticipated future impact[4].

Nanotechnology is expanding the life sciences sector's possibilities in the healthcare sector.The manipulation of materials at the atomic level shows that nanotechnology has the potential to bring about significant changes in many aspects of medical care, including diagnostics, disease monitoring, equipment operation, restorative medicine, vaccine development, and drug delivery. It also provides access to high-tech research tools that can be used to create medications that will enhance the way that different illnesses are treated. By targeting specific cells in the body with medication, nanotechnology can lower the chances of pharmaceutical failure and disapproval[5].

Nanomedicine uses nanotechnology in healthcare applications, including nanotechnology at the molecular level, nanoelectronic biological sensors, and nanoparticles for illness diagnosis and treatment. It ensures that medicine is ultimately significantly more precise by providing the ability to assess a person's physiology, drugs, and medical equipment down to the nanoscale. The applications of nanotechnology in medicine, prevention, and diagnosis are well-established. Among many other issues, this technology has the ability to transform the body on purpose. The use of nanoparticle medications has shown improved bioavailability, fewer adverse effects, and improved absorption of therapeutic medication. This technology is being used by the healthcare industry for medical devices and diagnostics. Rapid advancements in nanotechnology are leading to the development of novel diagnoses and therapeutics with higher success rates. Future uses of nanotechnology include versatile molecule structures for disease targeting and drug delivery, integrated sensory nanoelectronic systems, and nanoprobes. At the moment, nanomedicine is being used to treat cancer and produce smart drugs[6].

Overall, nanotechnology integrates detection, diagnosis, and mapping strategies to improve the understanding and management of diseases, ultimately leading to better patient outcomes and personalized healthcare. Nanotechnology has revolutionized various fields, including healthcare, by enabling precise detection, diagnosis, and mapping of diseases at the molecular level[7].

Nanotechnology in Detection

- Nanotechnology enables the development of highly sensitive and specific detection methods for identifying disease markers, pathogens, or abnormalities.
- Nanosensors and nanoprobes can detect minute quantities of biomolecules or changes in biological parameters, facilitating early detection of diseases[8].

1. Point-of-care Diagnostics

Medical diagnostic testing that is carried out close to the patient, frequently at the point of care, such as a doctor's office, clinic, or bedside, is referred to as point-of-care (POC) diagnostics. Quick strep tests, glucose meters for diabetes control, pregnancy tests, and some infectious illness tests, such as quick influenza tests, are a few examples of point-of-care (POC) diagnostics. POC testing is becoming even more capable because of emerging technologies like smartphone-based diagnostic apps and portable DNA sequencing devices.[9]

Overall, POC diagnostics play a vital role in modern healthcare by providing timely and convenient diagnostic solutions, ultimately improving patient care and outcomes[10].

These tests are designed to provide rapid results, allowing healthcare providers to make immediate treatment decisions. POC diagnostics have several advantages:

- **Rapid Results:** POC tests typically provide results within minutes to hours, allowing for immediate diagnosis and treatment decisions.
- **Improved Patient Outcomes:** Quicker diagnosis and treatment initiation can lead to improved patient outcomes, especially in critical conditions where timely intervention is crucial.
- **Reduced Turnaround Time:** By eliminating the need to send samples to a centralized laboratory, POC diagnostics reduce the time it takes to obtain results, enabling faster patient management.
- **Enhanced Accessibility:** POC tests can be performed in various healthcare settings, including remote or resource-limited areas where access to centralized laboratories may be limited.

- **Cost-Efficiency:** Although initial equipment costs may be higher, POC diagnostics can potentially reduce overall healthcare costs by minimizing hospital stays and unnecessary tests.
- **Streamlined Workflow:** POC testing can streamline clinical workflows by reducing the need for sample transportation and laboratory processing, leading to increased efficiency.
- **Increased Patient Satisfaction:** Patients benefit from receiving immediate results and quicker treatment, leading to higher satisfaction levels with their healthcare experience.

2. Biosensors

Biosensors are analytical devices that combine a biological sensing element (such as enzymes, antibodies, or whole cells) with a physicochemical detector to convert a biological response into a measurable signal. They are designed to detect specific biological analytes, ranging from small molecules to large biomolecules like proteins and nucleic acids. Biosensors have gained significant attention due to their potential applications in various fields, including healthcare, environmental monitoring, food safety, and security. Overall, biosensors play a crucial role in advancing analytical capabilities, enabling rapid, sensitive, and selective detection of biological analytes in various contexts. Continued research and innovation in biosensor technology hold promise for further enhancing their performance and expanding their applications. Biosensors find applications in diverse fields, including medical diagnostics (e.g., glucose monitoring, disease biomarker detection), environmental monitoring (e.g., detection of pollutants, pathogens), food safety (e.g., detection of foodborne pathogens, allergens), and security (e.g., detection of explosives, toxins)[11].

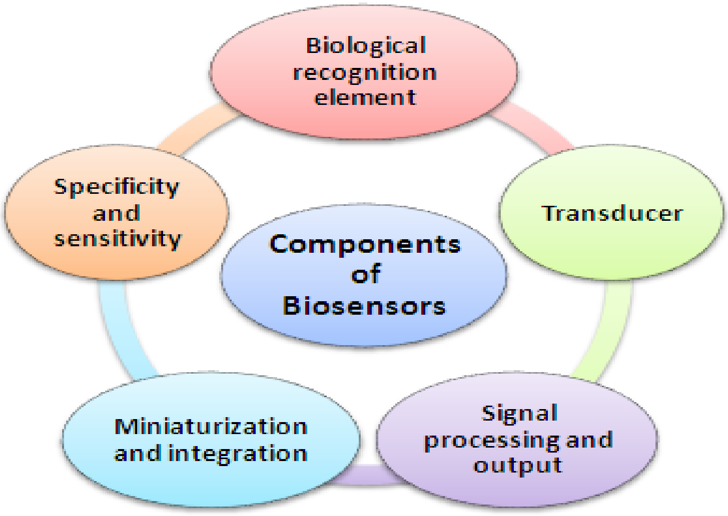

Fig. 1: Various components of Biosensors

Nanoscale sensors: Nanosensors can detect specific biomarkers associated with various diseases with high sensitivity and selectivity. These sensors often utilize nanomaterials such as carbon nanotubes, quantum dots, or gold nanoparticles functionalized with biomolecule receptors.

- **Lab-on-a-chip devices:** Nanotechnology enables the miniaturization of diagnostic tools into portable lab-on-a-chip devices, allowing for rapid and point-of-care detection of biomarkers.
- **Magnetic nanoparticles:** Functionalized magnetic nanoparticles can bind to target molecules, allowing for their easy isolation and detection using magnetic resonance imaging (MRI) or other imaging techniques.

Nanoscale sensors are devices designed to detect and respond to physical or chemical stimuli at the nanometer scale, typically ranging from 1 to 100 nanometers. These sensors utilize principles of nanotechnology to achieve high sensitivity, selectivity, and accuracy in detecting various analytes or environmental changes. Nanoscale sensors have applications across numerous fields, including healthcare, environmental monitoring, food safety, and security.[12]

Here are some key features and applications of nanoscale sensors:

- **High sensitivity:** Nanoscale sensors can detect very small changes in their environment, often down to single molecules or atoms. This makes them valuable for applications where high sensitivity is critical, such as medical diagnostics and environmental monitoring.
- **Small size:** Being at the nanometer scale, these sensors are extremely small, allowing for integration into miniature devices and systems. This is advantageous for applications requiring portability or integration into confined spaces, such as wearable health monitors or microfluidic devices.
- **Selectivity:** Nanoscale sensors can be engineered to selectively detect specific molecules or analytes by functionalizing their surfaces with recognition elements such as antibodies, aptamers, or molecularly imprinted polymers. This selectivity enables precise detection even in complex samples containing multiple components.
- **Real-time monitoring:** Nanoscale sensors offer the potential for real-time monitoring of various parameters, including biomarkers, pollutants, or pathogens. This capability is particularly valuable for continuous monitoring applications, such as environmental pollution tracking or disease progression monitoring.
- **Multiplexing**: Advances in nanotechnology enable the development of multiplexed sensor arrays capable of simultaneously detecting multiple analytes. This allows for comprehensive analysis in a single measurement, reducing time and cost compared to sequential measurements.
- **Biocompatibility:** Many nanomaterials used in nanoscale sensors exhibit biocompatibility, making them suitable for biomedical applications such as in vivo sensing, drug delivery, or implantable devices.
- **Enhanced performance:** Nanotechnology offers opportunities to enhance sensor performance through novel materials, such as carbon nanotubes, graphene, or quantum dots,

which possess unique properties such as high conductivity, large surface area, or quantum confinement effects.

- **Potential for integration:** Nanoscale sensors can be integrated with other nanoscale components, such as actuators or transducers, to create multifunctional nanosystems for advanced applications, including nanorobotics or lab-on-a-chip platforms.

3. Nanoparticles for Imaging

Nanoparticles have emerged as valuable tools in the field of imaging due to their unique properties, including their small size, large surface area, and tunable surface chemistry. These properties enable them to be tailored for specific imaging applications, such as magnetic resonance imaging (MRI), computed tomography (CT), positron emission tomography (PET), single-photon emission computed tomography (SPECT), and optical imaging. In summary, nanoparticles offer versatile platforms for imaging applications, with the potential to revolutionize diagnostic imaging and personalized medicine through their unique properties and functionalities.[13]

Here are some key points regarding the use of nanoparticles for imaging:

- **Contrast Agents:** Nanoparticles can serve as contrast agents in various imaging modalities. For instance, superparamagnetic iron oxide nanoparticles (SPIONs) are commonly used as contrast agents for MRI due to their high magnetic susceptibility, which results in strong T2 relaxation effects and thus enhances the contrast between tissues. Similarly, gold nanoparticles can enhance contrast in CT imaging due to their high X-ray attenuation coefficient.
- **Targeted Imaging:** Nanoparticles can be functionalized with targeting ligands (e.g., antibodies, peptides, aptamers) to specifically bind to molecular targets associated with diseases, enabling targeted imaging. This approach improves imaging sensitivity and specificity by allowing the visualization of specific cell types or biomarkers.
- **Multimodal Imaging:** Nanoparticles can be engineered to incorporate multiple imaging modalities within a single platform, facilitating multimodal imaging. This approach enables complementary information from different imaging techniques to be obtained simultaneously, improving diagnostic accuracy. For example, nanoparticles containing both fluorescent dyes and MRI contrast agents allow for fluorescence imaging and MRI of the same target.
- **Theranostic Applications:** Nanoparticles designed for imaging can also be utilized for therapeutic purposes, leading to the concept of theranostics. Theranostic nanoparticles can combine imaging capabilities with therapeutic functionalities, such as drug delivery, photothermal therapy, or radiotherapy. This integrated approach enables real-time monitoring of therapeutic responses and personalized medicine.

- **Biocompatibility and Biodegradability:** To ensure their clinical applicability, imaging nanoparticles must possess good biocompatibility and biodegradability. Biocompatible nanoparticles minimize adverse effects when administered in vivo, while biodegradable nanoparticles undergo degradation and clearance from the body, reducing the risk of long-term toxicity.
- **Challenges and Future Directions:** Despite their promising potential, several challenges remain in the development and translation of nanoparticle-based imaging agents, including optimization of their pharmacokinetics, immunogenicity, and scalability. Future research efforts are focused on addressing these challenges and exploring novel nanoparticle formulations, targeting strategies, and imaging techniques to further advance the field of nanoparticle-based imaging.

Nanotechnology in Diagnosis

- Nanotechnology plays a crucial role in disease diagnosis by providing advanced tools and techniques for accurate assessment and characterization.
- Nanoparticles functionalized with targeting ligands or contrast agents enhance imaging modalities such as MRI, CT scans, and fluorescence microscopy, enabling precise diagnosis of diseases at the molecular level.[14]

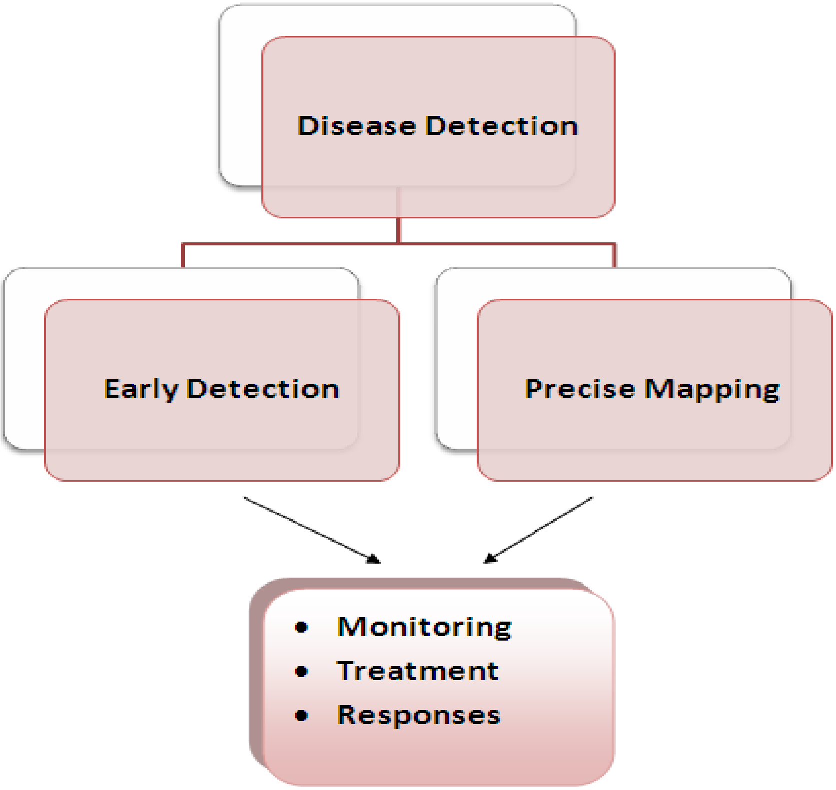

Fig. 2: Steps involved in disease detection

1. Cancer detection

Nanotechnology is considered one of the most promising advances in drug delivery in the current battle against cancer. Nanoparticles, rather than pharmaceuticals, are usually able to deliver conventional cancer medications to tumors with fewer side effects and enable the precise destruction of cancer cells in non-conventional treatments. More cytotoxic medication can be administered at the intended site, and its toxicity and efficiency are reduced when nanoparticles are used in chemotherapeutic delivery.[15]

Nanomaterials can target, image, and transport therapeutic compounds to cancer cells with great specificity and sensitivity, which makes them highly promising for use in cancer diagnosis. Since nanotechnology offers extremely sensitive, specific, and non-invasive diagnostic methods that can identify cancer early, inform treatment choices, and enhance patient outcomes, it has significant potential to transform the diagnosis and treatment of cancer. The creation of innovative nanotechnology-based instruments for customized medicine and cancer diagnostics is being advanced by ongoing research in this area.[16]

2. Dentistry

Everyone knows that dental implants can be made of engineered materials, especially when it comes to appearance. Dental health and boosting dental defenses are key additional areas. The field of nanodentistry encompasses many aspects of dentistry, such as preventing infection and restoring damaged teeth to their natural state. All disciplines of dentistry utilize nanotechnology, which takes advantage of the huge surface area to volume ratio of the nanomaterials to improve therapeutic and cosmetic effects through improved lesion penetration caused by small particle sizes. When bioactive molecules such as growth factors are released under control and at specific sites, along with when medications are used at lower dosages, the desired and ideal results are achieved with fewer adverse effects.[17]

3. Neurodengenerativre disease

Neurodegenerative diseases like Parkinson's and Alzheimer's are becoming more common, which comes at a high financial cost and with an aging population. The blood-brain barriers, which filter out and prevent the translocation of undesirable blood-borne molecules and, as a result, many therapeutic and diagnostic agents to the brain, hinder therapy even though the mechanisms involved are quickly becoming clear. Nanomaterials are being developed for theranostic purposes in the treatment of Parkinson's and Alzheimer's disease to improve the delivery of a range of molecules across the blood-brain barrier for the diagnosis and therapy of these diseases.[18]

4. Tuberculosis

Millions of people die from tuberculosis every year worldwide; the disease is treated with multiple medication formulations spread over several months; nevertheless, patient noncompliance can lead to multidrug resistance (MDR) of the Mycobacterium tuberculosis organism, which increases morbidity and mortality and causes MDR-TB. Alzahabi and coworkers describe the history, present course of treatment, and critical need for novel approaches to the management of pulmonary tuberculosis. They argue for drug-loaded nano- and micron-sized materials for inhalation treatment. They provide an overview of current studies on the use of metallic and organic nanomaterials as delivery systems for new and existing tuberculosis medications, both separately and in combination, to treat tuberculosis. They also emphasize the use of nanoparticles, like silver, that provide extra antibacterial qualities to increase the drug formulation's antimicrobial activity.[19]

Future Prospects:

Based on nanotechnology, more accurate sensors and biomarkers can be developed, which could be used to accurately and rapidly diagnose various diseases in the early stages. Before using nanomedicine to treat patients to its full potential, toxicity assessment and multistage clinical studies are required, just like with any other medical equipment or treatment. Nanomedicine will definitely be important for personalized medicine, from screening to diagnosis. In the future, instead of relying on a combination of inputs from exterior sensors, medical experience, and probabilistic diagnostic algorithms, nanotechnology will be able to identify problems locally. Athletes could utilize nanotechnology as an additional tool to assess which muscles have better circulation and produce less lactic acid. This would enable athletes to adjust their training and frequency in response to their less effective muscles. These can maximize the potential of their less effective muscles and modify their efficiency. Highly precise mapping of disease with improved targeting and chemical sensitivity is made possible by nanomedicine. Once a disease has been identified, nanomedicine can be used with greater efficacy to target cells while minimizing negative effects and damage to normal cells. Fundamentally, the difficulties of the future lie in the development of metallic nanoparticles' potential for evaluation and therapy, as well as in the loading and release of pharmaceuticals.[20]

Conclusion:

Nanotechnology, which focuses on anticipatory health care management, is behind the healthcare revolution. Nanotechnology minimizes the risk of adverse effects, increases therapeutic efficacy, and helps solve the issue of focused treatment administration. This technology can be used to detect, treat, and even cure cancer using gene therapy. Using nanorobotics for medical purposes is the most promising application. Its applications span a number of industries, including vaccine development, drug delivery, wearable technology, diagnostic and imaging tools, and antimicrobial items. Nanomedicine is expected to arise from the early diagnosis of various ailments and the development of more efficient medications and devices. Standard anti-cancer medications can be crossed intact and circulated throughout the brain when combined with nanoscale technologies. With the use of this technology, entire classes of existing medications have vast potential markets and benefits. It is feasible to create customized drug delivery systems, novel diagnostic techniques, and nanoscale medical equipment.

Recent developments in nanotechnology have made it possible for medical professionals to use nanoscale components, such as the biocompatibility of nanoparticles and nanobots, to enhance and accomplish targets in a living body.The use of nanorobotics can enhance pharmaceutical delivery in cancer therapy, increase healthcare efficiency, and monitor illnesses and pharmacokinetics.

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ROLE OF NANOTECHNOLOGY IN GREEN CHEMISTRY

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Abstract:

Nanotechnology is a rapidly growing science of producing and utilizing nano size particles. Nanoparticles compared to bulk materials exhibit improved characteristics due to their size, distribution and morphology and are used in various scientific fields. Now research on the impact of nanotechnology is on high demand. Green technology stands for the use of nanotechnology in improving chemical reactions like use of less hazardous chemicals, more efficient reactions with no side products. Green nanotechnology also includes treatment of various types of pollutants like water pollution, soil pollution etc. Photocatalysis by using nanoparticles is one of the important fields where pollutants are directly converted to carbon dioxide and water. Apart from this nanoparticles are also used in the areas of solar cells, biofuels and fuel cells. Here we are mainly focused about the role of nanoparticles in water pollutants removal like dyes, pesticides, drugs and heavy metals.

Keywords: Nanotechnology; Photocatalysis; Nanoscale Catalyst; Agrochemicals

Introduction:

Definition of Nanotechnology

Nanotechnology is defined as the manipulation of matter at the atomic and molecular level, materials and devices between 1 to 100 nanometers in size. This field allows for the development of faster and more efficient electronic devices, innovative drug delivery systems in medicine, unique materials like carbon nanotubes and graphene, in renewable energy technologies, and solutions for environmental challenges such as pollution remediation. While nanotechnology has the potential to address significant societal issues and drive innovation, it also raises ethical, safety, and environmental concerns that must be considered as advancements are made (Deshpande *et al.*, 2020).

Applications of Nanotechnology

- **Electronics:** Nanotechnology is brought out the creation of smaller, quicker and more effective electronics devices. Nanoscale substance employ in semiconductor making, result in formation of swifter and more energy-saving computer chips (Tulinski & Jurczyk, 2017).

- **Medicine:** In medicine sector, nanotechnology supply rich prospects for medication delivery, diagnostics and treatments. Nanosize drug delivery systems can strike selected cells or tissues, lessen unwanted outcomes and ameliorate therapeutic success. Nanosensors can recognize sicknesses at early stage, and nanomaterials investigation being carry out for tissue engineering and restorative drugs (Lu & Astruc, 2018).
- **Materials:** Nanotechnology transform Material Science by making innovator materials with peculiar traits. For an instance, carbon nanotubes and graphene befall extraordinary fortitude, conductivity and adaptability, creating them proper for assorted undertakings, which including aerospace, automotive and constructions industries.
- **Energy:** Nanotechnology play significant role in renewable energy technologies. Nanomaterials used in solar cells to augment efficiency and diminish costs. Nanotechnology also incentives formulation of high-capacity batteries and light weight substances for vitality storage and transportation.
- **Environmental Remediation:** Nanotechnology propose answers for ecological complications, like remediation of contamination and water purification. Nanomaterials style to catch contaminants or catalyse chemical reactions for ecological restoration (Bishnoi *et al.,* 2017).

Total, nanotechnology have enormous promise resolve several major issues confronting globe and to impulse innovation across diverse sectors. But, it also increases ethical, safety, and environmental concerns that necessitate behaved handling as field progress.

Green Chemistry

1. Green Chemistry Definition

Green chemistry, a sustainable form of chemical design, focuses on creating chemical product and procedures using fewer hazardous compounds (Jarrahi *et al.,* 2021). This innovative science strives for lessening the environmental footprint of chemistry through the application of renewable resources, lower energy intake, and elimination of pollutants.Green chemistry's primary intent lies in the significant decrease of harmful by-products and call for chemical processes that are eco-friendly endeavors. The method shifts emphasis on the utilization of safer alternatives, thereby indirectly promoting ecological health.

Advancements in this discipline have set goals in motion, which include deadly substance minimization during synthesis, energy conservation, and the reduction of waste. These points are key principles that guide green chemistry as it moves forward in creating cheaper, efficient, and sustainable processes.

Other essential aspects of this discipline lie in maintaining a proper balance between the academic realm and the industrial one. The collaborative effort between education, research, and practical implementing empowers green chemistry to provide solutions for environmental issues and, at the same time, foster economic growth.

Thus, green chemistry, a sustainable path towards innovative chemical engineering, ensures that future advancements thread the needle between environmental stewardship and economic prosperity. So, we, in unity, endeavor towards a less toxic planet by seeking, employing, and perfecting green chemistry technologies.

2. Principles of Green Chemistry

Chemists Paul Anastas and John Warner investigated the fundamentals of green chemistry for the first time in the early 1990s. These guidelines offer a foundation for creating and utilizing chemical processes and products that are safer and better for the environment by nature. Among the fundamentals of green chemistry are the following:

- **Prevention:** Treating or cleaning up waste and pollution afterward is preferable than preventing it at the source. According to Srivastava *et al.* (2004), this principle highlights how crucial it is to design processes to produce the fewest possible harmful compounds.
- **Atom Economy:** Chemical reactions ought to be planned to incorporate as much of the inputs as possible into the finished product, reducing waste and increasing effectiveness.
- **Creating Safer Chemicals:** Non-toxic chemical goods should be created.
- **Safer solvents and auxiliary materials:** To reduce threats to the environment and human health, the use of safer solvents and auxiliary materials should be given priority. This involves reducing or getting rid of volatile organic compounds (VOCs) and using water as a solvent.
- **Energy Efficiency:** Chemical processes must to be engineered to minimize energy usage while optimizing efficacy. This can be accomplished by developing catalytic processes, optimizing processes, and utilizing renewable energy sources.
- **Renewable feed stocks:** To minimize environmental effect and lessen dependency on fossil fuels, renewable feed stocks must to be used as starting materials whenever feasible.
- **Design for Degradation:** Chemical products should be made so that, after usage, they break down into harmless compounds, reducing their environmental impact and persistence.
- **Instantaneous Analysis**: Researchers and business experts can create novel solutions that not only address social demands but also reduce the threats to the environment and human health posed by chemical processes and products by adhering to the principles of green chemistry. Applications for green chemistry can be found in many different fields, such as manufacturing, materials science, agriculture, and pharmaceuticals.

Role of Green Chemistry in Nanotechnology

The development and implementation of nanotechnology can be greatly impacted by green chemistry principles in a number of ways (Sarkar *et al.,* 2020; Verma *et al.,* 2021).

- **Safer Methods for Synthesis:** Green chemistry encourages the production of nanomaterials through safer and more environmentally friendly synthesis techniques. This reduces the dangers to human health and the environment involved with the synthesis of nanomaterials by using non-toxic chemicals, renewable resources, and ecologically benign solvents.
- **Less Waste Production:** Green chemistry places a strong emphasis on the necessity of reducing the amount of waste produced during chemical reactions. Through the use of green chemistry concepts, scientists can create synthesis methods for nanotechnology that optimize atom economy while reducing the generation of waste materials and byproducts.
- **Energy Efficiency:** Green chemistry promotes the use of energy-saving techniques in the production and synthesis of nanomaterials.
- **Design of Sustainable Nanomaterials:** Improved sustainability profiles can be achieved by designing nanomaterials using the principles of green chemistry. By creating biodegradable, non-toxic, and renewable resource-based nanomaterials, scientists can lessen their negative effects on the environment and improve their compatibility with biological systems.
- **Safe Handling and Disposal:** Safe handling and disposal of nanomaterials are taken into account when practicing green chemistry. The possible hazards related to nanotechnology can be mitigated by creating nanomaterials with lower toxicity and environmental persistence as well as safe handling and disposal procedures.
- **Environmental Applications:** Water purification, pollution monitoring, and the cleanup of contaminated areas are just a few of the environmental remediation applications where nanotechnology holds great promise. When designing and using nanomaterials for environmental applications, researchers might apply the concepts of green chemistry to enhance their findings.
- **Life Cycle Assessment:** To examine the environmental impact of nanomaterials over the course of their whole life cycle, from synthesis to disposal, green chemistry promotes the use of life cycle assessment (LCA). The creation of more sustainable practices is aided by LCA's insightful analysis of environmental hotspots and prospective areas for advancement in nanotechnology applications.

Overall, by incorporating the ideas of green chemistry into nanotechnology research and development, the field may progress in a more sustainable and responsible way, ensuring that the advantages of nanotechnology are fulfilled while lowering any possible threats to the environment and human health.

Role of Nanotechnology in Green Chemistry

Through the creation of innovative materials, procedures, and technologies that support sustainability and environmental stewardship, nanotechnology significantly advances the objectives of green chemistry. The following is the relationship between green chemistry and nanotechnology (Ma *et al.,* 2019a; Mahmoodi *et al.,* 2010):

- **The catalytic process:** When used as extremely effective catalysts for chemical reactions, nanomaterials allow for the utilization of gentler reaction conditions, quicker reaction times, and lower energy consumption. Green chemistry places a strong emphasis on the value of catalysis in enhancing process selectivity and efficiency while reducing waste production. Through increasing the recyclability of catalysts, decreasing the requirement for hazardous chemicals, and permitting the use of renewable feed stocks, nanocatalysts can promote greener and more sustainable synthesis pathways.
- **Ecological Synthesis Pathways:** Nanotechnology provides inventive pathways for synthesis.
- Effective Separation and Purification: By using nanomaterials in these procedures, pollutants and impurities can be eliminated from a variety of streams, such as air, wastewater, and industrial effluents.
- **High selectivity:** Efficiency and capacity are provided by nanotechnology-based filtration membranes, adsorbents, and catalytic materials for eliminating pollutants, pathogens, and dangerous chemicals from the environment. Green chemistry places a strong emphasis on the value of environmentally friendly separation techniques in reducing pollution and advancing resource recovery.
- **Renewable Energy Technologies:** The development of renewable energy technologies, including fuel cells, solar cells, and energy storage systems, is greatly aided by nanotechnology. Quantum dots, carbon nanotubes, and nanostructured electrodes are examples of nanomaterials that improve the performance, stability, and efficiency of energy conversion and storage systems. Nanotechnology helps by increasing the efficiency of renewable energy systems.
- **Environmental Remediation:** Innovative approaches to pollution control and environmental remediation are provided by nanotechnology. Pollutants from soil, water, and air, such as emerging pollutants, heavy metals, and organic contaminants, can be specifically captured and broken down using nanomaterials. Remediation techniques based on nanotechnology, like air purification using photocatalytic nanoparticles and groundwater remediation with nano zero-valent iron (nZVI), provide sustainable and affordable solutions for dealing with environmental contaminants.
- **Green Nanomaterial Design:** The creation of environmentally benign nanomaterials with lower toxicity, biodegradability, and eco-friendliness is guided by the concepts of green chemistry. To create nanomaterials with little effect on the environment, researchers use sustainable precursor materials and green synthesis techniques. Researchers hope to reduce

any hazards related to nanotechnology and advance safer and more sustainable applications in a range of industries by creating green nanomaterials, including as

- Researchers hope to reduce any hazards related to nanotechnology and advance safer and more sustainable applications in a range of industries, such as consumer goods, electronics, and healthcare, by creating green nanomaterials.

In general, green chemistry ideas and practices can be advanced through the use of nanotechnology, which offers flexible tools and solutions that can be applied to create more environmentally friendly and sustainable chemical processes, materials, and technologies. Researchers can address urgent environmental issues while advancing social progress, economic expansion, and environmental sustainability by fusing green chemistry with nanotechnology.

5. Different green ways to carry out chemical reactions

There are a number of environmentally friendly methods for conducting chemical reactions that are consistent with the values of resource efficiency, sustainability, and environmental responsibility. Examples (Y. Chen *et al.,* 2018; Ma *et al.,* 2019b) include the following:

- **Solvent-Free Reactions:** A lot of conventional chemical reactions call for solvents, which can be dangerous for the environment and human health. Solvent-free or "neat" reactions either completely do away with the requirement for solvents or make use of substitute solvent-free methods like ball milling, grinding, or microwave heating. These techniques lessen the risks associated with solvents, energy use, and trash production.
- **Water as a Solvent:** Water is a plentiful, non-toxic, and environmentally safe green solvent. Aqueous phase reactions and hydrothermal synthesis are two examples of water-based reactions that have many benefits, such as high reaction rates, simple product separation
- **Bio-Based Feed Stocks:** Green chemistry encourages the use of biomass-derived renewable feed stocks as starting materials for chemical reactions. Examples of these feed stocks are sugars, vegetable oils, and other cellulosic materials. Because bio-based feed stocks are carbon-neutral, renewable, and biodegradable, they lessen the need for fossil fuels and help to reduce greenhouse gas emissions. Reduction of environmental effect is possible in the manufacture of biofuels, bioplastics, and biochemicals through the use of bio-based reactions such microbial fermentation and enzymatic catalysis.
- **Microwave-Assisted Reactions:** Compared to traditional heating techniques, microwave heating is an environmentally friendly technology that allows for the quick and precise heating of reaction mixtures. This results in shorter reaction times, greater yields, and less energy usage. In organic synthesis, polymerization, and material processing, microwave-assisted processes are frequently employed because they provide benefits in terms of effectiveness, scalability.

- **Green Catalysts:** The application of non-toxic, recyclable, and renewable resource-based catalysts is emphasized by green chemistry. Biocatalysts, which include microbes and enzymes, provide gentle reaction conditions and great selectivity, making it possible to synthesis complex compounds with little waste production. While reducing their negative effects on the environment and the depletion of resources, heterogeneous catalysts, such as supported metals and metal oxides, enable green catalytic activities like hydrolysis, oxidation, and hydrogenation.
- **Flow Chemistry:** Chemical reactions are conducted in a continuous stream of reactants that pass through a reactor system in flow chemistry, sometimes referred to as continuous-flow synthesis. Compared to batch reactions, flow chemistry has a number of benefits, such as better reaction control, increased safety, and less waste production and solvent consumption.
- **Green Solvents:** Green chemistry encourages the use of low-toxicity, low-volatility, and low-impact solvents on the environment. Supercritical fluids, ionic liquids, and natural solvents made from renewable resources like terpenes and fatty acids are examples of green solvents. Green solvents provide substitutes for traditional organic solvents in chemical reactions, mitigating the hazards to human health, volatile organic compounds (VOCs) emissions, and the environment.

5. Nanomaterials in Waste Water Treatment

Because of their special qualities, nanomaterials are very useful in wastewater treatment applications. The following are a few common types of nanomaterials (H. Chen *et al.*, 2020; R. Chen *et al.*, 2021).

- **Metal nanoparticles:** Excellent catalytic, antibacterial, and adsorption capabilities make metal nanoparticles—like titanium dioxide (TiO_2), iron (Fe), and silver (Ag)—effective for treating wastewater. Because of their well-known antibacterial properties, silver nanoparticles are used to disinfect water by preventing the growth of bacteria and other microbes. Through reduction and adsorption processes, iron nanoparticles—in particular, zero-valent iron (n ZVI)—are utilized to remove organic pollutants and heavy metals. Under UV light irradiation, organic contaminants are photocatalytically degraded using titanium dioxide nanoparticles.
- **Carbon-Based Nanomaterials:** Because of their high surface area, adsorption capacity, and chemical reactivity, carbon-based nanomaterials—such as carbon nanotubes (CNTs), graphene, and activated carbon nanoparticles—are frequently employed in wastewater treatment. For the adsorption and filtration of organic contaminants, heavy metals, and emerging pollutants from water, carbon nanotubes (CNTs) and graphene-based materials are utilized. Activated carbon nanoparticles are efficient adsorbents that can be used to remove a variety of contaminants from wastewater, such as pesticides, medications, and colors.

- **Metal Oxide Nanoparticles:** Suitable for wastewater treatment applications, metal oxide nanoparticles include zinc oxide (ZnO), manganese dioxide (MnO_2), and cerium oxide (CeO_2). These nanoparticles have good adsorption, photocatalytic, and antibacterial capabilities. Under UV light, zinc oxide nanoparticles are utilized to cleanse water and photocatalytically break down organic contaminants. Nanoparticles of manganese dioxide
- **Hybrid nanoparticles:** Using two or more different types of nanoparticles, hybrid nanomaterials provide improved performance and synergistic effects in wastewater treatment. For the removal of organic pollutants and heavy metals from water, graphene-based composites, such as graphene oxide (GO)-based materials adorned with metal nanoparticles or metal oxides, show better adsorption and photocatalytic characteristics. Similarly, for wastewater treatment applications, carbon nanotube-based composites—such as CNTs covered with metal oxides or nanoparticles—showcase increased catalytic activity and adsorption.
- **Polymeric Nanomaterials:** Adsorption, filtration, and membrane separation techniques are employed to remove impurities from water using polymeric nanomaterials, such as polymer nanocomposites and dendrimers. For the treatment of wastewater, polymer nanocomposites—polymer matrices reinforced with nanoparticles—showcase improved mechanical strength, chemical stability, and adsorption capacity. Through the processes of complexation and chelation, dendrimers—hyperbranched macromolecules with clearly defined structures—are used to remove organic contaminants and heavy metals from the environment. These are but a few illustrations of the wide variety of nanomaterials that are employed in the treatment of wastewater. As a result, each form of nanomaterial highlights the adaptability and potential of nanotechnology in sustainable water management by providing special qualities and benefits for solving particular problems related to water pollution and contamination.

6. Advantages of Green Chemistry over Nanotechnology

There are many benefits associated with green chemistry for society at large as well as the environment. Some of the main advantages are listed below (R. Chen *et al.*, 2021):

- **Diminished Environmental Impact:** The goal of green chemistry is to reduce or completely do away with the usage and production of dangerous materials, which does away with pollution and degrades the environment. Green chemistry works to mitigate the negative consequences of pollution on ecosystems, wildlife, and human health by creating chemical products and processes that are safer and more sustainable by design.
- **Conservation of Resources:** Green chemistry encourages the economical use of energy, water, and raw materials, which lowers resource consumption and waste production. Green

chemistry aids in resource conservation and sustainable resource management by optimizing atom economy and reducing waste materials and byproducts.

- **Healthier Workplaces and goods:** Green chemistry lays an emphasis on designing and producing chemical goods with non-toxic, biodegradable, and environmentally friendly compounds. This contributes to lowering worker, consumer, and community exposure to hazardous substances, improving public health outcomes and creating safer workplaces and cleaner environments.
- **Cost Savings:** By streamlining operations, cutting waste disposal expenses, and lowering the burden of hazardous chemical-related regulatory compliance, green chemistry can save businesses money. Green chemical methods can boost profitability and competitiveness in the market by increasing process efficiency, product quality, and resource use.
- **Innovation and Sustainability:** Green chemistry stimulates the creation of new, ecologically friendly, and sustainable materials, procedures, and technologies. Green chemistry principles can be used into R&D and commercialization processes to help businesses and organizations develop value-added goods and services that satisfy changing consumer demands for environmental responsibility and sustainability.
- **Global Environmental and Social Benefits:** Climate change, air and water pollution, resource depletion, and other major environmental and social issues are just a few of the issues that green chemistry has the ability to solve. Green chemistry supports worldwide efforts to attain environmental sustainability, social justice, and economic success for current and future generations by endorsing sustainable practices and technology.

All things considered, green chemistry provides a comprehensive method of creating and designing chemicals that takes into account social, economic, and environmental factors. Governments, corporations, and individuals may all work together to create a more resilient and sustainable future by adopting green chemistry practices and concepts.

7. Nanotechnology's advantages over green chemistry

Numerous industries, including medical, electronics, energy, materials research, and environmental remediation, can benefit greatly from nanotechnology. The following are some of the main benefits (Liao *et al.*, 2006):

- **Better Material Characteristics**: Because of their small size and high molecular weight, nanomaterials have distinct mechanical, chemical, and physical properties from their bulk counterparts.
- **Miniaturization:** Smaller, lighter, and more effective goods are the result of the miniaturization of systems and devices made possible by nanotechnology. To increase performance, functionality, and mobility, nanoscale components—such as nano electronics,

nanosensors, and nano machines—can be included into a variety of systems and devices, such as consumer goods, medical equipment, and electronics.

- **Advanced Drug Delivery:** By making it possible to create therapeutic agents with targeted and controlled release systems, nanotechnology has completely changed the way drugs are delivered. Drugs can be delivered to particular cells or tissues using nanoparticles, liposomes, and nanofibers, which lowers side effects and increases therapeutic effectiveness. Drug delivery methods based on nanotechnology also present prospects for customized medicine and the treatment of illnesses like neurological disorders and cancer.
- **Diagnostic instruments:** The development of sophisticated imaging methods and diagnostic instruments for illness monitoring and detection is a result of nanotechnology. High-resolution imaging and sensitive detection of biomarkers, pathogens, and disease-related chemicals are made possible by nanoparticle-based contrast agents, quantum dots, and nanosensors. This allows for early diagnosis and individualized treatment plans.
- **Energy Efficiency:** The advancement of renewable energy sources and energy efficiency are greatly aided by nanotechnology. By boosting light absorption, charge transport, and catalytic activity, nanomaterials including quantum dots, nanowires, and nanostructured surfaces improve the efficiency of fuel cells, solar cells, and energy storage devices. The production of strong, lightweight materials for energy-efficient building and transportation is another benefit of nanotechnology.
- **Environmental Remediation:** Innovative approaches to pollution control and environmental remediation are provided by nanotechnology. Pollutants from the air, water, and soil, such as heavy metals, organic contaminants, and emerging pollutants, can be captured and broken down by nanomaterials such nanoparticles, nanocomposites, and nanofiltration membranes. Remedial technologies based on nanotechnology offer sustainable and affordable solutions to environmental problems while preserving human health.
- **Water Purification:** By creating cutting-edge water purification technologies, nanotechnology has the potential to provide access to clean water. Water that has been treated with nanomaterial-based filtration membranes, adsorbents, and photocatalysts is safe to drink and use in agriculture. Water treatment systems based on nanotechnology provide scalable and affordable solutions for global water scarcity and contamination problems.

All things considered, nanotechnology presents enormous promise for resolving some of the most important issues facing society, such as energy, healthcare, and environmental sustainability. Researchers and creative thinkers can provide novel solutions that enhance quality of life, advance economic growth, and save the environment for future generations by utilizing the special qualities and powers of nanomaterials.

8. Advancement of Green Chemistry by Nanotechnology

Through the creation of innovative materials, procedures, and technologies that support sustainability and environmental stewardship, nanotechnology significantly advances the objectives of green chemistry. According to Xu *et al.* (2020), here is how green chemistry and nanotechnology interact:

- **The catalytic process**: When used as extremely effective catalysts for chemical reactions, nanomaterials allow for the utilization of gentler reaction conditions, quicker reaction times, and lower energy consumption. Green chemistry places a strong emphasis on the value of catalysis in enhancing process selectivity and efficiency while reducing waste production. Through increasing the recyclability of catalysts, decreasing the requirement for hazardous chemicals, and permitting the use of renewable feedstocks, nanocatalysts can promote greener and more sustainable synthesis pathways.
- **Sustainable Synthesis Pathways:** Nanotechnology provides creative pathways for the synthesis of materials and chemicals that have a smaller negative impact on the environment. Greener synthesis techniques, like microwave-assisted synthesis, electrochemical deposition, and green solvents, can be used to create nanoparticles and nanostructures, which can result in more environmentally friendly production processes. Researchers can create scalable, economical synthesis pathways that reduce resource consumption and waste production by utilizing nanotechnology.
- **Effective Separation and Purification:** By using nanomaterials in these procedures, pollutants and impurities can be eliminated from a variety of streams, such as air, wastewater, and industrial effluents. High selectivity, efficiency, and capacity are provided by nanotechnology-based filtration membranes, adsorbents, and catalytic materials for eliminating pollutants, pathogens, and dangerous chemicals from the environment. Green chemistry highlights how crucial environmentally friendly separation methods are to reducing pollution.
- **Renewable Energy Technologies:** The development of renewable energy technologies, including fuel cells, solar cells, and energy storage systems, is greatly aided by nanotechnology. Quantum dots, carbon nanotubes, and nanostructured electrodes are examples of nanomaterials that improve the performance, stability, and efficiency of energy conversion and storage systems. Green chemistry goals are aligned with nanotechnology, which helps reduce greenhouse gas emissions and reliance on fossil fuels by increasing the efficiency of renewable energy sources.
- **Green Nanomaterial Design:** The creation of environmentally benign nanomaterials with lower toxicity, biodegradability, and eco-friendliness is guided by the concepts of green chemistry. To create nanomaterials with little effect on the environment, researchers use

sustainable precursor materials and green synthesis techniques. Researchers hope to reduce any hazards related to nanotechnology and advance safer and more sustainable applications in a range of industries, such as consumer goods, electronics, and healthcare, by creating green nanomaterials.

- **In general, green chemistry** ideas and practices can be advanced through the use of nanotechnology, which offers flexible tools and solutions that can be applied to create more environmentally friendly and sustainable chemical processes, materials, and technologies. Researchers can address urgent environmental issues while advancing social progress, economic expansion, and environmental sustainability by fusing green chemistry with nanotechnology.
- **Environmental Remediation:** Innovative approaches to pollution control and environmental remediation are provided by nanotechnology. Pollutants from soil, water, and air, such as emerging pollutants, heavy metals, and organic contaminants, can be specifically captured and broken down using nanomaterials. Remediation techniques based on nanotechnology, such as photocatalytic nanoparticles for groundwater remediation and nano zero-valent iron (nZVI).

In general, green chemistry ideas and practices can be advanced through the use of nanotechnology, which offers flexible tools and solutions that can be applied to create more environmentally friendly and sustainable chemical processes, materials, and technologies. Researchers can address urgent environmental issues while advancing social progress, economic expansion, and environmental sustainability by fusing green chemistry with nanotechnology.

The development and deployment of nanotechnology in a sustainable and environmentally friendly manner are guided by core concepts of green chemistry.

1. **Safer Synthesis Techniques:** The principles of green chemistry advocate for the utilization of more sustainable and safe synthesis techniques in the production of nanomaterials. This includes creating ecologically friendly synthesis routes that make use of renewable resources, safe reagents, and solvents that don't harm the environment. Following the guidelines of green chemistry, scientists can create nanomaterials with less of an adverse effect on the environment and less toxicity by using green synthesis techniques.
2. **Lessening of Environmental Footprint:** Green chemistry places a strong emphasis on the necessity of reducing waste production and resource usage in chemical processes. Through the use of green chemistry concepts, scientists can create synthesis methods for nanotechnology that optimize atom economy, limit byproducts, and lower energy consumption. When compared to conventional methods, green nanotechnology processes have a smaller ecological impact and environmental footprint, which promotes environmental stewardship and sustainability.

3. **Safe Handling and Disposal:** Throughout a nanomaterial's life cycle, safe handling and disposal are important aspects of green chemistry. The design of nanomaterials with lower toxicity, biodegradability, and environmental persistence is guided by green chemistry concepts, reducing potential dangers to ecosystems and human health. Through the creation of safe handling, storage, and disposal procedures for nanomaterials, scientists make sure that uses of nanotechnology follow green chemistry guidelines and support worker and environmental safety.
4. **Resource Efficiency:** Green chemistry encourages the design and use of nanomaterials in a way that maximizes their usefulness and minimizes waste. Green chemistry concepts guide the development of nanotechnology-based products and processes that maximize material, energy, and resource efficiency. Green nanotechnology aids in sustainable resource management by lowering resource use and waste production.
5. **Sustainable Applications:** The development of nanotechnology applications that tackle urgent environmental and societal issues, like renewable energy, environmental remediation, and public health, is guided by the concepts of green chemistry. Innovative approaches to pollution control, water purification, healthcare, and renewable energy generation are provided by nanotechnology, which supports the objectives of green chemistry to advance sustainability, environmental protection, and human well-being.
6. **Life Cycle Assessment:** To examine the environmental impact of nanotechnology-related goods and activities over the course of their whole life cycle, green chemistry promotes the use of life cycle assessment, or LCA. The development of more environmentally friendly procedures and technologies is aided by LCA's insights into possible areas for improvement in nanotechnology applications as well as hotspots for environmental protection. By incorporating life cycle assessment (LCA) into nanotechnology research and development, scientists make sure that advancements in this field.

Overall, green chemistry plays a crucial role in guiding the responsible development and application of nanotechnology, ensuring that nanomaterials and nanotechnology processes are designed and utilized in a sustainable and environmentally friendly manner. By integrating green chemistry principles into nanotechnology research, development, and commercialization efforts, researchers and industry professionals can harness the potential of nanotechnology to address global challenges while minimizing environmental impact and maximizing societal benefits.

Limitations of Green Chemistry

Green chemistry has many advantages and prospects, but there are also some restrictions and difficulties that must be overcome. Several of these restrictions consist of:

1. **Technological Difficulties:** It might be difficult to develop environmentally friendly substitutes for traditional chemicals and methods that function just as well. Initiatives

pertaining to green chemistry may face technological obstacles concerning cost-effectiveness, efficiency, and scalability, which will call for creative thinking and research to get over.

2. **Cost Considerations:** Research, development, and infrastructure modifications may need upfront investments when implementing green chemical techniques and technology. Adoption of green chemistry can be hampered by initial investment expenditures, especially for small and medium-sized businesses (SMEs) and resource-constrained industries, even if it can result in long-term cost savings through increased process efficiency, less waste generation, and regulatory compliance.
3. **Regulatory Obstacles:** Diverse jurisdictions may have different certification procedures and regulatory obstacles for green chemical developments. Uncertainty and delays in market adoption may result from regulatory authorities' lack of uniform frameworks for assessing the effects of green alternatives on the environment and human health. These difficulties can be addressed by streamlining regulatory procedures and offering rewards for environmentally friendly innovation.
4. **Supply Chain Considerations:** Obtaining sustainable raw materials, green solvents, and renewable feed stocks may present supply chain difficulties for green chemistry projects. Investing in supply chain logistics, stakeholder involvement, and agricultural infrastructure may be necessary to provide a steady and dependable supply of environmentally friendly alternatives. Overcoming these obstacles can be facilitated by forming alliances with suppliers and encouraging cooperation throughout the supply chain.
5. **Consumer Awareness and Acceptance:** Issues with market demand, consumer awareness, and acceptance may arise for advancements in green chemistry. In order to drive market demand and acceptance, it is imperative to educate customers about the advantages of green products and technology, including less environmental impact, increased health and safety, and enhanced performance. Increasing consumer loyalty and trust in environmentally friendly supply chains can also benefit them.
6. **Technology Trade-offs:** Trade-offs between technology performance and environmental benefits may be present in some green chemistry programs. For instance, substituting green alternatives for conventional chemicals might impact how well a product works, how long it lasts, or whether it works with the infrastructure already in place. Achieving a successful implementation of green chemistry requires striking a balance between technical requirements, market demands, and environmental considerations.
7. **International Cooperation and Standardization:** Green chemistry projects necessitate coordination and cooperation amongst stakeholders from a variety of backgrounds, including business, academia, government, and civil society. Diverse interests, agendas, and

legal frameworks can make it difficult to come to an agreement on green chemistry standards, guidelines, and best practices on a worldwide scale. Global acceptance and use of green chemistry solutions can be aided by fostering information exchange and international cooperation.

Overall, even though green chemistry has a lot of potential to advance environmental stewardship and sustainability, overcoming its limits will require cooperation and creativity from a variety of stakeholders. Green chemistry can fulfill its potential to provide a more resilient and sustainable future for everybody by overcoming these obstacles (Leudjo *et al.*, 2017).

Nanotechnology's Drawbacks

Not with standing its potential, nanotechnology has a number of drawbacks and difficulties that need to be resolved in order to reach its full potential. Among these restrictions are the following (Shahmoradi *et al.*, 2019):

1. **Safety and Health Concerns:** Because of their peculiar characteristics and actions, nanomaterials may be hazardous to the environment and human health. The toxicity, bioaccumulation, and possible environmental permanence of nanoparticles are among the concerns. To reduce the threats that nanotechnology poses to human health and the environment, it is imperative to ensure the safe handling, disposal, and control of nanomaterials.
2. **Regulatory Uncertainty:** Because nanotechnology legislation differ from one country to the next, regulatory frameworks are unclear and inconsistent. Standardized criteria and risk assessment procedures must be established for nanomaterials in order to guarantee regulatory compliance and allay public worries about the effects of nanotechnology on the environment and safety.
3. **Ethical and sociological Implications:** Privacy, security, equity, and social justice are some of the ethical and sociological issues that nanotechnology brings up. Careful thought and ethical consideration are necessary when addressing issues like how nanotechnology affects employment, income inequality, and access to technology. In order to address these ethical and societal ramifications of nanotechnology, it is imperative that responsible governance, transparency, and public participation be promoted.
4. **Scale-up Challenges**: There may be logistical and technical difficulties when transferring nanotechnology techniques from the lab to the industrial level. Optimization and validation are necessary at every scale because variables like production costs, manufacturing scalability, and repeatability may vary in laboratory and industrial settings. Realizing the commercial viability and broad adoption of nanotechnology applications requires overcoming scale-up obstacles.

5. **Environmental Impact:** Energy consumption, resource depletion, and pollution are a few unintentional environmental effects of nanotechnology. Production techniques for nanomaterials, like the synthesis and manufacture of nanoparticles, may need large energy inputs and produce waste streams that worsen the environment. The environmental impact of nanotechnology can be reduced by creating sustainable nanotechnology practices and implementing green chemistry ideas.
6. **Public Perception and Acceptance:** How the general public views nanotechnology affects how society accepts and uses it. Public trust and confidence in nanotechnology applications may be impacted by worries about the safety of nanotechnology, its ethical ramifications, and its possible hazards. Building public trust in nanotechnology and fostering an informed conversation about it require correcting misconceptions, engaging the public, and increasing openness.
7. **Intellectual Property Rights:** Patenting, licensing, and technology transfer are some of the concerns that nanotechnology discoveries bring up in relation to intellectual property rights (IPR). To encourage investment in nanotechnology research and development, it is crucial to strike a balance between the need for innovation and competition and the protection of intellectual property. In the area of nanotechnology, clear and efficient intellectual property rights (IPR) frameworks can promote investment, cooperation, and technology commercialization.

Collaboration and cooperation between stakeholders, such as researchers, legislators, business partners, and civil society, are necessary to address these restrictions. Nanotechnology can realize its potential to address global challenges and improve quality of life in a sustainable and responsible manner by addressing a number of issues, including public perceptions, regulatory uncertainties, ethical implications, health and safety concerns, scale-up challenges, environmental impacts, and intellectual property rights.

Challenges overcome by Nanotechnology

Green chemistry can be improved and supplemented by nanotechnology in a number of ways, which can assist to overcome some of its drawbacks. The following are some ways that nanotechnology can help with the main problems related to green chemistry (Abdullah *et al.*, 2016):

1. **Enhanced Catalysis:** The selectivity and efficiency of green chemical processes can be improved by the special catalytic qualities that nanomaterials have to offer. Researchers can improve reaction rates, decrease energy consumption, and enhance atom economy by designing nanocatalysts with customized surface shapes and compositions through the application of nanotechnology. By facilitating the use of renewable resources, non-toxic reagents, and solvent-free conditions, nanocatalysts can enable cleaner and more

sustainable synthesis methods while overcoming some of the technical obstacles associated with green chemistry.

2. **Advanced Synthesis Techniques:** Thanks to nanotechnology, green chemicals and materials may be produced using sophisticated synthesis techniques. The synthesis routes based on nanomaterials, like electrochemical deposition, sonochemistry, and microwave-assisted synthesis, have several benefits, like shorter reaction times, increased yields, and better reaction control. These green synthesis techniques address the cost and scalability issues related to green chemistry projects by making use of sustainable precursors, ecologically friendly solvents, and energy-efficient processes.
3. **Customized Properties of Materials:** Nanotechnology enables the engineering and construction of nanomaterials with customized features and attributes to satisfy particular green chemistry standards. In order to maximize their effectiveness in green chemical processes including adsorption, catalysis, and separation, nanomaterials can be precisely adjusted in terms of size, shape, surface chemistry, and porosity. Researchers can get around restrictions on material performance and compatibility with green chemistry principles by tailoring the characteristics of nanomaterials.
4. **Sustainable Applications:** By creating green nanomaterials and using nanotechnology to power applications, nanotechnology offers creative answers to pressing social and environmental issues. Water purification, air filtration, renewable energy production, and sustainable agriculture are just a few of the green chemistry applications that can benefit from the use of nanomaterials like nanoparticles, nanocomposites, and nanofibers. Through the incorporation of nanotechnology into green chemistry endeavors, scientists can create economically viable and expandable remedies that advance resource efficiency and environmental sustainability.
5. **Safety and Environmental Monitoring:** Throughout their life cycle, green chemicals and nanomaterials can have their safety and environmental impact evaluated using methods and instruments made possible by nanotechnology. Real-time detection and characterization of nanomaterials in environmental matrices is made possible by sensors, analytical techniques, and monitoring tools based on nanotechnology. This aids in the identification of possible dangers and the reduction of unfavorable consequences. In line with the principles of green chemistry, researchers can guarantee the safe and responsible application of green chemicals and nanomaterials by integrating nanotechnology into environmental monitoring and risk assessment procedures.
6. Ultimately, by addressing some of the drawbacks and difficulties of green chemistry, nanotechnology presents encouraging prospects to enrich and supplement the concepts of the field. In a world that is changing quickly, researchers can create novel solutions that

advance sustainability, environmental stewardship, and human well-being by utilizing the special qualities and capacities of nanomaterials.

Challenges overcome by Green Chemistry

Principles of green chemistry provide complementary ways to deal with some of the drawbacks and difficulties of nanotechnology. According to Roujeni *et al.* (2018), green chemistry has the potential to assist circumvent some of the drawbacks of nanotechnology.

1. **1.Safety and Health Issues:** Green chemistry has a strong emphasis on creating safer substances and procedures, which can lessen the threats that nanomaterials pose to human health and safety. Researchers can prioritize the use of non-toxic precursors, reduce the production of hazardous byproducts, and design nanomaterials with lower toxicity and environmental persistence by integrating green chemistry principles into nanotechnology research and development.
2. **2.Environmental Impact:** By encouraging the use of sustainable materials and procedures, green chemistry lessens the negative effects of nanotechnology applications on the environment. By using green synthesis techniques, such as solvent-free procedures, bioinspired methodologies, and renewable feed stocks, researchers can reduce the amount of energy, resources, and trash produced during the manufacture of nanomaterials. In order to guide the development of more sustainable practices, green chemistry also promotes the use of life cycle assessment, or LCA, to examine the environmental impact of nanotechnology products and processes.
3. **Regulatory Compliance:** The concepts of green chemistry offer a framework for handling legal requirements and guaranteeing adherence to environmental, health, and safety laws. Through the application of green chemistry concepts in the creation of nanomaterials and nanotechnology applications, researchers may anticipate and address anticipated regulatory concerns, thereby enabling regulatory approval and commercial acceptability. Additionally, green chemistry encourages accountability, openness, and stakeholder participation in the creation and marketing of nanotechnology-based goods.
4. **Resource Efficiency:** The concepts of green chemistry encourage the design and use of nanomaterials in a resource-efficient manner, optimizing their functionality while reducing waste and resource consumption. Researchers can increase the yield and efficiency of nanomaterial synthesis while lowering the amount of energy and raw materials required by adjusting reaction conditions, catalysts, and process parameters. In order to further improve resource efficiency and sustainability, green chemistry also promotes the use of renewable feedstocks and green solvents in nanotechnology applications.
5. **Ethical and Societal Implications:** The concepts of green chemistry take into account ethical issues as well as societal ramifications, encouraging responsible innovation and

technological advancement. Researchers can address societal concerns, equity issues, and public perceptions connected to nanotechnology applications by including ethical frameworks, risk assessment procedures, and stakeholder engagement tactics into nanotechnology research and development. Green chemistry facilitates responsible governance of nanotechnology and ethical decision-making by encouraging interdisciplinary collaboration and discourse among scientists, policymakers, industry stakeholders, and civil society.

In general, green chemistry provides a comprehensive strategy to tackle the drawbacks and difficulties associated with nanotechnology, encouraging the creation of safer, more environmentally friendly, and socially conscious nanotechnology solutions that will benefit both people and the environment. Researchers may fully achieve the potential of nanotechnology while limiting its risks and optimizing its advantages by incorporating green chemistry concepts into nanotechnology research, development, and commercialization initiatives.

Summary and Conclusion:

To sum up, nanotechnology is vital to the advancement of green chemistry practices and concepts since it helps provide environmentally friendly and sustainable solutions for a variety of applications. Researchers can address some of the drawbacks and difficulties with conventional chemical processes and materials by utilizing the special qualities and powers of nanomaterials. This approach also aligns with the objectives of green chemistry, which support resource efficiency, environmental stewardship, and sustainability.

Designing and creating nanoparticles with specialized properties and functions to satisfy certain green chemistry criteria is made possible by nanotechnology. For green chemical processes, nanomaterials function as extremely effective catalysts, adsorbents, and membranes that promote cleaner synthesis routes, lower energy consumption, and less waste production. Advanced synthesis methods that use non-toxic chemicals, ecologically friendly solvents, and renewable resources, such as green synthesis routes and sustainable fabrication procedures, are also made possible by nanotechnology.

Furthermore, by optimizing the performance and use of energy, water, and raw materials in chemical processes, nanotechnology helps to save and maximize resources. The creation of strong, lightweight materials for energy-efficient uses like building, packing, and transportation is made possible by nanomaterials. Resource management techniques including water recycling, energy harvesting, and waste reduction are optimized by sensors and monitoring systems based on nanotechnology, resulting in more resource-efficient and sustainable operations.

Furthermore, throughout their life cycle, green chemicals and nanomaterials can have their safety and environmental impact evaluated using methods and instruments made possible by nanotechnology. Real-time detection and characterization of nanomaterials in environmental matrices is made possible by sensors, analytical techniques, and monitoring tools based on nanotechnology. This aids in the identification of possible dangers and the reduction of unfavorable consequences. According to the principles of green chemistry, researchers guarantee the safe and responsible use of green chemicals and nanomaterials by integrating nanotechnology into environmental monitoring and risk assessment procedures.

In summary, green chemistry ideas and practices can be advanced with the help of nanotechnology, which makes it easier to create novel solutions that advance sustainability, environmental stewardship, and human well-being. Researchers, businesses, and policymakers can address global issues like pollution, resource depletion, and climate change by incorporating nanotechnology into green chemistry initiatives. At the same time, they can fully realize the potential of nanotechnology to build a more resilient and sustainable future for all.

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HISTORY OF NANOTECHNOLOGY

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Abstract:

This chapter examines the history of nanotechnology, tracing its roots back to ancient alchemy and the search for the philosopher's stone. It examines the emergence of nanotechnology as a science and traces its development from microscopic research in the Renaissance to the emergence of quantum mechanics in the 20th century. Landmarks such as the invention of the scanning electron microscope (STM) and the discovery of fullerenes paved the way for control of matter at the atomic and molecular level. The integration of physics, chemistry, biology, and engineering fosters collaborative collaboration and creates a valuable opportunity for innovation. The social impacts of nanotechnology are explored, touching on ethical considerations, environmental impacts, and the integration of nanotechnology with other emerging technologies such as artificial intelligence and biotechnology. The summary concludes by looking to the future, considering possible nanotechnology advances that could define medicine, energy, information, and informatics. He emphasized the need for responsible governance, ethical governance and international cooperation to harness the enormous potential of nanotechnology for the benefit of humanity. Nanoscience and nanotechnology are the study and use of small objects and are also used in other sciences such as chemistry, biology, physics, information science and engineering.

Meaning of Nanoscience and Nanotechnology

The name "Nano" refers to the Greek prefix meaning "dwarf" or something small, one thousandth of a meter (10-9 m). We must distinguish between nanoscience and nanotechnology.

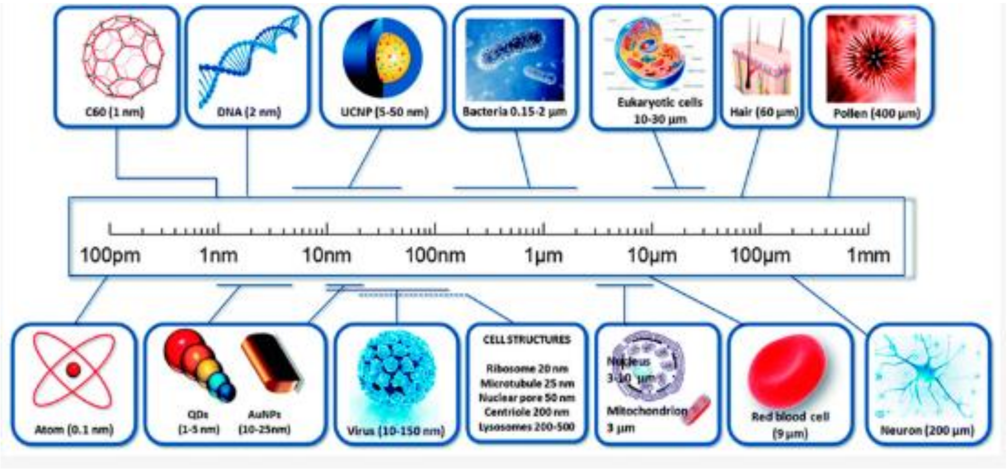

Fig. 1: Nanomaterial size comparison

Nanoscience is the technology of studying structures and molecules at the nanoscale between 1 and 100 nanometers and using them for practical applications such as materials called nanotechnology. For comparison, we should know that the thickness of a human hair is 60,000 nm and the radius of the DNA double helix is â€ ‹ â€ ‹ 1 nm (Figure 1). The development of nanoscience dates back to B.C., when scientists addressed the question of whether matter was continuous and therefore could be divided into infinitely smaller parts, or whether it consisted of small, indivisible and indestructible particles. It can be traced back to the Greeks and Democritus in the 5th century.

Nanotechnology is one of the most promising technologies of the 21st century. It is the ability to translate nanoscience theories into practical applications by observing, measuring, controlling, combining, controlling, and creating problems at the nanoscale. The US National Nanotechnology Initiative (NNI) defines nanotechnology as "the science, engineering, and technology at the nanometer scale (1 to 100 nm) of unique phenomena that lead to new applications in many types, including chemistry, physics, and biology." This definition shows that nanotechnology has two aspects. The first problem is the problem of controlling their shape and size at the nanometer scale. The second problem is about innovation: Nanotechnology has to deal with small things in a way that takes advantage of things on the nanometer scale.

We must distinguish between nanoscience and nanotechnology. Nanoscience is the combination of physics, information science, and biology and studies the manipulation of information at the atomic and molecular scale. There are some publications describing the history of nanoscience and technology, but there are no publications showing the development of nanoscience and technology from the beginning to now. Therefore, it is very important to explain the important events in nanoscience and technology studies and understand the development of nanoscience and technology in this field.

History of Nanotechnology

Nanoparticles and structures were used by the Romans in the early fourth century AD, representing one of the best examples of nanotechnology in the ancient world. The Lycurgus Cup in the British Museum represents one of the greatest achievements of the ancient glass industry. It is the oldest example of dichroic glass. Dichroic glass describes two types of glass that change color under certain lighting conditions.

This means that the glass has two different colors: when the glass is exposed to direct light, it appears green, and when light reflects off the glass, it appears red-red (2)

In 1990, researchers analyzed glass using transmission electron microscopy (TEM) to explain the phenomenon of dichroism [11].The visible dichroism (two colors) is due to the presence of nanoparticles with a diameter of 50-100 nm. X-ray analysis showed that the nanoparticles were a silver-gold (Ag-Au) alloy, with an Ag: Au ratio of approximately 7:3 and

10% copper (Cu) dispersed in the glass matrix. Au nanoparticles produce a red color due to the absorption of light (520 nm). The red-violet color results from absorption by larger particles, while the green color results from scattering of light by colloidal dispersions of silver nanoparticles with size >40 nm. The Lycurgus cup is considered one of the oldest synthetic objects.

Fig. 2: Lycurgus vessel. The glass appears green in reflected light (A) and red-violet in transmitted light (B)

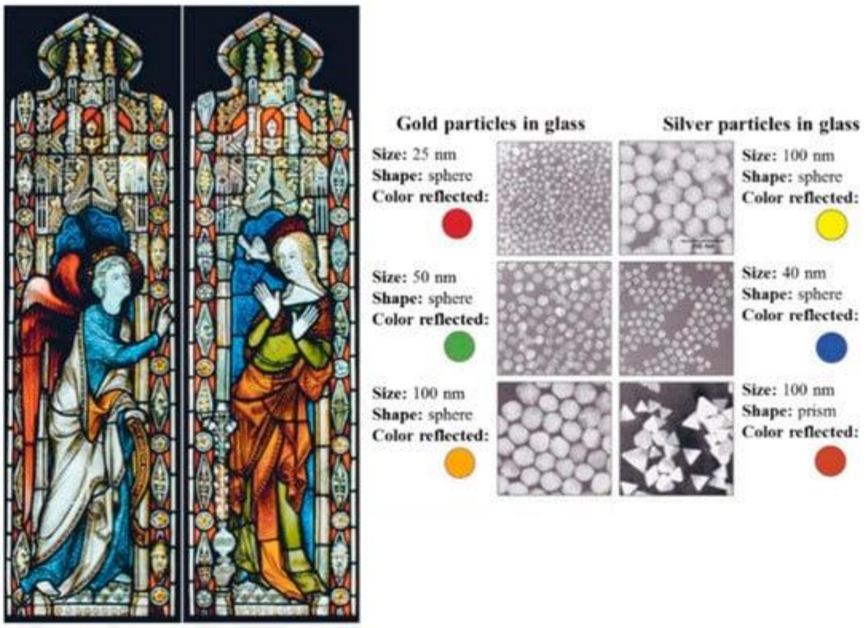

Fig. 3: Shows an example of the effect of different nanoparticles on a stained glass window

Shiny, sparkling "brilliant" ceramic glazes used in the Islamic world and later in Europe between the 9th and 17th centuries contain silver or copper (Cu) or other nanoparticles [15]. In the 16th century, Italians also used nanoparticles to create Renaissance pottery. These colors and materials have been consciously developed over centuries. But medieval artists and forgers did not know the reason for these wonders.

In 1857, Michael Faraday studied the preparation and properties of "ruby" gold colloidal suspensions. Their unique optical and electrical properties make them the most interesting nanoparticles. Faraday showed that gold nanoparticles could form solutions of different colors under certain light conditions.

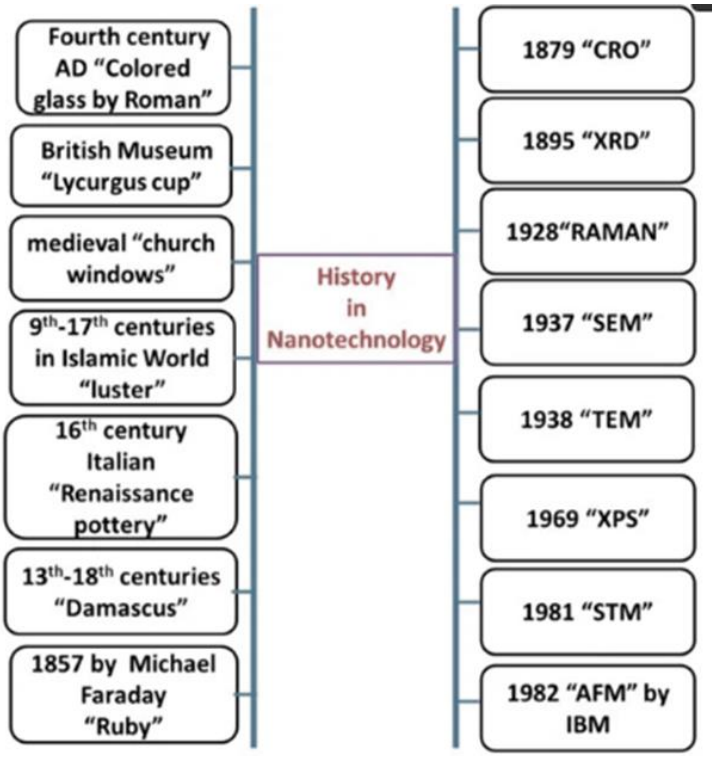

Fig. 4: Developments in Nanotechnology

In other words, the history of nanotechnology is fascinating; marked by major discoveries, developments, and breakthroughs. Here's a brief summary:

- 1959: Richard Feynman's Vision: The concept of nanotechnology was first proposed by physicist Richard Feynman in his famous lecture "There's More Room Underneath", where he discussed the possibility of controlling individual atoms and molecules.
- 1981: Scanning tunneling microscope (STM): Gerd Binnig and Heinrich Rohrer's invention allowed scientists to see and manipulate individual atoms on the surface. This development lays the foundation for nanotechnology, providing tools to study and control problems at the nanometer scale.
- 1985: Discovery of Fullerenes: Scientists Harry Kroto, Richard Smalley, and Robert Curl discovered fullerenes, a new type of carbon monoxide composed of hollow spheres or tubes. This discovery expands the possibilities of nanotechnology as fullerenes exhibit unique properties and potential applications.

- 1986: The term nanotechnology is coined: The term "nanotechnology" was coined by Japanese scientist Norio Taniguchi to describe the use of objects on the nanometer scale (usually between 1 and 100 nanometers).
- 1991: Development of Carbon Nanotubes: Sumio Iijima discovered carbon nanotubes, cylindrical carbon molecules with extraordinary strength and electrical conductivity. Carbon nanotubes have emerged as one of the best materials for many applications such as electronics, information science, and medicine.
- 1990s to early 2000s: Growth: During this period, nanotechnology research experienced rapid growth and advancement in many fields, including nanoelectronics, nanomaterials, nanomedicine, and nanobiotechnology. Governments and businesses around the world are beginning to invest heavily in nanotechnology research and development.
- 2000s–Present: Applications and Markets: Nanotechnology is widely used in industries such as electronics, medicine, electronics, electronics, and environmental remediation.Some important applications include nanoelectronics (e.g., smaller, more efficient electronic devices), nanomedicine (e.g., targeted drug delivery and diagnostics), and nanomaterials (e.g., stronger, lighter materials).Products incorporating nanotechnology are becoming more common, from electronics to medical devices.

Scope of Nanotechnology

It has many applications in the next generation. It is the third most developing field compared to IT and the Internet. In India, Bangalore and Chennai are IT and pharmaceutical hubs. The Government of India has launched various funding agencies such as Nanoscience and Nanotechnology Initiatives and the Ministry of Science and Technology.

Nanotechnology opens up an almost limitless range of research activities. Nanotechnology is experiencing an exciting period, especially in medicine. New diagnostic methods and treatments promise a wide development potential. For example, new drugs can be developed. Encouraged by the small increase in the electronics industry, interdisciplinary research is working on nanorobots. The current structure needs to extend below the size of blood cells and be able to move inside the human body. These nanorobots can carry medicines and deliver them, especially to medical facilities.

The development of long fibers that can be implanted into the human body will be the next advancement in minimally invasive surgery. Medicines can be used specifically as tissues.

Conventional mechanical and plant engineering also hopes to benefit from new materials that offer better properties when constructed and used. For this reason, rotors of wind turbines are now designed with special coatings that have a positive effect on performance.

While new systems are being developed to meet previously untapped energy needs, the focus is on energy production and storage. New ideas for electricity generation, such as temperature or air movement, combined with the increased capacity of storage media promise to make greater use of existing energy in this case.

The food industry is working on foods that have a longer shelf life due to nanoparticles, for example, or that differ in the home oven depending on their temperature. In agriculture, nanotechnology is also being used to create biological plant protection.

According to research conducted in Sweden and England, nanotechnology is seen as a promising technology in the construction industry. More importantly, its impact on real estate is very important. The construction industry is thought to be one of the main sectors affected by nanotechnology. A number of research and development activities are currently ongoing to implement many of the nanotechnological developments relevant to the construction industry. Venture capitalists and companies have made significant investments to unlock the potential for innovation through the use of nanotechnology. Through analysis of the European Commission's capability, major funds were allocated in 2002 to initiate the study GMA1-2002-72160 (NANOCONEX).

Nanotechnology is considered an important application for advancement in the field of civil engineering. The application of civil engineering in the construction portfolio is very important.

Nanotechnology is also used in water purification. Nanotechnology can also improve water quality and availability. Water can be reused using advanced techniques and materials.

The salinity of the water will also decrease. With the use of nanotechnology, carbon fiber reinforced plastics have also been developed. Because they are light, they do not show good electrical properties. Plastic solar cells can also be used to produce solar energy much cheaper than traditional silicon semiconductors. These batteries can be used to save energy and are environmentally friendly as they reduce carbon emissions. Almost all developed countries are trying to use LED lighting instead of traditional lighting. Many smart materials are created using nanotechnology. Smart materials can be affected by external stimuli such as temperature, humidity, electric fields, and magnetic fields.

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A REVIEW ON THE IMPORTANCE OF NANOTECHNOLOGY IN HORTICULTURE

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Abstract:

Nanotechnology is emerging as a transformative tool in horticulture, offering innovative solutions to enhance crop productivity, quality, and sustainability. This review highlights the potential applications of nanomaterials and nano-based technologies in addressing key challenges such as nutrient management, pest control, soil health improvement, and environmental stress tolerance in horticultural crops. Nano-fertilizers, nano-pesticides, and nano-sensors enable targeted delivery and real-time monitoring, while nanomaterials like nano-clays and nano-silica enhance soil fertility and structure. Furthermore, nanotechnology facilitates targeted genetic improvement of crops, enhancing yield, nutritional quality, and disease resistance.

Keywords: Nanotechnology, Nanomaterials, Nano-sensors, Horticulture.

Introduction:

Nanotechnology, a rapidly emerging and advancing field of science and technology, involves the manipulation of materials at the nanoscale, typically ranging from 1 to 100 nanometers. In recent years, nanotechnology has gained increasing attention and application in horticulture for producing quality planting material, nano fertilizers, improving nutrition of plant, nano sensors for monitoring plant health, sensors to detectthe quality of soil and water, nano pesticides for disease and pest management and even hitech packaging for enhancing the shelf-life. Horticulture, the science and art of cultivating fruits, vegetables, flowers, and ornamental plants, plays a crucial role in global food security, environmental sustainability, and economic development. With the growing challenges posed by climate change, soil degradation, water scarcity, and increasing demand for food, there is an urgent need for innovative solutions to enhance crop productivity, resource efficiency, and environmental resilience. Nanotechnology offers a range of tools and techniques that can address these challenges and revolutionize horticultural practices (Anjali *et al.*, 2012).

Scope of Nanotechnology in Horticulture:

Enhanced Nutrient Uptake and Fertilizer Efficiency:

Nanoparticles can be engineered to encapsulate and deliver nutrients and fertilizers directly to plant roots, enhancing nutrient uptake efficiency. This targeted delivery system can reduce nutrient losses through leaching and volatilization, thereby improving fertilizer efficiency and reducing environmental pollution (Barhoumi *et al.*, 2015).

Controlled Release of Pesticides and Plant Growth Regulators:

Nanotechnology enables the development of nano-formulations of pesticides and plant growth regulators that can be released in a controlled manner, providing prolonged protection against pests and diseases while minimizing the negative impacts on beneficial organisms and the environment (Curtis *et al.*, 2006).

Improved Water Use Efficiency:

Nanoparticles like nano-hydrogels can enhance soil water retention and reduce water loss through evaporation, thereby improving water use efficiency and drought tolerance in horticultural crops. This is particularly beneficial in regions facing water scarcity and drought conditions.

Soil Health and Structure Enhancement:

Nanomaterials such as nano-clays and nano-silica can improve soil structure, increase nutrient retention, and enhance microbial activity, leading to improved soil fertility and health. Healthy soil is essential for optimal plant growth, root development, and nutrient uptake.

Disease Resistance and Stress Tolerance:

Nanotechnology can be employed to develop nano-formulations of biopesticides, antimicrobial agents, and stress-relieving compounds that can enhance disease resistance and stress tolerance in horticultural crops. This can reduce the reliance on chemical pesticides and fertilizers, promoting environmentally friendly and sustainable farming practices (*Bhattacharyya et al.,* 2009).

Genetic Improvement and Crop Enhancement:

Nanotechnology offers tools and techniques for targeted delivery of genetic material, such as RNA interference and CRISPR-Cas9 systems, to modify and enhance the genetic traits of horticultural crops. This can lead to improved yield, nutritional quality, shelf life, and post-harvest storage of crops.

Quality Enhancement and Nutritional Value:

Nanoparticles can be used to encapsulate and deliver bioactive compounds, vitamins, and antioxidants to horticultural crops, enhancing their nutritional value, flavor, aroma, and overall quality. This can increase consumer acceptance and market value of the produce.

Nanomaterials used in Horticultural Crops:

Nanomaterials have been explored and utilized in various aspects of horticulture to improve crop yield, quality, and sustainability. These nanomaterials, due to their unique physicochemical properties, offer innovative solutions to challenges faced in plant nutrition, pest management, soil health, and environmental stress tolerance (Cynthia, 1998).

Here are some of the commonly used nanomaterials in horticultural crops:

Nano-Fertilizers:

Nano-fertilizers are nano-sized formulations of conventional fertilizers that are designed to enhance nutrient uptake efficiency, reduce nutrient losses, and improve plant growth and yield. Nano-fertilizers can encapsulate nutrients like nitrogen, phosphorus, and potassium, delivering them directly to plant roots and ensuring targeted release over time, thereby reducing environmental pollution and increasing fertilizer efficiency.

Nano-Pesticides:

Nano-formulations of pesticides and insecticides are developed to improve the efficacy, stability, and targeted delivery of active ingredients to pests and pathogens while minimizing negative impacts on beneficial organisms and the environment. Nano-pesticides can provide prolonged protection against pests and diseases, reduce chemical residues in crops, and enhance overall crop health and yield (Zhao, 2019).

Nano-Sensors:

Nano-based sensors are used for real-time monitoring of various parameters related to plant health, soil quality, and environmental conditions. These sensors can detect changes in nutrient levels, moisture content, pH, temperature, and disease presence, allowing for timely interventions, optimized resource management, and improved decision-making in horticultural practices (Servin and White, 2016).

Nano-Materials for Soil Improvement:

Nanomaterials like nano-clays, nano-silica, and nano-hydrogels are used to enhance soil structure, water retention, nutrient availability, and microbial activity. These nanomaterials can improve soil fertility, reduce soil erosion, and enhance root development, leading to improved plant growth, yield, and resilience to environmental stresses such as drought and salinity (Singh and Prasad, 2017).

Nano-Carriers for Controlled Release:

Nano-carriers such as liposomes, nanoparticles, and nanocapsules are used to encapsulate and deliver bioactive compounds, nutrients, and genetic material to horticultural crops. These nano-carriers can protect sensitive molecules from degradation, facilitate targeted delivery to specific plant tissues, and provide controlled release over time, thereby enhancing the bioavailability and efficacy of these compounds in promoting plant growth, stress tolerance, and quality (Khan *et al.,* 2018).

Nanomaterials for Genetic Improvement:

Nanotechnology offers tools and techniques for targeted delivery of genetic material, such as RNA interference (RNAi) and CRISPR-Cas9 systems, to modify and enhance the genetic traits of horticultural crops. This can lead to improved yield, nutritional quality, disease resistance, and post-harvest shelf life of crops (Purohit *et al.,* 2017).

Conclusion:

Nanotechnology, with its innovative and transformative capabilities, holds significant promise for revolutionizing horticultural practices across various domains, from crop nutrition and pest management to soil health and environmental sustainability. The integration of nanomaterials and nano-based technologies in horticulture offers potential benefits such as enhanced nutrient uptake efficiency, improved fertilizer and pesticide delivery systems, real-time monitoring of plant health and environmental conditions, soil structure and fertility enhancement, and targeted genetic improvement of crops.

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NANOTECHNOLOGY AS A BOON FOR MODERN INDIAN AGRICULTURE

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Abstract:

Due to high population in India, the country demands modern agriculture which is directly correlated with nanotechnology to improve crop yield. Our nanotechnology has direct impact on crop yields and quality of soil in sustainable agriculture. Nanotechnology is used in agriculture (or farming) through utilisation of biopesticide, biofertilizer, biological control of plant diseases. Phytopathogen are killed by secretion of siderophores and antibiotics through fungi and bacteria (microbes). Plastic nanoparticles e.g. elgin, lactide, glutamic acid have great impact in agriculture. Silver nanoparticles kill germs also and they also help in plant flourish. Nanocarbons like graphene and fullerene helps in seed germination and also induce the plants growth. Fungicides play an important role in disease control. Fungicide has composition of copper or nickel ferrite nanoparticles play an important role in disease control. Some viruses like tomato, potato, and alfalta mosaic virus diseases are also controlled by these nanoparticles. A phosphate and salt chitosan solution acts as nanophosphorus fertilizers which improve millets and beans crop even in desert. Mycorrhizal fungus and root endophytes help in development of eco friendly agriculture.

Introduction:

The term nanoparticles may be defined as a spherical particle with small size to large surface area (10-500nm) can be applied in the field of medical, industries, food technology and agriculture field with beneficial activities. It has great importance as catalyst in various field. These nanoparticles are synthesised by various means i.e physical, chemical and biological methods. These nanoparticles include, plant growth hormones like siderophore, antibiotics, fungicides, silver nanoparticles etc. Nanoparticles are polymeric particles composed of natural or artificial polymers. Due to their spherical shape and high surface area to volume ratio, these particles have a wide range of potential applications (Berry and Curtis 2003). Nanoparticles are distinguished from micro particles (1-1000 um), fine particles (sized between 100-2500 nm) and Coarse particles (2500-10000 nm) because their smaller size. It derives much different physical or chemical properties like colloidal properties and ultrafast optical effects or electric properties. The production of nanoparticles with specific properties is a branch of nanotechnology. Nanotechnology are being investigated as potential drug delivery system.

Drugs, growth factors or other biomolecules can be conjugated to nanoparticles to aid targeted delivery. Nanoparticles are also studied for possible applications as dietary supplements for delivery of biologically active substances i.e mineral elements (Scognamiglio, 2013; Sekhon, 2014).

Nanotechnology can increase agricultural production and its application include:

1. Nano formulation of agrochemicals for applying pesticides and fertilizers for crop improvement.
2. The application of nanosensors in crop protection for the identification of diseases and residue of agrochemicals.

Some of the main applications of these nanoparticles in agriculture are discussed in the following points:

- i. Role of nanoparticles in crop improvement.
- ii. Nanotechnology used as nanofertilizer.
- iii. Nanotechnology in disease protection as nanopesticides.
- iv. Pathogen detection.
- v. Nanobiosensors in soil-plant system.

i. Nanotechnology in Crop improvement

Due to new challenges in agriculture, nanotechnology played an important role in modern agriculture. The chief aim of application of nanotechnology are to increase crop yield and to increase the crop improvement. Nanotechnology may improve our knowledge in various agricultural field and crops and also helpful in the enhancement of crop yields or nutritional values, as well as in monitoring of environmental conditions and enhancing plants ability to absorb nutrients or pesticides (Tarafdar *et al.*, 2013). The use of nano devices and nano materials could open innovative applications in the field of biotechnology and agriculture. Nanotechnology has great impact on agriculture and crop improvement, which are discussed as follows-

- a) Nanocapsules for delivery of pesticides, fertilizers and to improve the bioavailability of nutraceuticals in standard ingredients.
- b) Nanoparticles are used to deliver DNA to plant i.e targeting genetic engineer DNA.
- c) Nanosensors for monitoring soul condition, crop growth and for the detection of animal and plant pathogens.
- d) Nanoparticles are used to bind selective chemicals and also to remove chemicals or pathogens from food (Yao *et al.*, 2014).

ii. Nanotechnology used as Nanofertilizer

The term nanofertilizer refers to a product that delivers nutrients to crops in one of three ways. The nutrients can be encapsulated inside nanomaterials such as nanotubes or nanoporous materials, coated with a thin protective polymer film or delivered as particles or emulsion of nanoscale dimensions.

Nitrogen is the key nutrients source for food biomass and fertilizers in terms of energy. Nitrogenous fertilizers are the key source for growth and nutrition of the plant between 50 and 70% of the nitrogen applied using conventional fertilizers plant nutrients formulations with dimensions greater than 100 nm is lost owing to leaching in the form of water soluble nitrate, emission of gaseous ammenic and nitrogen, oxides and long term in corporation of mineral nitrogen into soil organic matter by soil microorganisms. Nanofertilizers are one of the most promising solutions or substitutes for conventional fertilizers. These engineered materials are composed of nanoparticles containing macro and micronutrients that are delivered to the plant rhizosphere in a regulated manner (Karthik and Geetha, 2013). These nanofertilizers contain essential minerals and nutrients i.e N, P, K, Fe and Mn and are bonded alone or in combination with nano dimensional absorbents.

The other nanobiofertilizers are as siderophore and secondary metabolites as secreted by pseudomonas sps. when these bacteria grown under iron limiting condition, produces the sidesophores i.e Pyoverdine (Pseudobactin) salicylate and Pyochilin. These sidesophores might give these bacteria a competitive advantage over other rhizosphere microorganisms especially pathogens (Roleto *et al.*, 1999). When growth slows down and cells enter the stationary phase, pseudomonas fluorescent produces a battery of secondary metabolites i.e. hydrogen cyanide (HCN), indole acetic acid (IAA), 2,4- diacetylphloroglucinol (DAPG) Pyoliterin (Plt) and Pyrrolnitrin. In particular, cytochrome oxidase of many organisms is strongly inhibited by cyanide (Way *et al.*, 1988).

The nanoparticles of Au, SiO_2, ZnO and TiO_2 may initiate the development of plants by enhancing elemental uptake and use of nutrients (Khot *et al.*, 2012). The real Impact of nanomaterials on plants depends on their composition, concentration, size, surface charge and physical chemical properties beside the susceptibility of the plant species (Anil, 2024).

Nanoparticles (nanomaterials) act as biofertilizers might have the properties such as crop improvement with eco friendly. The compound of nitrogen and phosphorus have different types of effects on growth and photo toxicity were reported by Shankramma *et al.* (2016), including magnetic nanoparticles and plant growth.

iii. Nanotechnology in Disease Protection as Nanopesticide

Plant growth promoting rhizobacteria (PGPR) are used as nano model organisms to study not only the mechanism of disease suppression but also the ecological impact of introduced plant beneficial bacteria PGPR strains produces secondary metabolites e.g. Siderophores, HCN, IAA, antifungal metabolites, antimicrobial compound, 2-4-diacetylphloro-glucinol (DAPG) which acts as biocontrol agent for diseases and disease causing microbes to protect the plant from diseases (Krauss and Lóper, 1995).

The HCN produced by Pseudomonas fluorescence (PGPR strain) cause growth stimulation or promotion of producer strain but inhibit growth of some fungus, Edward *et al.*, 1998. IAA a plant growth hormone used whose synthesis is induced in the stationary phase in P. fluorescence. Another mechanism by which a biocontrol agent acts to protect plants from pathogens depends on the production of anti fungal metabolites (O' Sillivan and O' Gara, 1992); 2,4- diacltylphloro-glicinol (DAPG) an antimicrobial compound produced by P. fluorescence is also an important factor in the control of black root rot on tobacco (Keel *et al.*, 1990).

iv. Pathogen Detection through Nanotechnology

Typically, identification and typing of bacterial Isolates is done by characterising phenotypic properties. Now a days methods based on genome analysis of organisms are gaining increasing attention. The RFLP (Restriction Fragment Length Polymorphism) analysis may be useful as a genetic typing for bacterial strains. A useful class of bacterial RFLP fingerprinting detects sequence variations within the operons, coding for ribosomal RNAs, which contain highly conserved as well as variable regions. The conserved reasons are used to detect DNA restriction fragments containing RNA genes, whereas the variable reasons provide the basis for the RFLPs (Grimont and Grimont, 1996).

The quantitative PCR technique is the gold standard of pathogen diagnosis: this process amplifies a small amount of genetic material in a simple and simultaneously labels with a fluorescent tag so it can be detected and quantified by a machine known as fluorometer. The significance of this technique is that even small amount of pathogens genetic material can be detected and quantified.

v. Nano Biosensors in Soil-Plant System and Disease Diagnosis

Nano biosensors are portable and sensitive detectors of chemical and biological agents, useful for point of care testing of patients. The sensor may be defined as electronically gated to respond to the binding of a single molecule of a nucleic acid or protein.

Nano biosensors have been used to analyse the fertility, pH, moisture content, mineral concentration, detection of pests and deficiencies of mineral in the soil before the onset of diseases. The nano biosensors involve various nano materials such as nanotubes, nanowires, nanoparticles, nanocrystals and nanocomposites. Network of nano biosensors can estimate the yield and detection of various disease of crops during crops in fields. Recently there are various proposals to associate these nano biosensors with information technology to facilitate the farmers problem. Nano biosensors are promising tool for detecting and diagnosing infectious diseases such as corona virus disease, human immunodeficiency virus and hepatitis (Ayouni *et al.,* 2021; Mieyum *et al.,* 2023).

Conclusion:

Biosensors in which nano structures are used are known as nano biosensors and have high efficiency and sensitivity due to their wide level of sample stabilization. By reducing the size of the biosensors and the need for very small sample sizes that result from the use of nanostructures it is possible to design aggregate biochips. These systems are very important for clinical diagnosis. Diagnostic applications and all the necessary components for sample presentations, sensing and data processing are gathered in them. Biochip technology with the minimum required sample size is suitable for outpatient analysis of patient samples by less skilled personnel and eliminates the need for medical diagnostic laboratories that require extensive equipment and waste of time and money, and the possibility of simultaneous analysis of several analyte in a sample and thus allows accurate and fast diagnosis. In electrochemical biosensors various electrochemical techniques are used to convert the chemical interaction and detect the analyte.

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RECENT TRENDS IN DRUG DELIVERY SYSTEM & ITS ADVANTAGES OVER CONVENTIONAL METHODS

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Abstract:

Nanotechnology has revolutionized drug delivery, offering innovative solutions to improve the treatment of various diseases. This article investigates the uses of Nano drug delivery systems in the treatment of various illnesses and presents a comparativeresearch that highlights their advantages over conventional drug delivery techniques. Nano drug delivery systems prove invaluable in infectious disease management, improving drug solubility, stability, and targeted delivery. They reduce required dosages and minimize systemic side effects. Nano vaccines elicit more potent and specific immune responses against pathogens. In conclusion, Nano drug delivery systems offer significant advantages over traditional drug delivery methods, including enhanced drug targeting, reduced side effects, improved drug stability, and the ability to overcome biological barriers. While these advantages hold great promise, for further drug delivery systems.

Keywords: Nano Drugs, Delivery Systems, Diseases.

Introduction:

The landscape of drug delivery systems has experienced remarkable transformations in recent years, representing a paradigm shift in the field of medicine. This chapter explores the latest trends in drug delivery systems and elucidates their advantages over traditional methods. From targeted delivery to the integration of smart technologies, these innovations are reshaping the way therapeutic agents are administered, with the overarching goal of improving treatment efficacy and patient outcomes.

- ✓ **Targeted Drug Delivery:**
  The advent of targeted drug delivery marks a pivotal advancement in the field. This section delves into the mechanisms employed to precisely target specific cells, tissues, or organs. By minimizing exposure to healthy tissues, targeted drug delivery enhances therapeutic effects while mitigating side effects—a critical development, particularly for drugs with narrow therapeutic indices.
- ✓ **Controlled Release Systems:**
  A significant stride in drug delivery is the development of controlled release systems. This section explores how these systems offer the advantage of sustained and regulated drug

release over an extended period. This not only reduces the frequency of administration but also contributes to maintaining a constant therapeutic concentration, optimizing treatment outcomes.

- ✓ **Personalized Medicine in Drug Delivery:**
  The era of personalized medicine is influencing drug delivery strategies. This section examines how tailoring drug release rates and targeting specific anatomical sites based on individual patient characteristics contribute to more effective and efficient therapeutic outcomes. The customization of treatments aligns with the unique needs of each patient, fostering a new frontier in healthcare.
- ✓ **Improved Bioavailability:**
  Many drugs face challenges related to poor bioavailability. This section explores how modern drug delivery systems address issues such as solubility, stability, and absorption, thereby enhancing bioavailability. By maximizing the percentage of the administered dose that reaches the systemic circulation, these innovations optimize therapeutic effects.
- ✓ **Minimizing Side Effects:**
  A critical advantage of advanced drug delivery systems is the reduction of side effects. This section elucidates how targeted delivery and controlled release contribute to minimizing adverse effects on healthy tissues. This is particularly relevant for drugs with potential toxicities to organs or systems unrelated to the therapeutic target.
- ✓ **Enhanced Patient Compliance:**
  Improving patient compliance is a key goal of recent drug delivery innovations. This section explores how systems requiring less frequent administration, such as long-acting implants or patches, contribute to enhanced patient adherence. This is especially pertinent in the management of chronic conditions where continuous medication is essential.
- ✓ **Non-Invasive Administration Routes:**
  The evolution of drug delivery includes the development of non-invasive routes. This section discusses innovations such as transdermal patches, inhalation, and oral mucosal delivery. These methods not only offer convenience but also reduce the discomfort associated with traditional injection methods, fostering greater patient acceptance.
- ✓ **Nanotechnology in Drug Delivery:**
  Nanoparticles and Nano carriers represent a frontier in drug delivery. This section explores how these technologies improve drug solubility, stability, and bioavailability. Additionally, they enable targeted delivery to specific cells or tissues, showcasing the potential of nanotechnology in advancing therapeutic interventions.
- ✓ **Smart Drug Delivery Systems:**
  The integration of smart technologies is a cutting-edge trend in drug delivery. This section discusses how responsive drug delivery systems may respond to physiological changes in

the body, delivering medications in a regulated way as needed. The potential of these systems to optimize therapeutic effects is discussed, highlighting their role in the future of healthcare.

- ✓ **Advancements in Biologics Delivery:**
  With the rise of biologics, a dedicated exploration of advancements in their delivery is warranted. This section discusses how new delivery systems ensure the stability and targeted delivery of complex molecules such as proteins and gene therapies, paving the way for innovative treatments.

Conventional drug delivery methods refer to the traditional ways in which pharmaceutical compounds are administered to patients. These methods have been in use for a long time and continue to be relevant in various medical contexts. Here's a detailed description of some common conventional drug delivery methods:

These conventional drug delivery methods have been foundational in the field of medicine, providing a range of options for healthcare professionals to administer medications based on the specific needs of patients and the characteristics of the drugs themselves. While these methods continue to be widely utilized, ongoing research and development are exploring more advanced and targeted drug delivery systems to further enhance therapeutic outcomes.

Nanotechnology based drug delivery methods have emerged as a groundbreaking approach to enhance the effectiveness and precision of drug delivery. These methods leverage nanoscale materials and structures to design carriers that can transport therapeutic agents to specific cells or tissues. The advantages of recent nanotechnology based drug delivery methods are extensive and transformative. Here's a detailed exploration of these advantages:

Nanotechnology in medicine and healthcare:

Nano medicine is the term used to refer to the applications of nanotechnologies in medicine and healthcare. Nanomedicine employs nanoscale technology and nano-enabled approaches to prevent, diagnose, monitor, and cure illnesses. Nanotechnologies exhibit significant potential in the field of medicine, including in imaging techniques and diagnostic tools, drug delivery systems, tissue-engineered constructs, implants and pharmaceutical therapeutics, and has advanced treatments of Several disorders, such as cardiovascular disease, cancer, musculoskeletal ailments, mental and neurological diseases, bacterial and viral infections, and diabetes.

Types of nanoparticles:

To far, various nanoparticles and nanomaterials have been studied and authorized for therapeutic usage. The following sections address several typical forms of nanoparticles.

Micelles

Micelles are amphiphilic surfactants composed of lipids and amphiphilic molecules. Under water circumstances, micelles spontaneously aggregate and self-assemble into spherical vesicles with a hydrophilic outer monolayer and a hydrophobic core, making them suitable for incorporating hydrophobic therapeutics. Micelles' unique features allow for increased solubility of hydrophobic medicines, hence enhancing bioavailability. Micelles range in diameter from 10 to 100 nm. Micelles have a variety of uses, including drug administration, imaging, contrast, and therapeutic agents.

Liposomes

Liposomes are spherical vesicles with particle sizes ranging from 30 nm to several microns made out of lipid bilayers. Liposomes can be utilized to deliver hydrophilic therapeutic compounds into the aqueous phase and hydrophobic molecules into the liposomal membrane layer. Liposomes are versatile; their surface properties may be changed with polymers, antibodies, and/or proteins, allowing macromolecular medicines such as nucleic acids and crystalline metals to be incorporated into them. Poly(ethylene glycol) (PEG)ylated liposomal doxorubicin (Doxil®) is the first FDA-approved Nano medication used to treat breast cancer, and it increases the effective drug concentration in malignant effusions without increasing the total dosage.

Dendrimers

Dendrimers are macromolecules composed of branching repeating units that extend from a central core and contain outside functional groups. These functional groups can have anionic, neutral, or cationic terminals and can be employed to change the overall structure as well as the chemical and physical characteristics. Therapeutic compounds can be enclosed within dendrimers or linked to their surface groups, making them extremely bioavailable and biodegradable. Dendrimer conjugates containing saccharides or peptides have been demonstrated to have increased antibacterial, antiprion, and antiviral activities, as well as better solubility and stability upon therapeutic drug. Polyamidoamine dendrimer-DNA complexes (dendriplexes) have been studied as gene delivery vectors, and they show potential for enabling successive gene expression, targeted medication administration, and improving treatment effectiveness. Dendrimers are potential particle systems for biomedical applications, such as imaging and medication administration, because of their transformability.

Carbon nanotubes

Carbon nanotubes are cylindrical molecules made of rolled-up sheets of carbon atoms (graphene). They can be single-walled, multi-walled, or made up of multiple concentrically interconnected nanotubes. Carbon nanotubes have a large exterior surface area, allowing them to reach significantly high drug loading capacities. Furthermore, carbon tubes' distinct optical, mechanical, and electrical features have made them desirable as imaging contrast agents and biological sensors.

Metallic nanoparticles

Metallic nanoparticles consist of iron oxide and gold nanoparticles. Iron oxide nanoparticles are made of a magnetic core (4-5 nm) and hydrophilic polymers like dextran or PEG. In contrast, gold nanoparticles are made up of a gold atom core surrounded by negative reactive groups on the surface, which may be functionalized by adding a monolayer of surface moieties as ligands for active targeting. Metallic nanoparticles have been employed to provide image contrast in laser-based treatments, as well as optical biosensors and drug delivery vehicles.

Quantum dots

Quantum dots (QDs) are fluorescent semiconductor nanocrystals (1-100 nm) with promising biological uses, including medication delivery and cellular imaging. Quantum dots have a shell-core structure, with the core structure commonly consisting of periodic table elements in the II-VI or III-V groups. Quantum dots have been used in medical imaging because of their unique optical qualities and small size, as well as their exceptional brightness and stability.

Revolutionizing Medicine: Applications and Advantages of Nanotechnology in Drug Delivery"

The extensive explanations of numerous nanotechnology applications in medication delivery illustrate the enormous benefits and possible advances that this technology may offer to the medical industry. Here's an overview of the main points for each application.

1. Targeted Drug Delivery:

Advantages:

- Enhanced Efficacy: Precision targeting improves therapeutic outcomes.
- Reduced Side Effects: Minimizes exposure to healthy tissues, mitigating adverse effects.

2. Improved Bioavailability:

Advantages:

- Increased Absorption: Enhances the bioavailability of poorly water-soluble drugs.
- Optimized Pharmacokinetics: Enables better control over drug release and distribution.

3. Controlled Release Systems:

Advantages:

- Reduced Administration Frequency: Prolongs drug release, reducing the need for frequent administrations.
- Steady Therapeutic Levels: Maintains consistent drug concentrations, improving patient compliance.

4. Combination Therapy:

Advantages:

- Synergistic Effects: Enhances therapeutic efficacy through the delivery of multiple drugs.

- Overcoming Resistance: Addresses drug resistance by targeting multiple pathways.

5. Active and Passive Targeting:

Advantages:

- Selective Accumulation: Achieves higher drug concentrations in disease sites.
- Personalized Treatment: Tailors drug delivery based on patient-specific disease characteristics.

6. Intracellular Delivery:

Advantages:

- Access to Intracellular Targets: Delivers drugs to compartments within cells, expanding treatment possibilities.
- Improved Therapeutic Potential: Enhances the efficacy of drugs acting on intracellular pathways.

7. Reduced Toxicity:

Advantages:

- Enhanced Safety Profile: Reduces off-target effects, making nanocarriers suitable for drugs with narrow therapeutic indices.
- Lower Dose Requirements: Achieves therapeutic effects with lower drug doses, minimizing the risk of adverse reactions.

8. Imaging and Diagnostics:

Advantages:

- Real-Time Monitoring: Provides immediate information on drug distribution and therapeutic response.
- Personalized Treatment Monitoring: Allows adjustments to treatment plans based on individual patient responses.

9. Biological Barriers Overcoming:

Advantages:

- Treatment of CNS Disorders: Facilitates drug delivery to the brain for neurological disorder treatment.
- Extended Therapeutic Applications: Expands the range of diseases targeted through nanotechnology.

10. Versatility in Formulations:

Advantages:

- Tailored Characteristics: Formulations can be customized for specific drugs and therapeutic needs.

- Multifunctional Carriers: Allows incorporation of various functionalities, such as targeting ligands and imaging agents.

These advancements collectively contribute to the potential of nanotechnology to revolutionize drug delivery, making treatments more effective, targeted, and personalized.

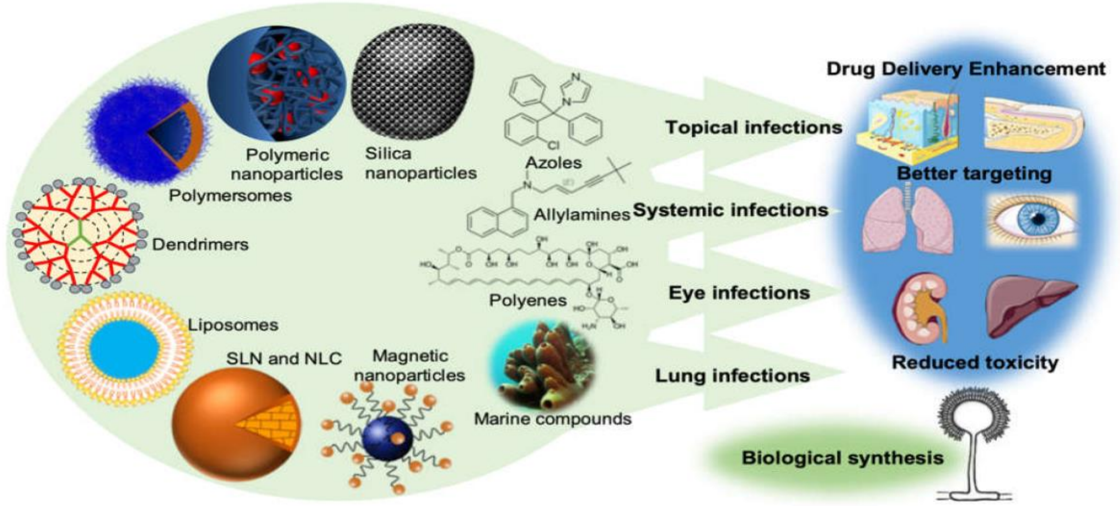

Fig. 1: Drug Delivery Enhancement

In conclusion, recent advancements in nanotechnology based drug delivery methods offer a spectrum of advantages that revolutionize drug administration. The ability to precisely target, control release, and overcome biological barriers opens new avenues for therapeutic interventions, paving the way for more effective and personalized treatments across various medical disciplines. Ongoing research in this field continues to uncover novel strategies and applications, reinforcing the transformative potential of nanotechnology in drug delivery.

Table 1: comparison of recent nanotechnologybased drug delivery methods with conventional drug delivery methods based on their key characteristics

Characteristic	**Nanotechnology Based Drug Delivery**	**Conventional Drug Delivery**
Size of Drug Carrier	Nanoscale particles (e.g., nanoparticles, liposomes) that are often <100 nanometres in size.	Micron scale particles or bulk drug formulations.
Drug Targeting	Enhanced targeting capabilities due to surface modifications and ligand attachment, allowing precise delivery to specific cells or tissues.	Limited targeting, often relying on passive diffusion or systemic distribution.
Drug Solubility	Improved solubility of poorly water-soluble drugs through encapsulation or formulation.	May require additional solubilizing agents or complex formulations.

Bioavailability	Enhanced bioavailability by protecting drugs from degradation and facilitating absorption.	May suffer from low bioavailability due to degradation or poor absorption.
Controlled Release	Provides sustained or controlled release of drugs over time, reducing the need for frequent dosing.	Typically, immediate release formulations, requiring more frequent dosing.
Reduced Side Effects	Lower risk of off target effects and reduced dosage requirements, potentially minimizing side effects.	Increased risk of systemic side effects and potential toxicity.
Drug Stability	Protects drugs from degradation, increasing their stability in various environmental conditions.	May require strict storage conditions to maintain drug stability.
Ease of Administration	May require specialized equipment for synthesis and administration, depending on the Nano system.	Generally simple administration methods, such as oral tablets or injections.
Cost	Often more expensive due to research and development costs and specialized manufacturing.	Typically, more cost-effective in terms of production.
Clinical Applications	Extensively researched for various therapeutic areas, including cancer, infectious diseases, and neurological disorders.	Established and widely used for many drug types and conditions.
Regulatory Approval	May face regulatory challenges due to novel delivery systems, requiring thorough testing and validation.	Established regulatory pathways for approval, based on historical data.
Future Potential	Continues to evolve with potential for personalized medicine and targeted therapies.	May benefit from incremental improvements, but limited in terms of revolutionary advancements.

It's important to note that the choice between nanotechnologybased drug delivery and conventional methods depends on various factors, including the specific drug, the targeted disease, cost considerations, and regulatory requirements. Nanotechnologybased drug delivery holds great promise for improving the effectiveness and safety of drug therapies, particularly for challenging diseases and conditions.

Potential risks of nanotechnologies

Although the new science of nanotechnology has grabbed the public's curiosity, there have been substantial arguments over its safety and potential health hazards related with its use. The use of nanomaterials presents new problems, particularly in anticipating, identifying, and managing possible health hazards. According to research, low-solubility nanoparticles are more harmful and poisonous on a bulk basis than bigger particles. Nanoparticles may also bring concerns such as explosions and catalytic effects. It is vital to highlight that only some nanomaterials are deemed hazardous, notably those with strong reactivity and mobility. Until more detailed investigations prove the dangerous consequences of nanomaterials, their sheer existence in a laboratory setting will not represent a threat to mankind or the environment. The potential dangers of nanotechnology are essentially classified into three categories: health, environment, and society.

Conclusion

There is little doubt that nanotechnologies have improved patients' quality of life by serving as a platform for breakthroughs in the biotechnological, medicinal, and pharmaceutical industries. They have also facilitated healthcare operations, such as diagnosis, therapeutic treatments, and follow-up monitoring. There is a continuing effort to produce and develop innovative nanomaterials that enhance illness diagnostics and therapies in a targeted, accurate, powerful, and long-lasting manner, with the ultimate goal of making medical procedures more customized, cost-effective, and safe. The future of nanotechnology depends on employing the proper nanomaterials while minimizing any potential negative effects. It is vital to highlight that, like any other product, risk assessments are necessary before new nano-based products are certified for clinical and commercial usage in order to reduce any possible dangers to human health and the environment. A comprehensive life cycle review is necessary to determine the long-term viability and safety of their use.

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UNDERSTANDING OF NANOSCIENCE AND NANOTECHNOLOGY

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Abstract:

The field of science and technology is remarkably changed due to the nanomaterials. The important discoveries and development of nanoscience and nanotechnology in various field of science and technology makes life easier. It is very interesting and growing field which includes different structures and devices with novel properties. Nanoscience deals with the synthesis of nanomaterial. Nanomaterial's can be prepared from many materials. Nanotechnology is the engineering and controlling of material at nanometer and making their applicable devices. Nanotechnology entered into almost every field of science and contributed to Chemistry, Physics, material science, information technology, and computer science. The material is called nanomaterial when its size reduced between the range 1-100nm scales. At the nanoscale the physicochemical properties of materials are tremendously changed than that of bulk material. The synthesis of nanomaterials is the focus of nanoscience. Numerous materials can be used to create nanomaterials. The engineering, manipulation, and application of materials at the nanoscale to create useful devices is known as nanotechnology. Nanotechnology has impacted practically every scientific discipline, including computer science, information technology, physics, chemistry, and material science. When a material grows between the 1-100 nm scales, it is referred to as a nanomaterial. Material's physicochemical characteristics undergo significant changes at the nanoscale compared to bulk materials. Notably, the properties such as quantum confinement effect in semiconductor, surface plasmon resonance in metal particles and superparamgnetism in magnetic material are observed. Semiconductor nanoparticles have attracted lot of attention in the recent years in both fundamental research and technical applications, because of their unique size dependent optical and electronic properties arising from quantum confinement effect. Magnetic nanostructured metal and metal oxide have attracted more attention due to their application in various fields such as catalysis, magnetic recording devices drug delivery and hyperthermia. Nanotechnology played very important role in medical field, especially in the treatment of cancer. Nanoscience and nanotechnology opened up the new scientific research into nanoparticles and opened up new opportunities in the world. Nanotechnology is the future of advanced technology.

Keywords: Nanoscience, Nanotechnology, Nanomaterial, Nanoparticle

Introduction:

The word nano comes from ancient Greek prefix dwarf. The meaning of dwarf is very small. A nanometer is one billionth of a meter; it is approximately 100,000 times smaller than a diameter of human hair. Thus, materials that are between 1 and 100 nm in size, at least in one of the three dimensions, are considered nanomaterial [1-2]. Additionally, they must have a spherical surface area per unit volume greater than 60 m^3/cm^3. [3-4].

The study of things and material manipulation at the atomic, molecular, and macromolecular scales where properties differ greatly from those at a bulk scale—is known as nanoscience [5] Different structures are shown in Figure 1.1 to demonstrate the size range. The design, characterization, manufacture, and use of systems, devices, and structures by manipulating size and form at the nanoscale is known as nanotechnology. [6]. Research and development in the broad, multidisciplinary field of nanoscience and nanotechnology is underway. Its global growth has been tremendous in the last few years. It has the ability to completely transform not just the types and range of functions that can be accessed, but also the processes used to manufacture materials and products. It is already having significant commercial impact, and going into the future, that impact is bound to increase. Quantum dots, nanowires, nanocrystals, and nanotubes are examples of individual nanostructures; nanoclusters, nanoarrays, and assemblies are examples of collections of nanostructures. [7, 8]. At a talk given on December 29, 1959, at the American Physical Society meeting at Caltech, renowned scientist Richard Feynman said, "There is Plenty of Room at the Bottom." For the first time, the idea of using atoms as building blocks to make nanoscale items was discussed. Nowadays this lecture is specifically mentioned to as a model of nanotechnology [9].

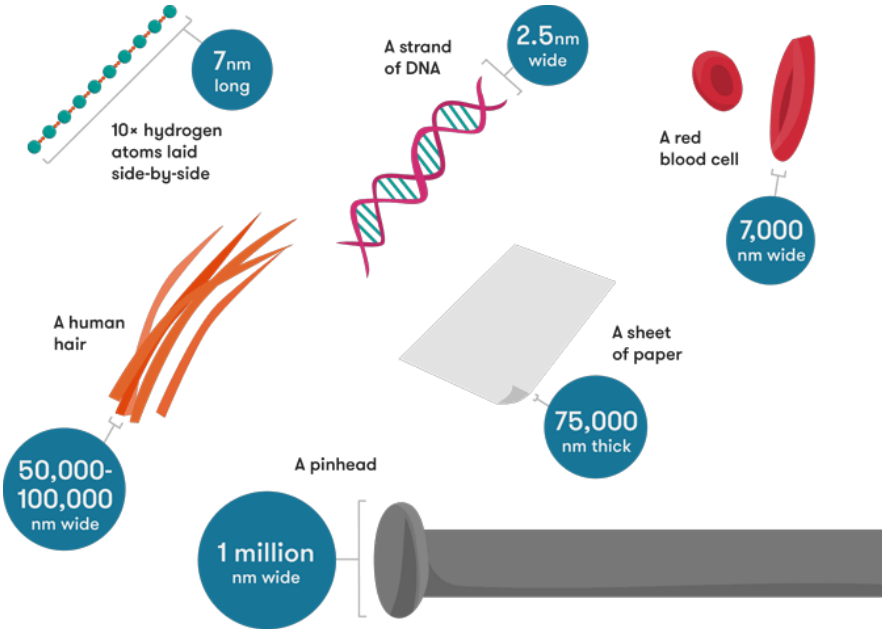


Fig. 1.1: Different sized objects

Why Nanomaterials?

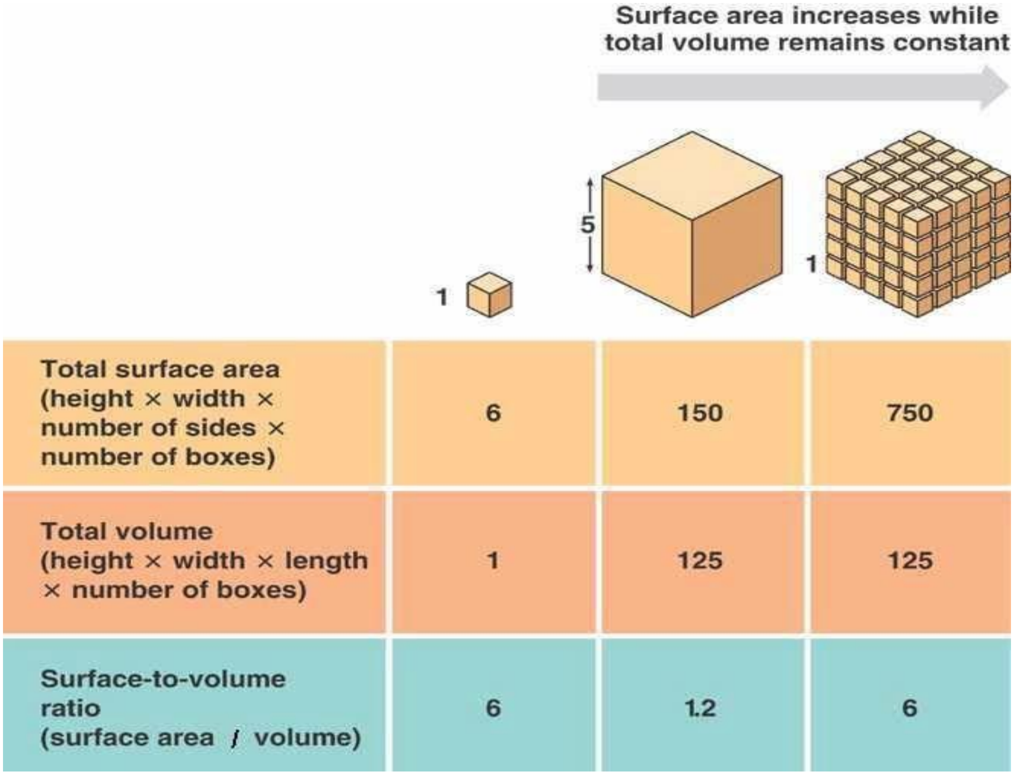
Now a days, nanomaterials are becoming important for the advancement of mankind as a whole. For example, employing green technology that solely uses nanomaterials is the only way to lower the risk of global warming and climate change in the first place [10-12]. Taking into account that 36 research has shown that technology employing nanoparticles is more effective than technology using bulk materials. Tools for the identification and control of the pandemic diseases that are spreading the globe are being developed using nanomaterials. During corona virus pandemic situation nanoparticles were used to identify and treat corona virus disease. Lot of people from all over world killed during this pandemic [13-15]. Nanomaterials are supposed to be used in the future. Nanoscience and nanotechnology played vital role in development of the world. So, it is necessary to understand and have enough knowledge about it. The growth of the globe is significantly influenced by the nanoscience, nanotechnology and ultimately by nanomaterial. Therefore, it is essential that everyone should have sufficient knowledge to understand the nanomaterial [16-19].

Nanomaterial has unique optical, structural, thermal, catalytic, magnetic and electrical properties compared to their respective bulk material [20]. Because of these unique physicochemical properties, they have very wide applications in various fields such as catalysis, medical, agriculture, water purification, energy storage etc. [21-22]. The two key characteristics that distinguish nanomaterials from their bulk counterparts are the quantum confinement effect and the surface to volume ratio. [23]:

i) Surface area and volume ratio
ii) Quantum confinement effect

Surface area and Volume Ratio:

A larger amount of substance comes into contact with the surrounding material as the surface to volume ratio rises. In addition to that the atoms situated at the surface have very few direct neighbors and their number on surface is also increased [24]. This result in better catalysts, since a greater proportion of the material is exposed for potential reaction. The physical and chemical properties of material whether it is bulk or nanomaterial, it depends on its surface properties. Surface is the boundary between material and surrounding environment (i.e solid, liquid or gas). Surface of any material is very important as: it allows a material in out, it can initiate or terminate a chemical reaction; it can allow flow of energy or material across an interface. If a large material is divided into a nanomaterial, the surface area is increased but the total volume of nanomaterial will not change, it will remain same. As particles get smaller, their surface area to volume ratio gets larger. The number of reactive sites in nanomaterial increased with increased surface area. As a result of this nanomaterial shows more chemical reactivity as compared to bulk material [25]. How would surface increases with decrease in size that is explained by taking an example of cube. Figure 1.2 shows the surface areas when cube of 1 m^3 were progressively cut into smaller cube until cube of 1 nm^3 formed.



Total surface area (height × width × number of sides × number of boxes)	6	150	750
Total volume (height × width × length × number of boxes)	1	125	125
Surface-to-volume ratio (surface area / volume)	6	1.2	6

Fig. 1.2 An illustration showing the impact of the nanostructured material's enhanced surface area. The congenital properties of nanomaterials such as the solubility, density, surface tension, catalytic, electrical spectroscopic, and mechanical properties are influenced due to large surface areas in them [26-32].

Quantum Confinement Effect:

In metals and semiconductors, the electronic wave function of conduction electrons is delocalized over the entire particle. Hence, electrons can be characterized as "particles in a box," with the size of the box having a significant impact on the particle's energy and density of state. As the length of the box gets shorter, the distance between the energy levels gets bigger. In terms of amount, En= n2h2/8mL2.

Where n=1, 2, 3… L= Length of box h= Planck’s constant

In the case of semiconductors this simply means that the band gap, starting from the bulk value, increases as the size of the nanocrystal decreases. Since a nano crystal is a small semiconductor box, as the box gets smaller, the band gap between the valence state and the empty state widens. Figure 1.3 gives schematic representation of effect of decrease in size on the band gap of a semiconductor Nanocrystal.

The electrical charge carriers within semiconductor nanocrystals are spatially enclosed due to the quantum confinement effect. This effect allows one to adjust the energy of discrete electronic energy levels and optical transitions using the size and shape of these semiconductor nanocrystals. Thus, it is possible to tune the light emission from these particles through ultra violet, visible, nearinfrared and mid infrared spectral ranges [33-34].

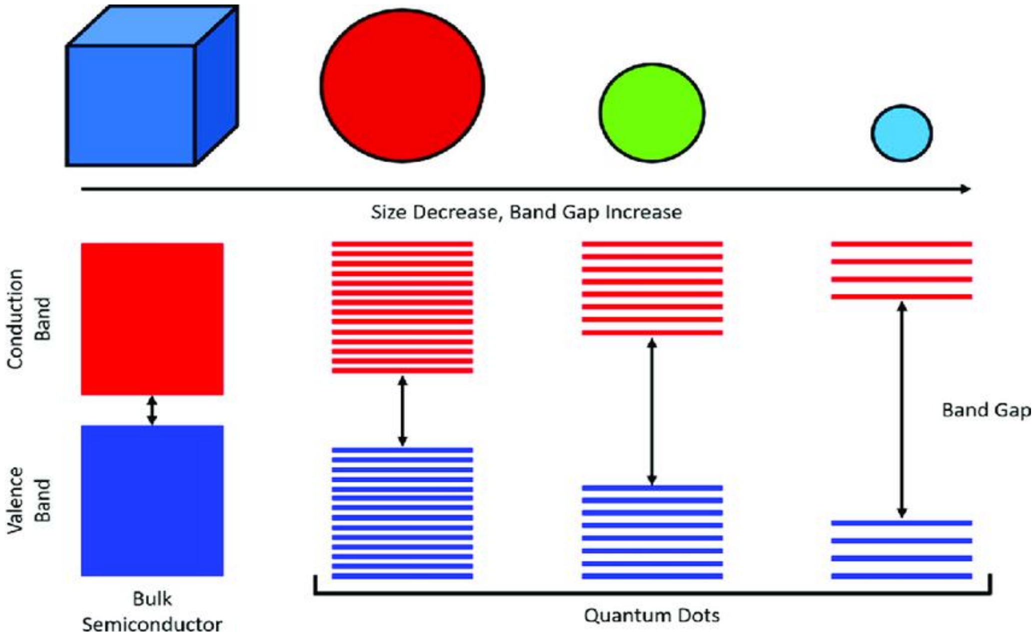


Fig. 1.3 Band gap increases as nanocrystal gets smaller.

Classification of Nanomaterials Based on dimensionality

Nanomaterials are the key element of nanotechnology. Nanomaterials are defined as materials where at least one of their dimensions is in the nanoscale, i.e. smaller than 100 nm [22]. Nanomaterials are categorized into four groups according to their dimensionalities, summarized in Fig. 1.4

Zero-dimensional (0-D)

All the three dimensions of the nanomaterial it is in the nanoscale range. Examples are quantum dots, fullerenes, and nanoparticles.

One-dimensional

One dimension exists outside the nanoscale for the nanomaterials in this class and other two dimensions is in nanoscale range. Examples are nanotubes, nanofibers, nanorods, nanowires, and nanohorns.

Two-dimensional

The nanomaterial in this class have only one dimension in the nanoscale and other two dimensions outside the nanoscale. This class of nanomaterials consists of two dimensions that are outside the nanoscale and one dimension that is inside the nanoscale. Nanofilms and nanosheets are a few examples.

Three-dimensional

The materials in this class are not limited to any particular dimension of the nanoscale. A 3D substance has all dimensions that are larger than 100 nm or outside the nanometer range. [35-40]. Bulk powders, nanoparticle dispersions, nanowire and nanotube bundles, etc. are all included in this class.

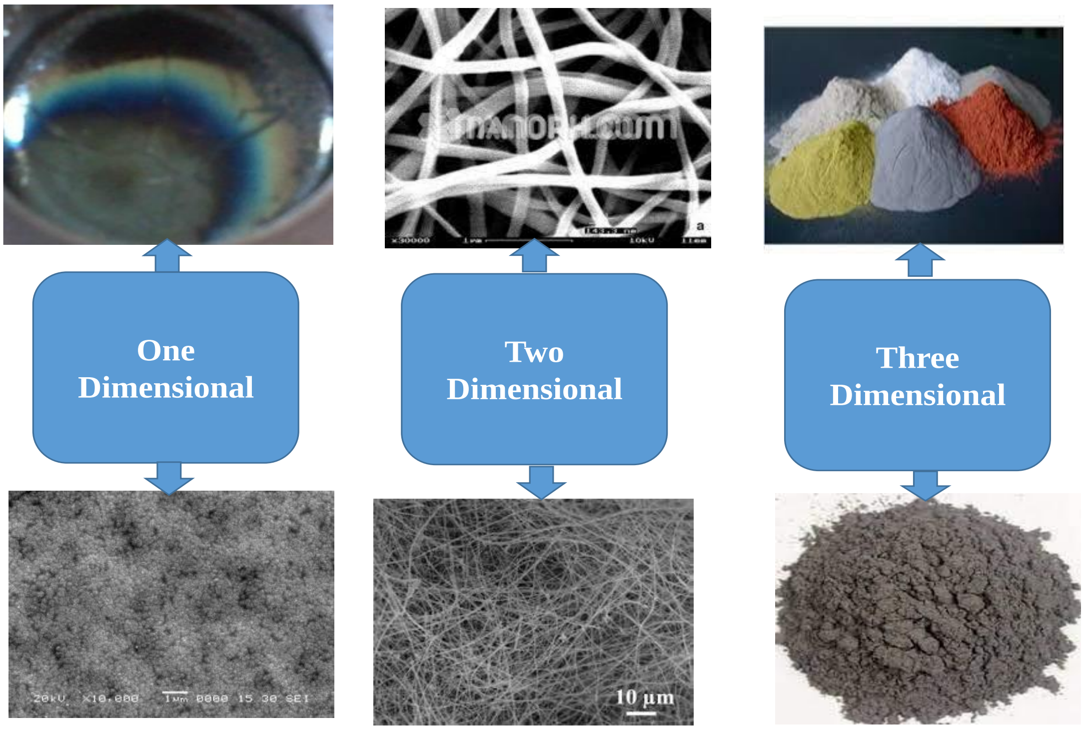


Fig. 1.4: Classification of Nanomaterials based on dimensionality

Classification of Nanomaterials Based on chemical composition:

The four main classes of nanoparticles are organic/dendrimers, inorganic, carbon-based, and composite, based on their structural composition

Organic nanomaterial

The organic nanomaterials are mainly made up of protein, lipid, polymer and organic compounds [41]. These nanoparticles are non-toxic and bio-degradable. For the administration of drugs, organic nanomaterials, particularly three-dimensional dendrimers, are helpful. [42-43].

Inorganic nanomaterial:

The term "inorganic nanoparticles" refers to particles that are devoid of carbon atoms. In simple terms, inorganic nanoparticles are defined as semiconductor nanomaterials based on metal or metal oxide. [43-44]

Carbon based nanomaterial:

The five primary components of carbon that make up carbon-based nanomaterials are carbon nanotubes, graphene, fullerenes, carbon nanofiber, and carbon black. Because of their special electrical conductivity, high strength, electron affinity, optical, thermal, and sorption properties, carbon-based NPs are used in a wide range of applications, such as drug delivery[34], energy storage [35], bioimaging, photovoltaic devices, and environmental sensing applications to monitor microbial ecology or to detect microbial pathogens [45-47].

Composites nanomaterial:

Materials reinforced by nanoparticles are called as nanocomposites. Based on the matrix material, nanocomposites are classified into three categories: polymer matrix composites, metal matrix composites, and ceramic matrix composites. The properties of nanocomposites are improved when nanomaterials are distributed homogeneously into each other [48-50].

Classification of Nanomaterials based on pore dimension:

The diameter and size of the pores in a material can be used to classify it in a useful way because most of its features that are relevant to adsorption and diffusion applications depend on it. Any typical dimension between 1 and 100 nm is indicated by the prefix nano. When material interact with other molecule, their characteristics alter dramatically in this range. The size of molecules that can actually diffuse within is determined by the pore diameter, and the qualities of diffusion and interaction can be inferred from a comparison between the pore size and the guest molecule's dimension. We can anticipate that the molecule-wall interaction and the molecule-molecule interaction will be common if the two dimensions are the same. Conversely, in the event that the guest molecules are smaller than the

Microporous materials (d<2 nm):

Materials with micropores (d<2 nm): These materials have incredibly tiny pores. They often exhibit slow diffusion kinetics and high interaction characteristics, and they can only host tiny molecules like gasses or linear molecules. They are typically utilized in gas storage materials, membrane filters, and gas purification systems. Na-Y and naturally occurring clay materials are two examples.

Mesoporous materials

Materials with pores with a diameter large enough to accommodate large molecules, such as aromatic systems or large polymeric monomers, are known as mesoporous materials (2<d<50 nm). Capillarity frequently contributes to the diffusion kinetics of the adsorbed molecules, causing pore filling after an initial interaction with the pore wall. These systems can be employed as liquid or vapor adsorbing systems or as (2<d<50 nm): nano-reactors for polymerization**.** MCM-41, MCM-48, SBA-15, and carbon mesoporous materials are a few examples.

Capping agents and synthesis of Nanoparticles:

As stabilizers that limit nanoparticle overgrowth and stop them from aggregating or coagulating during colloidal synthesis, capping compounds are crucial. The contact between the nanoparticles and their preparation medium is stabilized by the capping ligands. Capping on specific structural characteristics of nanoparticles their exterior. These stabilizing substances are essential for changing biological activity and the way the environment is seen. Such alterations in the physical-chemical and biological properties of nanoparticles are caused by the steric effects of capping agents deposited on their surface.

The size of nanoparticles and surface chemistry is controlled by using capping agents [51-53]. An amphiphilic molecule with a non-polar hydrocarbon tail and a polar head group makes up the capping agent. Because capping agents are amphiphilic, they improve compatibility and confer functionality with another phase. The non-polar tail of the nanosystem interacts with the surrounding medium while the polar head interacts with the metal atom [54]. A variety of capping agents have been used in the production of nanoparticles, including small ligands, surfactants, polymers, dendrimers, cyclodextrins, and polysaccharides. All of these have been successfully employed as capping agents, exhibiting significant therapeutic and environmental cleansing effects through slight changes in nanoparticles [55].

Stabilization of Nanomaterial:

Polymers, Ligands, Solvent or anions are commonly used to stabilize metal nanoparticles.

Polymers

These are either water soluble polymers or surfactants, which not only protect but also stabilize metal clusters and prevent further agglomeration by controlling the growth of cluster. Polymers selected for this purpose are polyvinyl alcohol, polyvinyl pyrrolidone and polyethylene glycol. Polymers are complex and giant molecules. They are different from low molecular weight compounds and are formed from number of monomer units. The size of polymer molecule is decided by the repeat units present init, denoted as degree of polymerization.

Polyvinyl alcohol (PVA)

This polymer is of the degradation type. This polymer has a high degree of chemical stability and is very hydrophilic and soluble in water. Polyvinyl acetate is hydrolyzed in the presence of an acid or an alkali to produce PVA. The non-polar tail of the nanosystem 25 interacts with the surrounding medium while the polar head interacts with the metal atom. [54].

A variety of capping agents have been used in the production of nanoparticles, including surfactants, small ligands, polymers, dendrimers, cyclodextrins, and polysaccharides. Material's properties change considerably at the nanoscale when they interact with other molecules.

Much attention has been paid to application of PVA in various biomedical fields such as artificial kidney membranes, skin replacement materials and drug delivery system.

Polyvinyl pyrrolidone(PVP)

PVP is prepared from its monomer N-vinyl pyrrolidone. It is available in various degree of polymerization K-30, K-80 an dK-90.

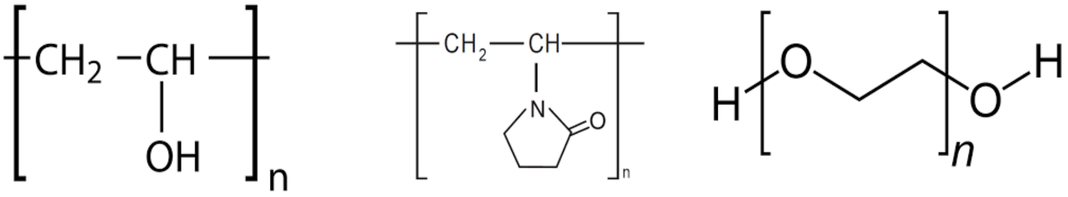
It is used in detergent formation to prevent soil formulation, to prevent soil redeposition on synthetic fibres and as a protective colloid for pigments in cosmetics. PVP may serve as a vehicle for transport of material in the blood stream. The detoxifying effects of PVP have also been observed in studies on various toxins generated in injections such as tetanus and diphtheria.

Ligands Amino acids:

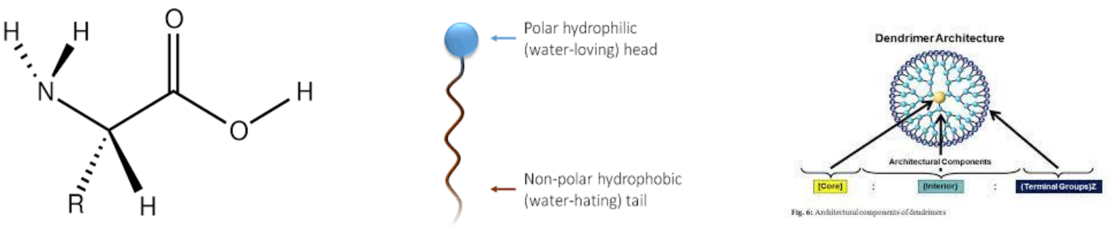
The advantage of using α-AA as capping agents is that a single molecule offers amino and carboxy groups for conjugating essential biomolecules. Additionally, they improve the biocompatibility of the nanoparticles they cap and lessen problems related to their size, biodistribution, contact with immune cells, and inflammatory induction that arise when using them in biomedical applications.

Dendrimer:

Dendrimers, are a biocompatible macromolecule. Because of their special qualities, they are employed as carriers of different molecular configurations. Furthermore, they help to increase the effectiveness and activity of an active medication Because of their distinct structural characteristics, dendritic effect, and polydentate nature, dendrimers have become popular among the various classes of capping agents. It as efficient multifunctional capping agents for metal nanoparticles for use in bioimaging drug delivery and sensor applications [56-61]



Polyvinylalcohol **Polyvinylpyrrolidone** **Polyethylene- glycol**



Aminoacids **Surfactants** **Dendrimers**

Figu. 1.5: Structrues of different capping agent

Bottom-up and top-down methods of synthesis

There are two methods to manufacture nanomaterials, both top-down and bottom-up.

- ✓ According to the bottom-up method, molecules self-assemble into increasingly complex assemblies atom by atom, molecule by molecule, and cluster by cluster from the bottom up
- ✓ In the bottom-up approach, molecular components arrange themselves into more complex assemblies‟ atom-by-atom, molecule-by-molecule, and cluster- by cluster from the bottom. The main driving force behind the bottom-up approach is the reduction in Gibbs free energy. Thus the materials produced are close to their equilibrium state. An example of bottom-up approach is the synthesis of nanoparticles by colloid dispersion.
- ✓ The top-down method uses conventional workshop or micro-fabrication techniques to synthesis and direct nanomaterials to their assemblies. These techniques involve the use of externally controlled tools to cut, mill, and shape material into their desired order. Very tiny objects cannot engineer by this approach.
- ✓ Lithography is the hybrid of bottom-up and top down approach where both theapproaches are used. The growth of thin film is a bottom-up method whereas itching is a top-down method [62]

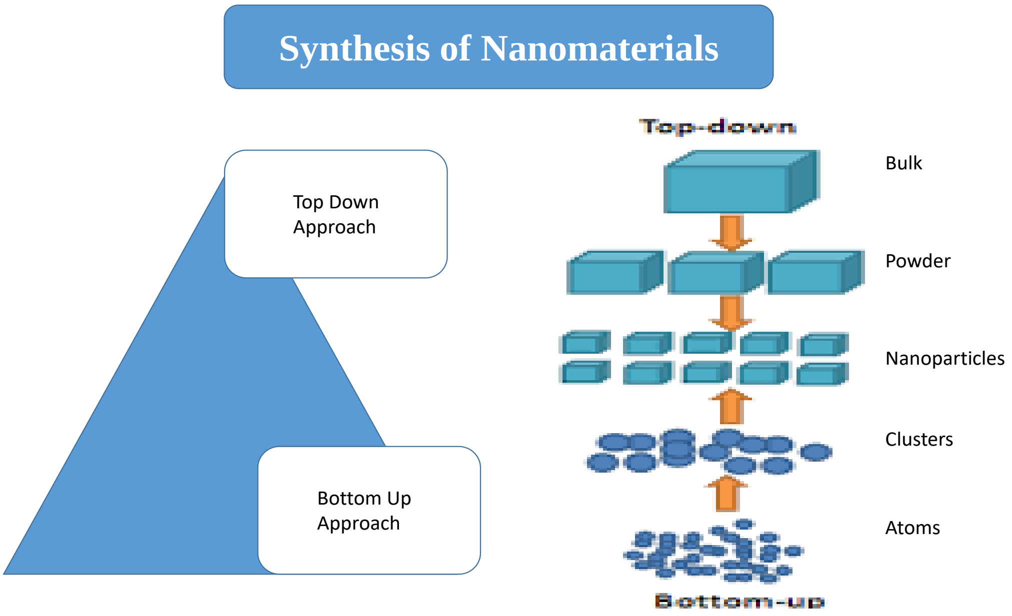


Fig. 1.6: Synthesis of Nanomaterials

Synthetic methods

A short review of some of the methods for obtaining nanometer sized metal oxide; metal oxide ferrite and metal nanoparticles are described here.

Sol –gel Method

The sol gel method is based on inorganic polymerization reactions. The method involves four different steps. Precursor of the metal or non-metal alkoxide hydrolyzes with water or alcohol according to the hydrolysis process and undergoes a water condensation and form a gel. Higher temperature calcinations are needed to decompose the organic precursor and leads to formation of oxide nanoparticles. The size of sol particles depends on the solution composition, P^H, and temperature. The nanoparticles of Co_3O_4, ZnO, CuO synthesized by using this method [63].

The steps in Sol-Gel synthesis are as follow:

- The precursor is an aqueous solution of the metal M alkoxide: M-OR, where R is the alkyl group (e.g. C_2H_5). The reaction of metal alkoxide and water results in formation of sol.
- During polycondensation process gel is formed so it is also called as gelation. The gel formed is have three dimensional structure which is surrounded by solvent molecules. The acidity and alkalinity of solution decides whether formed gel is uniform or non-uniform. If P^H of solution is acidic it forms uniform cross linked gel and if it is alkaline it forms heterogeneous gel with clusters in it.
- Polycondensation is followed by aging of gel. To remove solvent molecules entrapped in gel structure it is dried by heating at 200^0C temperature. After drying macro porous, low density aerogel powdered was obtained. In general calcination of aerogel powder is done in the temperature range of $400\text{-}800^0$C.

Reaction at calcination:

Chemical reduction method

It is one of the most common and facile methods for obtaining metal nanoparticles of desired size and shape. Non spherical particles have been synthesized by chemical method using surfactants or polymers that influence the thermodynamics and kinetics of crystal growth along a certain direction. A number of chemical reducing agents are used. Sodium borohydride, hydrazine hydrate, Hydrogen (H_2), N, N‟dimethylformamide, formaldehyde etc. are generlally used reducing agents for reduction purpose. The control of the particle size is done by changing the ratio of nucleation rate to particle growth. Some solvents such as methanol, ethanol and isopropanol played dual role. They act as a solvent as well as reducing agent. The refluxing of alcohols in the presence of stabilizers yields well dispersed metal nanoparticles [63-64]

Hydrothermal synthesis

Hydrothermal method is useful for the large scale production of nanosized and micro sized particles. The method in which water is used as a solvent is called hydrothermal method. The solvent other than water such as propanol, glycol are used then the method is called solvothermal method. In this method, the chemical precursors are dissolved in suitable solvent and placed in Teflon lined steel vessel also called autoclave. The autoclave can withstand temperature upto 300°C and pressure about 0.01 GPa. General purpose autoclaves are given in Figure 1.13.

Hydrothermal method is a very old method. The method was first used by German scientists Robert Bunsen in 1839 to synthesize crystals of strontium carbonate and barium carbonate. The method was then used by geologists and has become popular amongst nanotechnologies due to the advantages like large yield and novel sizes and shape of nanoparticles obtained using this method.

The method is very useful when the precursor salt is not dissolved at ordinary temperature. It is also advantageous to use the method to grow nanoparticles if the material has a high vapour pressure near its melting point or the crystalline phases are not stable at melting point. Different oxides, sulphides, tungstates and carbonate nanoparticles have been synthesized by hydrothermal method.

Another type of hydrothermal method is known as forced hydrolysis. This particular method uses diluted inorganic metal salt solutions between 10-2 and 10-4 M, and the hydrolysis process is done at temperatures higher than 150°C. The hydrothermal process is used for making ferrite, metal oxide, and magnetic metal nanoparticles like Co and Ni [66–67].

Fig. 1.7: Autoclave with Teflon cylinder used for hydrothermal synthesis

Electrochemical Method:

The pioneering work on electrochemical reduction method to produce metal nanoparticles was developed by Reetz *et al.,* The modifications in electrochemical reduction method can produce highly amorphous metal oxide nanoparticles by simple verification of current density and nature of stabilizing agent [68]. To control the size of particle the parameters temperature, concentration, reducing agent and solvent also played important role.

Sonochemical method

A potent instrument for the creation of metal nanoparticles is high intensity ultrasound. The ultrasound irradiation causes acoustic cavitations, which leads to the formation growth and impulsive collapse of bubbles in a liquid. The temperature and pressure inside the bubbles rise as a result.

There are three different pathways under sonication

a) Reduction by H atoms
b) Reduction by secondary reducing radicals created when H atoms and OH radicals are extracted from organic compounds
c) Reduction by radicals formed from the pyrolysis of the additives has been identified at the interfacial region between cavitations bubbles and the bulksolution

Metal nanoparticles such as Co, Ni and Fe and their oxide nanoparticles have been synthesized by the sonochemical reduction technique [69-70]

Polyol method

Fievet *et al.,* developed the polyol method [71]. Most commonly metal and metal alloys are synthesized by using polyol. The method involves heating of inorganic metallic compound in a liquid polyol such as ethylene glycol, diethylene glycol, triethylene glycol or mixture of these glycols at a given temperature. The polyols used for the synthesis act as a solvent, stabilizing and reducing agent. Along with polyol, secondary reducing agents such a hydrazine or heterogeneous nucleating agents like Pt, Ru have used during synthesis of metal and alloys [72].

Combustion method

Preparing metal oxide and ferrite nanoparticles through combustion is a rapid and energy-efficient process. In this method organic compound or polymer is used as a fuel such as glycine, urea, citric acid, and polymers such as PVA, PVP and PEG. The fuel is stiochiometrically added with metal nitrates. This method involves exothermic redox reaction between oxidizer and fuel. The transition metal ions used in the synthesis form complex with fuel during aging process. After aging the precursor gel is heated on hot plate which removes water content initially and then various gases are liberated with formation of metal oxide nanomaterials and carbonaceous matter of fired fuel [73].

Nanotechnology:

The use of nanotechnology to humans is not new, despite the fact that it seems to be a relatively recent topic of study. Natural asbestos nanofibres were used for ceramic matrices 4500 years ago, which is when nanomaterials were first used in construction. Four millennia ago, the Egyptians—among the world's most ancient, affluent, and forward-thinking cultures—realized the potential of nanotechnology. The historical trajectory of nanomaterials and nanotechnology prior to the millennial. The domains of technology, health and medicine, energy, transportation, and the environment are all positively impacted by nanotechnology.

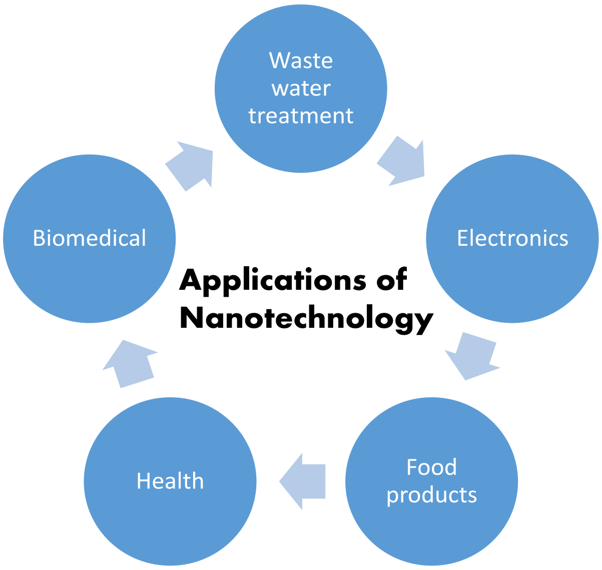


Fig. 1.8: Application of nanotechnology in various field

Application of Nanotechnology:

Magnetic nanoparticles have been applied in different research fields, such as sensor developments, magnetic resonance imaging in medicine, drug delivery systems, hyperthermia, and magnetic separation. The different applications of magnetic nanoparticles are shown in Figure 1.8 cobalt are in fact very attractive in the biomedical field for their high magnetic anisotropy and saturation magnetization which give rise to suitable magnetic behaviour at room temperature, but the presence of cobalt makes it potentially toxic [28-29]. This difficulty of cobalt ferrite and cobalt nanoparticles is overcome by protecting these nanoparticles by suitable encapsulating agent such as polyvinyl alcohol, polyvinyl pyrrolidone, polyethylene glycol, and silica [74-77].

Quantum dots (QDs) have come up as one of the most dynamic and interesting nanotechnology interfaces in recent decades. ZnS, CdS, ZnSe, CdTe, and PbSe colloidal quantum dots (QDs) that emit from the UV to the infrared have been created. QDs have several benefits over conventional organic dyes and fluorescent proteins, including high quantum yields, photochemical stability, and a narrow, adjustable, symmetric emission from visible to infrared wavelengths. Since 1998, QDs with different 24 surface capping ligands have been used extensively as fluorescent species for tumor imaging, cell labeling, and clinical diagnostics.

QDs have garnered significant interest lately due to their unique ability to serve as markers of chemical and biological ionic species fluorescence.

It was discovered that CN-, Cu^{2+}, Hg^{2+}, and Ag^{+} had a significant impact on QD fluorescence intensity [78-81]

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ROLE OF NANOTECHNOLOGY IN CHEMICAL ENVIRONMENT REMEDIATION

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Abstract:

The contamination of the environment by chemicals leads to environmental pollution which causes serious risks to human health, natural systems, and sustainability as a whole. There are various groups of chemicals that harm the environment and create an imbalance in the entire ecosystem. These problems necessitate creative remediation techniques that effectively reduce the harmful impacts of contaminants while preserving the ecosystem. An extensive summary of current developments, techniques that help in the remediation of such problems is mentioned here and new directions in chemical environment cleanup are also given and Nanotechnology is now involved in providing a solution to the problem. This chapter includes information about the major pollutants that contaminate the Environment and cause harm to the environment and the involvement of nanoscience in the remediation of such problems. Nanotechnology involvement in the chemical environment remediation or treatment by various means is mentioned.

Keywords: Environmental Pollution, Hazardous Chemicals, Chemical Remediation, Nanotechnology, Nanoparticles, Nanocomposites.

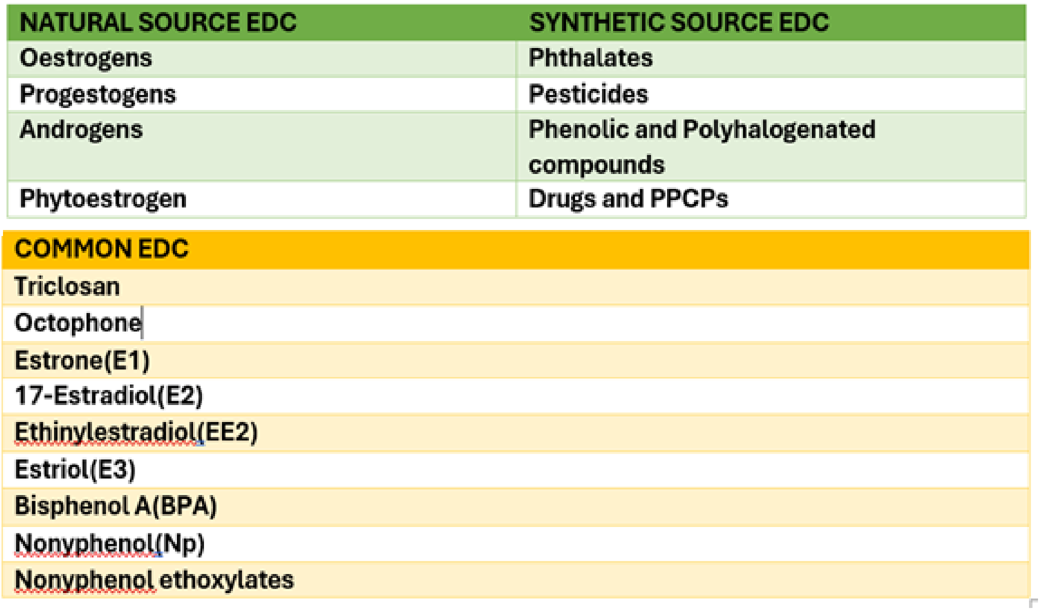
Introduction:

Environmental pollution is the world's biggest issue. It disrupts the atmosphere's regular functioning, altering the course of the climate, the life cycles of living things, and the systematic functioning of environmental activities. It also has an adverse effect on the quality of the air, water, and soil, all of which are impacted by different pollutants. Heavy metals, particulate matter, dyes, volatile organic compounds, oil spills, chlorinated organic compounds, and chlorinated solvents, as well as industrial waste, herbicides, pesticides, organo-phosphorous compounds, CFCs and their derivatives, halogenated derivative herbicides, toxic gases, fertilizers, and various other chemicals, can all contaminate the environment [1-2]. This enduring issue has now been solved by nanotechnology, and cleanup methods based on these approaches have been somewhat successful in stopping additional environmental harm [3-4]. Researchers are always looking into using nanotechnology to clean up pollutants in the soil, water, and air; also considering Nanotechnology as the chemical environment remediation technology [5]. Nanoscale materials with environmental applications have been used for the last few years.

There has been a notable movement in the synthesis of nanoparticles towards ecologically benign and sustainable methods [6]. Nanoscale materials have been employed to clean up contaminated soil, air, and water metal oxide-based nanoparticles, Nanoparticle filters, zero-valent metal, Nano-membranes, carbon-based nanomaterials, nano-based sorbents, and nanocomposites in the treatment of water and wastewater are significant additional application of nanotechnology in environmental management [7-8].

Chemicals that harm Environment

There are various groups of chemical substances that have a direct or indirect effect on the environment which degrades the quality of air, water, and soil and also affects the living organisms and creates disturbance in an ecosystem [9]. In situ, the chemical method is used to cure such problems. There are numerous ways to categorize environmental dangers. Chemical, physical, biological, and psychological are a few of them [10]. Some chemicals and pollutants are produced by people and found in consumer goods, many other chemicals and pollutants are found in the environment naturally [11]. Some are industrial effluents, household waste, chemicals released during various reactions, etc. The concentrations of oxygen, nutrients, pH, salinity, and other chemicals in the environment are examples of critical chemical properties. Variations in the concentration of these chemicals and their derivatives may lead to environmental pollution [12]. Chemical hazards are compounds that pose a risk to the environment, animals, or people. They could manifest as gases, liquids, solids, mists, dust, fumes, or vapours [13-14]. There are some POPs (Persistent Organic Pollutants) that show harmful effects on the ecosystem. POPs are a class of hazardous substances that can linger in the environment for several years before decomposing [15]. Another class of chemicals is EDC which is Endocrine disruptive chemicals, these are those chemicals that harm the endocrine system and normal Physiology of human and aquatic life forms and also show harmful effects on the environment. Many Environmental pollutants also known as endocrine-disrupting chemicals (EDCs) can interact with the endocrine system exogenously at certain levels [16]. Synthesized EDCs may be confused with naturally occurring hormones when they enter human bodies. The EDCs typically bind to ligands and take up the position of natural hormones, which causes differences in gene networks and target cell activities. Some highly hazardous compounds found in tiny concentrations in watery environments can cause cancer or create mutations that interact with the endocrine glands, interrupting vital functions of the organism such as development and reproduction known as xenobiotics, or manmade compounds, these contaminants don't just happen naturally in the environment. Because no evolutionary mechanism has been able to metabolize these chemicals, nature is unable to deal with the biological breakdown of these molecules. Due to their inability to readily biodegrade, these materials frequently remain in wastewater treated using conventional techniques and build-up. In addition to endangering human health, the use of contaminated water resources has an impact on the growth and health of animal and plant populations [17]. As a result, several scientific institutions are conducting studies on the topic of eliminating harmful pollution. Researchers studying water and wastewater treatment have been increasingly interested in EDC, a new class of pollutants Figure 1. The main cause of this attention is the variety of risks that EDC presents to the environment and living things. EDC can cause endocrine disorders in both humans and wildlife which indirectly impact the ecosystem as these chemicals interfere with living systems hence disturbing the life cycle of living organisms which directly or indirectly affects the normal functioning of environmental activities [18].



NATURAL SOURCE EDC	SYNTHETIC SOURCE EDC
Oestrogens	Phthalates
Progestogens	Pesticides
Androgens	Phenolic and Polyhalogenated compounds
Phytoestrogen	Drugs and PPCPs

COMMON EDC
Triclosan
Octophone
Estrone(E1)
17-Estradiol(E2)
Ethinylestradiol(EE2)
Estriol(E3)
Bisphenol A(BPA)
Nonyphenol(Np)
Nonyphenol ethoxylates

Fig. 1: Study of natural and artificial sources of EDCs

Environment Toxicology

A branch of toxicology called "chemical toxicology" examines how a chemical agent's structure influences how it acts on living things. An interdisciplinary branch of research called environmental toxicology (the negative consequences that substances, chemicals, or circumstances may have on humans, animals, or the environment) studies the detrimental impact that different chemical, biological, and physical agents have on living things [19]. It is defined as the study of the detrimental and dangerous consequences of environmental contaminants on human health. It is the study of the detrimental effects that hazardous substances have on living things [20]. It mostly affects the biosphere, ecosystem level, and community Figure 2.

Chemical Environment Remediation

Toxin removal from the environment is known as environmental remediation. Anthropogenic environmental pollution is increasing, disrupting the health and environmental systems. Green chemistry is very helpful in chemical remediation and it is also considered as a sustainable method for the remediation of the environment. Nowadays Green chemistry plays a major role in every field including environment remediation, synthesis techniques, and various other methods and methodologies. Green chemical techniques for air and water purification, soil, groundwater, and environmental rehabilitation are considered major parameters which are very helpful. This concept is explored and applied as a systematic framework for design, and future directions in green chemistry and in-situ chemical method for removing dangerous compounds from the environment is chemical remediation. Depending on the application, it employs different techniques, but most include oxidation or reduction reactions with either organic or inorganic molecules.

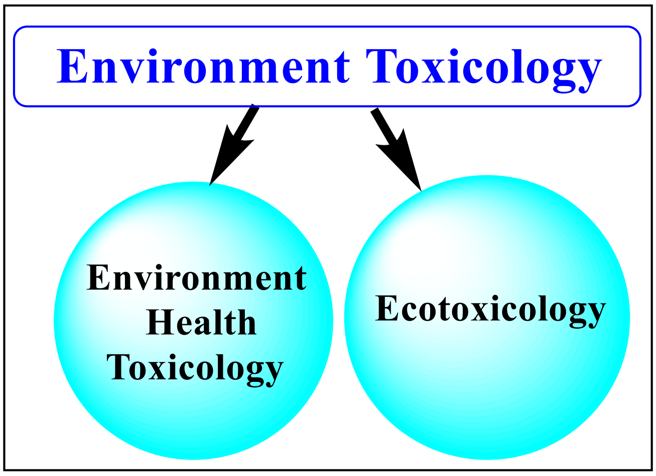


Fig. 2: Environmental toxicology of hazardous chemicals

Methods of Environment Remediation

There are various methods that help in remediation, Among the methods used for environmental remediation include pump and treat, stabilization, oxidation, reduction dredging, precipitation, soil vapor extraction, photodegradation, chelation, thermal desorption, bioremediation, and nano remediation [21]. Chemical environment remediation techniques use a variety of chemical procedures to reduce pollution or contamination in the air, water, or soil [22]. Here are a few typical methods such as chemical oxidation; to convert pollutants into safe byproducts, oxidizing agents are injected into polluted soil or groundwater. Ozone, permanganate, and hydrogen peroxide are a few examples of oxidizing agents. Chemical reduction, in contrast to oxidation, is the process of converting hazardous compounds into less dangerous forms by introducing reducing agents to contaminated areas. Sodium dithionite and zero-valent iron (ZVI) are common reducing agents. Some of the Environmental remediation techniques involve various parameters which are shown in Fig. 3.

Chemical stabilization/solidification, to stabilize or solidify contaminants and stop them from spreading, chemicals are mixed with polluted soil in this technique. To immobilize pollutants, binders like fly ash, cement, or lime are frequently utilized. Chemical precipitation: is a procedure where pollutants are added to contaminated water and allowed to precipitate out of solution, making removal easier. For example, if lime is added to water that contains heavy metals, the metals may precipitate as insoluble forms. Chemical neutralization, chemicals that raise the pH to a more neutral level can be added to neutralize contaminants that are acidic or alkaline. For instance, acidic soil or water can be made less acidic by adding lime (calcium hydroxide). Chemical chelation, metal contaminants can be bound by chelating agents in contaminated settings to create stable complexes that are less harmful and easier to remove. Chelation agents like ethylene diamine tetra acetic acid (EDTA) are frequently used. Phytoremediation, utilizing plants to eliminate, break down, or stabilize pollutants in soil, water, or the air is a non-chemical method of remediation. Certain plants have the ability to take in contaminants, store them in their tissues, or degrade them through biochemical reactions **[23]**. Enhancement of bioremediation, in certain cases, the application of chemical additives might improve the bioremediation procedures, which employ microorganisms to degrade pollutants. Pollutant degradation can be accelerated and microbial activity can be stimulated by adding nutrients or oxygenating substances. Chemical degradation reactions can convert some contaminants into less hazardous forms. For example, by adding chemicals or catalysts that encourage their breakdown, some organic contaminants can be destroyed.

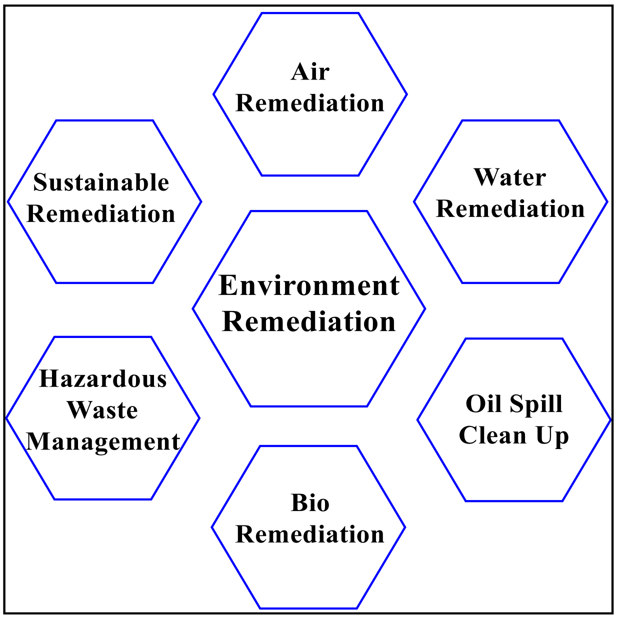


Fig. 3: Environmental remediation of the chemical compounds

Nanotechnology in Chemical Environment Remediation

Nano remediation is a widely used method nowadays and it is considered as most useful and appropriate method for chemical environment remediation. The development of smart materials that can simultaneously detect and eliminate dangerous chemical pollutants from our surroundings depends heavily on nanostructures. The ability of nanotechnology to modify materials at the nanoscale level, leading to greater reactivity, efficiency, and selectivity, presents intriguing options for chemical environment remediation. The following are some applications of nanotechnology in environmental remediation:

1. Nano-Scale Sorbents: Because of their enormous surface areas and high reactivity, nanomaterials like carbon nanotubes, graphene, and nanoscale metal oxides are good

sorbents for contaminants. Compared to conventional materials, they are more effective at absorbing pollutants from soil, water, or the air [24].

2. Nano-Enhanced Chemical Oxidation: Chemical oxidation processes can be improved by using nanoparticles of oxidizing agents such as manganese dioxide or zero-valent iron (ZVI). Due to their larger surface area-to-volume ratios, these nanoparticles come into more contact with pollutants and speed up oxidation processes [25].
3. Nano-Catalysts: Nanoparticles can act as catalysts to speed up chemical processes that lead to the breakdown of pollutants and help in environmental cleanup. For instance, the breakdown of organic contaminants or the reduction of hazardous metals can be catalyzed by metal nanoparticles such as iron, palladium, or titanium dioxide [26].
4. Nano-Enabled Photocatalysis: This sustainable method of environmental remediation uses semiconductor nanoparticles, such as zinc oxide or titanium dioxide, to capture solar energy and catalyze the breakdown of contaminants [27].
5. Nano-Enabled Filtration Membranes: By using nanotechnology, sophisticated filtration membranes with functionalized surfaces or nanoscale pores can be created. These membranes have the ability to efficiently filter contaminants, pathogens, and microbes out of streams of water or air [28].
6. Nano-Bioremediation: By acting as carriers for microbial consortia or enzymes, nanoparticles can improve the stability, activity, and movement of these substances in the environment, hence increasing bioremediation processes [29].
7. Nanoparticles can be added to soil amendments to increase their effectiveness in immobilizing or breaking down pollutants, enhancing soil quality, and encouraging ecological restoration. This process is known as nano-enabled soil remediation [30].

While the use of nanotechnology to clean up the environment has great promise, it is vital to consider the risks associated with releasing created nanoparticles into the environment, including their toxicity, long-term destiny, and ecological effects. Regulatory frameworks and risk assessments are necessary to ensure the responsible and safe use of nanomaterials in remedial applications [31-32]. By using semiconductor nanoparticles as catalysts and/or sensing devices, nanotechnology can help us purify our water and air supplies. Furthermore, new avenues for the development of environmentally friendly oxidation technologies for environmental cleanup are made possible by the use of light and ultrasound to activate these nanoparticles [33]. Semiconductor materials also play an important role in nanotechnology and help in environment remediation as Semiconductor nanoparticles as photo-catalysts and semiconductor-metal nanocomposites for improving the efficiency of photocatalytic processes, Simultaneous detection and degradation of low-level organic contaminants [34].

Conclusion:

In this study, the contamination of humans and natural ecosystems with chemicals threatens human life and the sustainability of our planet. This pollution is caused by several groups of chemicals interfering with the ecosystem's delicate harmony. Without novel remediation methods, it would be impossible to mitigate such deleterious effects while at the same time protecting the ecosystem. This article gives an extensive review of the present status and creation technologies utilized to counteract ecological contamination from various sources. Vital though exclusive consideration is given to examination actions relating to the use of nanotechnologies for remediation. We need to further investigate and explore new areas of chemical environment cleanup with an increasing emphasis on innovative nano-technology-based solutions in the future. With the help of nanoscience, we can take our first step towards a more sustainable and clean future for our planet. In this article, various techniques and applications of nanotechnology have been mentioned for the remediation of the environment.

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STUDY OF NANO BIOPESTICIDES FOR SUSTAINABLE DEVELOPMENT OF AGRICULTURE

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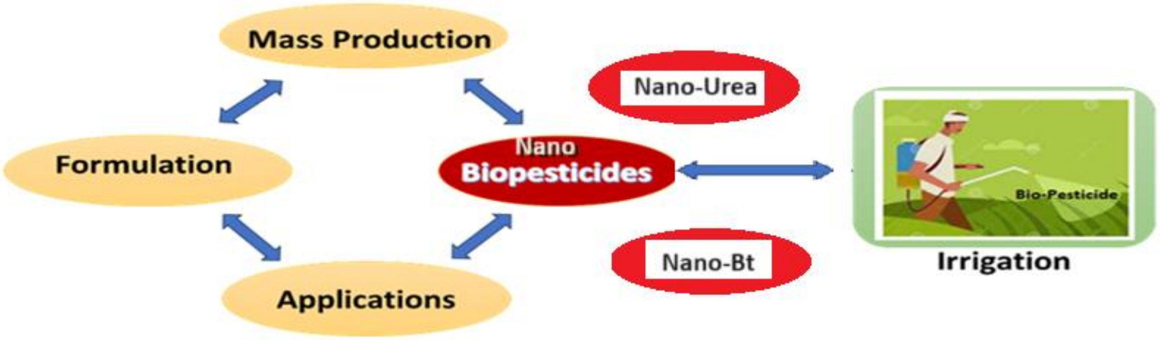
Abstract:

Nowadays there is an immense strain on crops, plants, etc. due to the world's population. Food consumption is more and land for farming is less. So, people use chemical pesticides to increase crop production and to protect plants but this leads to pollution and severe side effects. The use of chemical pesticides is not a good way, we have to go on an alternative that includes biological control. Nano-biopesticides have the ability to increase unintended pesticide mobility as well as the ability to wet and disseminate farming formulas i.e., decrease organic solvent runoff). The features that are needed to formulate nano-biopesticides, characteristics like solubility, rigidity, flexibility, crystal structure, thermal resistance, and biological degradation, are exhibited by nanomaterials and nanocomposites. Additionally, nano-biopesticides have a high specific surface area and a greater affinity for their target. The delivery of nano-biopesticides to plants by nano-emulsions, nano-encapsulates, and nanocontainers, are a few of the procedures that have been considered recently. This work gives a brief introduction, source, and study of the efficient activity of nano-biopesticides. In this article, we discussed the types of nano-biopesticides, nano-urea, and the manner of operation of *Bacillus thuringiensis* in the nano range. It will provide a deep difference between the eco-friendly efficiency of chemical pesticides and nano-biopesticides.

Keywords: Agricultural Formulations, Crop Production, Nano-Biopesticides, Nano-Urea, *Bacillus thuringiensis*, Eco-friendly.

Graphical Abstract:



Introduction:

There is immense strain on agriculture to generate more food due to the world's population. Nowadays more consumption of food and land for farming is less and the impact of climate change is very high which affects the plants. So, plant protection is very necessary to decrease the loss of plants from pests and diseases in farming to get fresh results. In agriculture, compounds are by targeted biological effects, as opposed to more general chemical pesticides, which are referred to as biopesticides. Chemicals used to eradicate pests in agriculture by targeted biological effects, as opposed to more general chemical pesticides, are referred to as biopesticides. The use of chemical pesticides is not a good way, we have to go on an alternative that includes biological control. Chemical compounds with nanoparticles that are biologically generated and meant to be employed as pesticides are called nano-biopesticides. By utilizing oxides of metals and particles that are actively mixed with micelles, nano-formulations 183 polymers, etc., the efficacy and efficiency of nano-biopesticides are increased. Hence, qualifying nano-biopesticides must have intrinsic qualities including target-oriented gradual improved solubility of weakly soluble active compounds, a progressive release of active substances, and active chemicals that shouldn't breakdown too soon Even when employed in small quantities, nano-biopesticides shouldn't lose effectiveness. Furthermore, by combining nano-biopesticides with an understanding of the pathogen's life cycle and the pest's behaviour, the particular nature of the target and its product can be improved [1]. It describes goods that have organic creatures or materials produced from natural materials (such germs, flora, fauna, or expected mineral deposits), especially their genetic information or metabolites, for the purpose of managing pests. Enhanced agricultural pesticides that have entomopathogenic nematodes or microorganisms like bacteria, fungi, or viruses as active elements to attack certain pest species. Conventional insecticides frequently endanger both the environment and human health. By combining organic or genetically altered micro-organisms or plant extract into nanomaterials, nano-biopesticides present a possible substitute [2]. By boosting the stability, solubility, and bioavailability of bioactive substances, nanoparticles can enhance their transport to target organisms. By avoiding harm to beneficial creatures, nano biopesticides can be specially developed to target pests and reduce collateral damage to ecosystems. Nano biopesticides often have a lesser environmental persistence and a lower danger of bioaccumulation when compared to traditional pesticides. By strengthening bioactive chemicals' adherence to target surfaces, penetration into pest tissues, and general activity, nanostructures can increase their effectiveness. With the use of nanomaterials, bioactive chemicals can be released gradually under regulated conditions to provide long-lasting pest control with less frequent reapplication required [3] Figure 1.

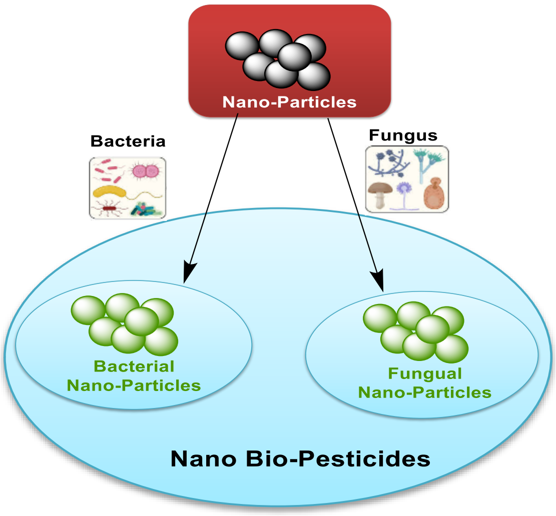


Fig. 1: Nano-biopesticides formed from nanomaterials with bacteria and fungus

Importance of Nano Biopesticides:

For a number of reasons, nano-biopesticides are crucial to contemporary agriculture and pest control. Comparing nano biopesticides to traditional chemical pesticides, the former is more environmentally friendly. They may lessen damage to non-target creatures, reduce environmental pollution, and protect biodiversity. Nano biopesticides are frequently less hazardous to humans and other mammals than chemical pesticides [4]. This lowers the chance that farmers, agricultural labours, and consumers will experience short-term or long-term health impacts from pesticide exposure. It is possible to design nano biopesticides so that they selectively kill pests, leaving healthy creatures like pollinators, natural predators, and soil microbes unharmed. This focused strategy reduces disturbance to ecosystems and maintains ecological balance. Chemical pesticides may lose their effectiveness over time when pests develop resistance to them, necessitating the use of stronger chemicals [5]. Nano biopesticides, especially those produced from biological agents, offer a special mode of action that can help prevent insect populations from developing resistance. In Integrated Pest Management (IPM) strategies, other elements like cultural practices, elements of biological management, and monitoring procedures can be enhanced by the use of nano biopesticides. Farmers can attain more sustainable and efficient pest control results by combining several pest management strategies [6]. Sustainable pest management strategies are essential for maintaining food security in light of the world's expanding population and the strain they are placing on food production systems. With the help of nano biopesticides, agricultural yields can be increased while the harmful effects of pesticide use on the environment and public health are reduced [7]. Multidisciplinary cooperation amongst domains including biology, agriculture, environmental science, and nanotechnology is required to produce nano biopesticides. This encourages creativity and opens doors for advancement in science, technology, and the agriculture industry's economic prosperity [8]. All things considered, nano biopesticides are a promising development in pest control that adheres to the values of efficacy, safety, and sustainability in farming methods. To ensure responsible and sustainable use, however, their deployment necessitates governmental control, stakeholder participation, and careful evaluation of potential dangers. When compared to chemical pesticides, nano biopesticides frequently exhibit reduced toxicology toward unintended party creatures, such as Individuals and other animals. This lowers the possibility of both short-term and long-term health impacts from pesticide exposure [9]. Nano biopesticides support sustainable agriculture by fostering more environmentally friendly pest management techniques and lowering dependency on chemical pesticides. They provide long-term food security, protect ecosystem services, and uphold the health of the soil [10]. Because nano biopesticides can be customized to target certain insect issues and crop kinds, pest control tactics can be made more flexible. In order to apply them using foliar application, seed treatment, or soil soaking, they might be prepared as sprays, powders, or coatings [11]. The positive environmental and health characteristics of biopesticides, particularly nano-biopesticides, have led to a growing number of regulatory agencies worldwide endorsing them. The development and commercialization of nano biopesticides for agricultural applications is made easier by this regulatory acceptance. All things considered, nano biopesticides are a promising development in pest management, providing long-term, sustainable, and ecologically benign ways to solve agricultural problems with the least amount of harm to the environment or human health Figure 2.

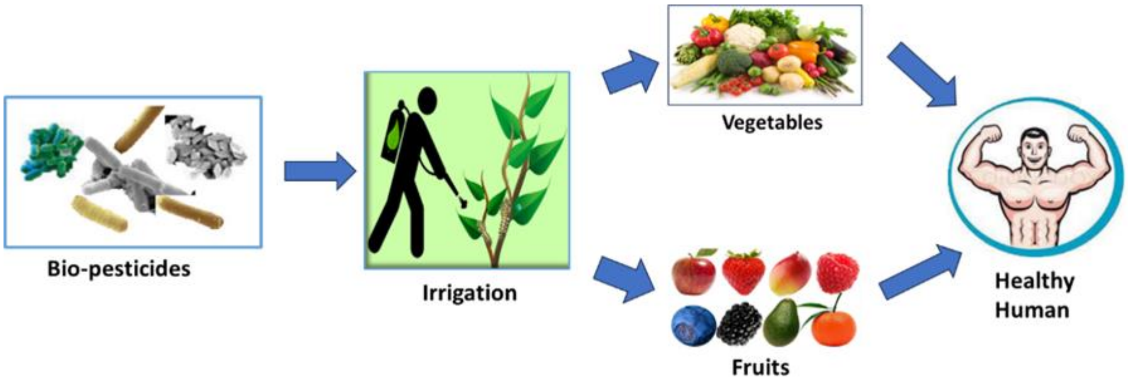


Fig. 2: Impact of Nano-biopesticides in Human Health

Classification of Nano Biopesticides:

A new category of pesticides called nano biopesticides uses nanotechnology to increase durability, transport, and Biopesticide efficiency. Their composition and method of action allow for a general classification of them. These are a few of the primary kinds:

1. **Nanoparticle-based biopesticides**:

Among them are antimicrobial metals and nanoparticles of metal oxide, such as oxide of zinc silver, and copper. They can be used to directly eradicate pests or to stop their development [12]. These emulsions have droplet sizes in the nanoscale range. They boost the stability and distribution of hydrophobic biopesticides and other essential oils, which increases their efficacy against pests [13].

2. Nanoscale Carriers:

The active component of these vesicular systems is contained within a cavity that is encircled by a polymer membrane. The biopesticides are delivered with precision and under control [14].

Nanoliposomes that enhance the stability and bioavailability of biopesticides by encasing them [15]. To encapsulate biopesticides and provide regulated release and protection against environmental degradation, biodegradable polymers like poly(lactic-co-glycolic acid) (PLGA) are utilized to generate nanoparticles [16].

3. Nanocomposites:

To generate materials with improved qualities for pest management, they blend organic molecules with inorganic nanoparticles (such as clay or silica) [17]. Made of nanoparticles and biopolymers (such as chitosan), they provide the advantages of improved pest control efficiency together with biocompatibility [18].

4. Microbial Nano Biopesticides:

As a result of their enhanced stability and penetration, these natural compounds work better as biopesticides when they are nano-formulated. *Bacillus thuringiensis* and other microbial agents are better formulated and delivered with the use of nanotechnology, which ensures improved stability and continuous release. After being obtained from dead moth larvae that had infected stored grain, a different strain was reported a little over ten years later Gram-positive bacteria, or Bt, are widely distributed and frequently found in soil all over the world. The vast range of subspecies that exist, the range of insects that each target, and the identification and characterization of the proteins that impart target insect specificity have all been the subject of much investigation Over the course of the last 20 years, Bt has been used in agriculture as a source for insecticidal proteins that can be expressed in transgenic plants. Bt was initially used in foliar spray formulations. Bt presents an enticing substitute for the use of synthetic chemicals due to its effectiveness and good safety profile. This is due to its target pest selectivity, in-plant delivery, and environmental advantages. The successful creation and widespread use of Bt crops make them the paradigm for increasing insect control choices through biotechnology developments. Numerous great reviews have been written that detail various elements of Bt and their insecticidal proteins [19].

Mode of Action of *Bacillus thuringiensis* in nano range on Plant

Bt has been used in agriculture as a source of insecticidal proteins that can be expressed in transgenic plants. Bt was initially used in foliar spray formulations. Bt presents an enticing substitute for the use of synthetic chemicals due to its effectiveness and good safety profile This is due to its target pest selectivity, in-plant delivery, and environmental advantages. The successful creation and widespread use of Bt crops make them the paradigm for increasing insect control choices through biotechnology developments. Numerous great reviews have been written that detail various elements of Bt and their insecticidal proteins. Top-down methods of micro-ionization, such as milling by jet, milling by ball, and high-pressure homogenization to transform harsh powders into incredibly fine particles, can make Bt available in nanoform. Some methods employed result in typical particle sizes between 2.5 and 5 µm, with a minor portion of the particles falling below the 1 µm size Although these techniques are simple to scale up and produce repeatable results, there can occasionally be variations in batch-to-batch extraction, and the usage of grinding balls throughout the process can contaminate the finished product. Since solubility and particle size are inherently correlated, micro-ionization has been effectively used to increase drug solubilization. However, the viability and effectiveness of Bt may be diminished by heat produced during the high-speed milling operation. Therefore, it is necessary to mill while making provisions for cooling [20] Fig. 3.

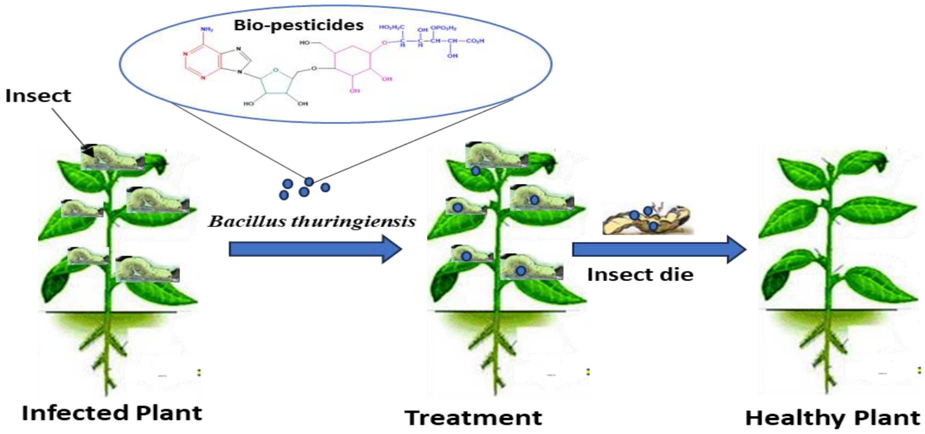


Fig. 3: Function of Nano-*Bacillus thuringiensis*

Nano-Urea

One significant vital ingredient needed for improved crop growth and development is nitrogen, which can be found in nano urea. When sprayed during crucial stages of crop growth, IFFCO Nano Urea liquid, which is based on nanotechnology, efficiently satisfies crop nitrogen requirements. It's employed as a substitute for traditional urea and other nitrogenous fertilizers for healthier soil, a better environment, and increased farmer profitability. In its nano form, nano urea has 4% nitrogen by weight [21].

Spray crop leaves with a solution made from 2 to 4 milliliters of nano urea liquid per liter of clean water. For optimal outcomes, apply twice during the first stages of growth (tillering/branching); Earlier than a week before flowers appear. As nano urea encourages precision and sustainable agriculture, it might be a part of 4 R nutrient stewardship. Because of its energy- and resource-efficient industrial manufacturing, it supports clean and green technologies. According to testing carried out by GLP-certified and NABL-accredited laboratories, nano urea is safe for both the environment and the user. Thus, nano urea presents itself as a viable, environmentally friendly, and sustainable eco-friendly substitute for urea and other traditional bulk nitrogenous fertilizers. As an alternative to traditional urea, it is a nutrient (liquid) that gives plants nitrogen. In a 500 ml container, it has 40,000 mg/l of nitrogen, which is the same amount of nitrogen nutrients as one bag of regular urea. The efficiency of nano urea liquid in providing nitrogen to plants is over 80%, compared to the 30–40% of conventional urea. More than 11,000 farmers have used it to assess its efficacy on 94 crops, including wheat and rice [22]. There has been an observed yield increase of 8% on average. India's urea requirements must be met via imports. It has been demonstrated to be successful and efficient in improving the nutritional quality of plants while increasing their output. As in the figure, the growth of plants is increasing in a fine direction with having resistance towards the disease due to temperature, bacteria, and other factors also as it gets proper nutritional value by using nano-biopesticides, Bt, and Nano-Urea Figure 4.

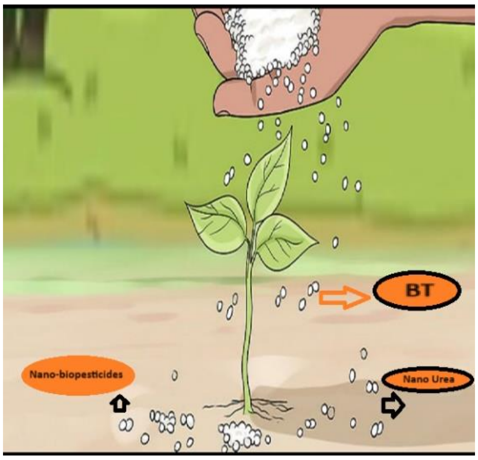


Fig. 4: Effect of nano-biopesticides, Bt, and nano-urea

It will also significantly reduce global warming, which will have an effect on climate change and sustainable development, and improve the quality of subsurface water. It will effectively increase farmers' income and is inexpensive for them. Additionally, it will drastically reduce the majority of logistics and storage [23].

Sources and Material for Nano-biopesticides

Terpene-based nano biopesticides come in a number of forms, including neem extracts, citrus or orange oils, as well as essential oils made from Chenopodium ambrosioides variation nr. D-limonene, the main ingredient in orange or citrus oils is harmful to a variety of pest species of insects. Aphids, which come in about 100 different kinds, are regarded as agricultural pests that harm a variety of crops. Due to their propensity to acquire resistance to common synthetic insecticides like carbamates and their capacity to contaminate an array of crops. The melon and cotton aphid are two of the most significant aphid pest species [24]. In May of each year of the initiative, plug plants of Hebe 'Purple Pixie' and pansies were planted in pots with a diameter of 9 cm. The plants that were potted were Hebes in a soil-based growth media and Pansies in a peat-based environment for growth. To facilitate watering, pots were set up inside an open-air polytunnel and supported by capillary flooring. Plants were raised till they started to flower in July or August, at which point they were moved to either a ventilated polytunnel (for Hebe plants) or a vented glasshouse compartment (for pansy plants) [25]. Before being used in tests, a community made up of one M. persicae clone which is recognized for being unable to resist carbamate and pyrethroid insecticides was grown on pak choi (*Brassica rapa L.*) seedlings. Before being used in tests, *Aphis gossypii* were obtained from a store that sells ornamentals and raised on seedlings of cotton (*Gossypium hirsutum L.*). The two aphid populations were kept in 47.5 × 47.5 x 47.5 cm fine mesh bug cages. Every week, the plants were switched out and new, aphid-infested plants were collected from the ones that were thrown out. The temperature, relative humidity, and light/dark ratio of the controlled environment rooms in which the insect cages were housed were set to 60% at 20°C [26]. These are different biopesticides that could be used in the normal range but converting them into nano range, will raise the level of effectiveness of the pesticides and additionally diminish the soil pollution as they will work on that part of the plant which is in need (root, leaves, etc) [27]. Nano-biopesticides, mode of action with its active sites mentioned in Table 1.

Table 1: Nano-Biopesticides with their active agent and mode of action

Product	Active Agent	Mode of Action	Reference
Biochemical			
Aza-Direct	Azadiraction	Growth and molting disruption	[28]
Nema-Q	Saponins	Nematicidal effects	[29]
Regalia MAXX	Excerpt of Reynoutria sachalinensis	wide-ranging antibacterial efficacy	[30]
Microbials			
Lipel	Bacillus thuringiensis	Effect on Moth Eggs and Larvae	[31]
Cordalene	Bacillus thuringiensis	Midgut cell death caused by cryotoxins via signal transduction	[32]
Daman	Beauveria bassiana	Larvicidal properties and growth retardation	[33]
PIPs			
Bt-cotton	Cry1Ac, Cry2Ab toxins	function as a digestive toxin that causes pores to form	[34]
5345	Cry1Ac gene	kills insets by entering an intestinal membrane through a pore.	[35]
At+ - Potato	RNAi	causes target genes involved in infection and maintenance to be silenced post-transcriptionally	[36]

Comparative study between chemical pesticides and Nano biopesticides:

Aspect	Chemical Pesticides	Nano Biopesticides
Pests Controlled	Insects, weeds, fungi, rodents, and other pests that threaten crops, human health, or ecosystems.	Agricultural pests, including insects, pathogens, and other vermin, with a focus on selectivity and environmental safety.
Mechanism of Action	Eliminates pests directly by penetrating skin or affecting external structures. Absorbed by plants and carried through tissues. Often used in baits.	Encapsulates active ingredients in nanoparticles, protecting them from environmental factors and enhancing stability and longevity.
Effects on Crop	Effectively reduce or eliminate pest infestations, increase yields, and improve crop quality. Overuse may cause phytotoxicity, leading to crop damage.	Improve pest control and reduce environmental impact. Natural agents delivered via nanoparticles may enhance efficacy and sustainability.
Side Effects on Human Health	Pesticide residues can cause acute poisoning and long-term health issues like cancer and endocrine disruption. Direct exposure risks for agricultural workers.	Generally lower human health risks due to reduced chemical use and targeted delivery, though safety assessments are still needed.
Effects on Environment	Can contaminate water sources, affect non-target organisms, and cause air pollution. Potentially harmful to ecosystems.	Often biodegradable with reduced chemical load, posing a smaller environmental threat. Designed to decompose into harmless substances.

Chemical pesticides have long been known for their ability to effectively manage illnesses and pests. They frequently produce quick and effective results, eliminating bugs upon contact or consumption. The comparative study between the chemical pesticides and nano-biopesticides is mentioned below in Table 2. Nano biopesticides are generally made at the nanoscale and originate from natural sources, nano biopesticides are being investigated more and more for the purpose of controlling pests. In the long term, they can provide tailored and environmentally friendly pest management options, even if they do not always have the same instant efficacy as conventional pesticides. Human health may be in danger from chemical pesticides, particularly for individuals who handle, apply, or eat produce that has been treated. Prolonged exposure to specific chemical pesticides has been linked to adverse health outcomes, such as neurological diseases, cancer, and problems with reproduction. Nano Biopesticides are those pesticides that are frequently thought of as safer substitutes. They are less hazardous to human beings and the surroundings because they are obtained from natural sources and might be less harmful. To guarantee their safety in diverse circumstances, research is continuously being conducted. Nano-biopesticides represent a vital advancement in pest management, offering a holistic approach to crop protection that aligns with our vision for a resilient and thriving agricultural sector.

The primary goal of the creation of nano-biopesticides is environmental sustainability. We reduce the ecological footprint associated with traditional chemical pesticides by utilizing the power of organically produced active chemicals at the nanoscale. Our formulations minimize contamination of soil and water, reduce off-target effects on beneficial organisms, and prioritize targeted insect management. Additionally, because nano-biopesticides are biodegradable, the environment will not be harmed by them and ecosystem integrity will be preserved for future generations.

Conclusion:

Implementation of nano-biopesticides made from various microorganisms can be applied to enhance and replenish soil fertility and guarantee sustained agricultural output. In this case, businesses and research institutions must work together as much as possible; otherwise, it seems unlikely that biopesticides and nano-biopesticides will ever fully replace chemical pesticides. Currently, chemical and biopesticides are both necessary for the agriculture sector to use but surely, we can say that nano-biopesticides have more efficiency to target on the pests and other diseases of plants and crops. Nano-biopesticides do not affect Human wellness and our surroundings as well because they are target-oriented and also do not use heavy amounts of hazardous chemicals and they are the future prospects for the farmers and citizens of the whole world.

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ADVANCED NANOTECHNOLOGY USED FOR THE DEGRADATION OF MICROPLASTICS

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Abstract:

There are serious environmental risks as a result of the extensive use of chemicals in many industrial, agricultural, and residential applications. An extensive review of the wide variety of chemicals that endanger the sustainability and health of the ecosystem is given in this chapter. The chapter looks at the origins, modes of dispersion, ecological effects, and possible health hazards associated with both established and newly discovered pollutants. The chapter also examines the cumulative and synergistic impacts of chemical pollution on ecosystems, highlighting the necessity of using comprehensive strategies for environmental restoration and management. There is also a discussion of methods for reducing chemical pollution, including legislation, pollution control techniques, and the creation of safer substitutes. Additionally, it highlights how crucial stakeholder involvement and interdisciplinary collaboration are to the advancement of nanotechnology-based pollution management and remediation technologies.

Keywords: Hazards, Synergistic, Ecological Effect, Nanotechnology, Strategies.

Graphical Abstract:

Introduction:

Overconsumption, dumping, and littering of plastics have resulted in widespread contamination and severe environmental repercussions. To now, only a small percentage of waste plastics are reused and recycled, creating a considerable problem in the sector. This study focuses on eco-friendly and possibly lucrative plastic separation and recovery processes, such as dissolution/reprecipitation and supercritical fluid extraction. These technologies have demonstrated encouraging results in the production of high-quality recovered polymers that are similar to virgin materials. To fully realize the potential of plastic and polymer recycling, it is critical to develop industrial standards, biodegradability certification programs, and effective consumer education to help them pick ecologically friendly goods. In addition, future research will emphasize the creation of novel multi-phase compatibilizers and highly effective recycling methods. enhancement of standardized assessment systems for recovered plastics and goods. Plastic waste management has become a critical issue as a result of excessive use and a lack of appropriate recycling options [1]. Alternative approaches, such as energy recovery and chemical recycling, have been investigated to overcome the disadvantages of traditional recycling technologies, such as high labour costs and water contamination. Everything that we receive is wrapped, boxed, and protected in plastic. Ultimately, we cannot argue that plastic has become a need in our day-to-day existence. Plastic is present in the environment (air and water) in the form of microplastics which enter our body through various modes [2] Figure 1.

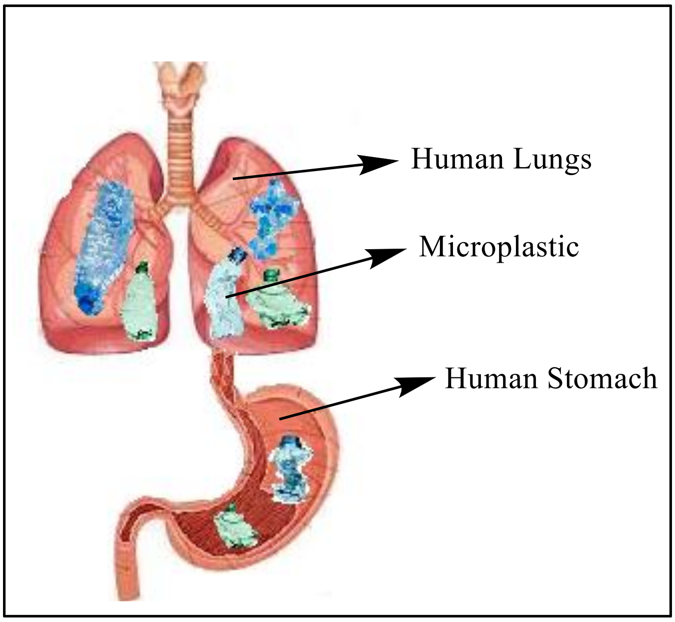

Fig. 1: Microplastics present in the human system

Approximately 200 tons of plastic waste is dumped into the rivers, lakes, and oceans every day which harms lakes, rivers, and seas' aquatic environment in a way that cannot be replaced. Research shows that just a small percentage of plastics are recycled, with the remainder adding to environmental degradation. Plastic waste persists in environmental landfills for a very long time, harming wildlife greatly, dispersing toxins, and eventually killing various living things. Some hazardous toxic chemicals can harm the environment, either through direct pollution or by contributing to secondary effects such as climate change or ecosystem disruption **[3]**. Here are some examples mentioned below:

1. **Pesticides and Herbicides**: Chemicals used in agriculture to suppress weeds and pests can seep into the ground and contaminate non-target creatures, aquatic life, and pollinators like bees.
2. **Heavy Metals:** Ecosystems and humans are both at risk from metals including lead, mercury, cadmium, and arsenic. They can build up in the food chain, water, and soil, resulting in extensive environmental harm as well as health issues.
3. **Chlorofluorocarbons (CFCs):** These artificial materials were widely used such as in Aerosol propellants, air conditioning, and refrigerators. They resulted in ozone layer depletion which shields the planet from dangerous UV radiation, to thin, increasing the risk of UV exposure and its consequences for human health and the ecosystem.
4. **Organic pollutants that linger (POPs):** POPs are organic substances that are resistant to deterioration and have a lengthy environmental half-life. Dioxins, some insecticides, and polychlorinated biphenyls (PCBs) are a few examples. They bioaccumulate in organisms, endangering human health and animals.
5. **Nitrogen and Phosphorus:** Overuse of phosphorus and nitrogen fertilizers in farming can result in eutrophication by nutrient runoff into water bodies. This process causes hazardous algal blooms and fish fatalities by lowering oxygen levels in aquatic habitats.
6. **Plasticizers:** To give plastics flexibility and durability, chemicals like phthalates and bisphenol A (BPA) are utilized. They can seep into the environment from plastic items, contaminating food supplies, soil, and water. Certain plasticizers have negative impacts on animal and human reproductive and developmental health because they are endocrine disruptors.
7. **Persistent Microplastics:** Microplastics are environmental contaminants that are omnipresent and consist of tiny plastic particles less than 5 mm. They may cause harm to marine life, make their way up the food chain, and even endanger human health if consumed.

Plastic Recycling

Plastic waste recycling is a crucial step in mitigating the environmental impact of plastic materials. Recycling plastic debris can help to reduce the quantity of plastic that ends up in landfills and seas and prevent harm to ecosystems Figure 2. By implementing the 3rs approach of reduce, reuse, recycle we can effectively manage plastic waste and promote a more sustainable future.

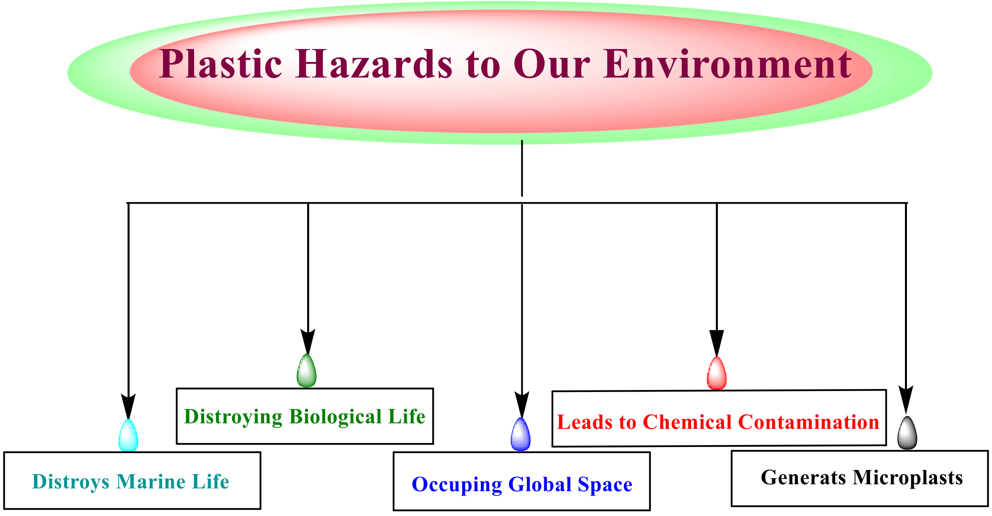

Fig. 2: Plastic hazards to our environment

Addressing the environmental impact of these chemicals requires concerted efforts, including regulation, pollution prevention measures, and the development of safer [4]. The main ones are plastics and polymers that need to be degraded for the sake of the environment Table 1 [5-11].

Table 1: Types of plastic with grade code and its utensils

S.No.	PLASTIC	GRADE CODE	EXAMPLE		REFERENCE
1.	POLYETHYLENE TRTRAPHTHALATE	♳	WATER BOTTLES, JARS, CAPS		[5]
2.	HIGH DENSITY POLYETHYLENE	♴	SHAMPOO BOTTLES, GROCERY BAGS		[6]
3.	PLYVINYL CHLORIDE	♵	CLEANING PRODUCTS, SHEETINGS		[7]
4.	LOW-DENSITY POLYETHYLENE	♶	BREAD BAGS, PLASTIC FILMS		[8]
5.	POLYPROPYLENE	♷	YOGURT CUPS, STRAW, HANGERS		[9]
6.	POLYSTYRENE	♸	TAKE-AWAY AND HARD PACKAGING TOYS		[10]
7.	OTHER	♹	BABY BOTTLES, NYLON, CDs		[11]

Additionally, adopting advanced methods and systems for the collecting, salting, and reprocessing of recyclable plastics and further enhance recycling efforts and create new opportunities for the circular economy. Furthermore, government policies and regulations should prioritize the reduction of plastic consumption, encourage the use of renewable energy in the recycling process, and enforce extended producer responsibility to ensure that manufacturers accept responsibility for the whole life cycle of the products. By working together and involving the public, businesses, and governments, we can redirect the bulk of plastic trash from landfills to recycling facilities over the next several decades.

1. Destroying marine life: Recent studies have shown the massive volumes of plastic debris that pollute rivers and oceans. Rivers, shorelines, and boats are some of the places where plastic debris enters the ocean. Sea turtles, seabirds, sharks, fish, and all other forms of aquatic life are affected by plastic garbage. Animals suffocate, become tangled in or stuck in abandoned bottles or ne, and stuff plastic into their bellies thinking it's food and others. When the animals die, the environment in which they are essential components begins to vanish as well.

In addition to killing marine life, plastic pollution damages ecosystems by ruining their habitats **[**12]. The vast plastic clumps found thousands of miles across, comprising actual tons of plastic, are known as the ocean garbage patches. Ocean currents have trapped small microplastic beads in place along with solid plastic trash in some regions. These regions currently include enormous tracts of the ocean and are inaccessible to the majority of organisms. Ocean ecosystem declines have effects that go beyond the sea [13]. Humanity also suffers from hunger, excessive heat, extensive soil degradation, and other disasters.

2. Destroying biological life: In addition to harming the ecosystem, plastic kills animals on land. They tangle and choke in different ways just like aquatic animals do and this has repercussions for ecosystems, which are dependent on all of their components for survival. The population decreases and ecology gets smaller and weaker. They tangle and choke in different ways which has repercussions for ecosystems that rely on all of their components. The ecosystem becomes weaker and smaller. Initial studies show that plastic has a detrimental influence on plant growth. This impacts not just the carbon-storing and oxygen-producing ecosystems nearby, but also our capacity to cultivate crops and feed animals.

3. Occupying global space: Keeping plastic waste under control is difficult, especially considering the number of plastic weights produced daily. Globally human activity generates 380 million tons of plastic waste annually which is a huge number. The weight of plastic is not the problem. The space that plastic waste takes up is a major issue. Since most people don’t want to live next to a landfill, finding a place to dispose of plastic waste typically requires transporting it far away. Recycling looks like a way to deal with this issue [14]. Ninety percent of plastic garbage, however, is burned or buried. Plastic manufacturers deceived people into thinking that plastic could be recycled, even though this isn't practical. Recycled plastic cannot be reused more than once or twice, is far more expensive to recycle, and has fewer applications. Avoiding plastic that will end up in the trash is the wisest course of action.

.4. Leads to chemical contamination: Plastic pollutes the environment. Plastics are essentially formed of gas and oil. Unsafe chemical compounds such as benzene, toluene, ethylbenzene, xylene, carbon monoxide, hydrogen sulfide, ozone, sulfur dioxide, and many more are produced during the mining of these nonrenewable resources. A large portion of the world either burns plastic waste or tries to recycle it because there is nowhere to keep plastics. Toxic substances released into the air by these two activities are bad for the environment and people.

5. Generates microplastics: Plastics do not break down easily as compared to organic stuff. Many materials, including paper, cotton, and hemp decompose into harmless chemicals. Plastics do not break down in some ways, but the resulting very small plastic particles known as microplastics, can be bigger than a stone or smaller than a single cell. These microscopic particles pollute people, soil, plants, animals, and waterways. These can be smaller than a single cell or larger than a stone. Microplasts pollute humans, soil, plants, animals, and waterways. Recently, the consequences of microplastics have been investigated. Microplastics have been demonstrated to have an impact on the microorganisms that inhabit the soil, its bacteria, and the tiny insects that aid in decomposition. Microplastics also affect animals in several ways, such as growth retardation, reproductive organ damage, DNA damage, and more. When microplastics degrade, the chemicals that coat plastics such as chemical stabilizers and flame retardants also leak out. It seems probable that a comprehensive understanding of the consequences of microplastics will take years to come [15].

Plastic Stewardship

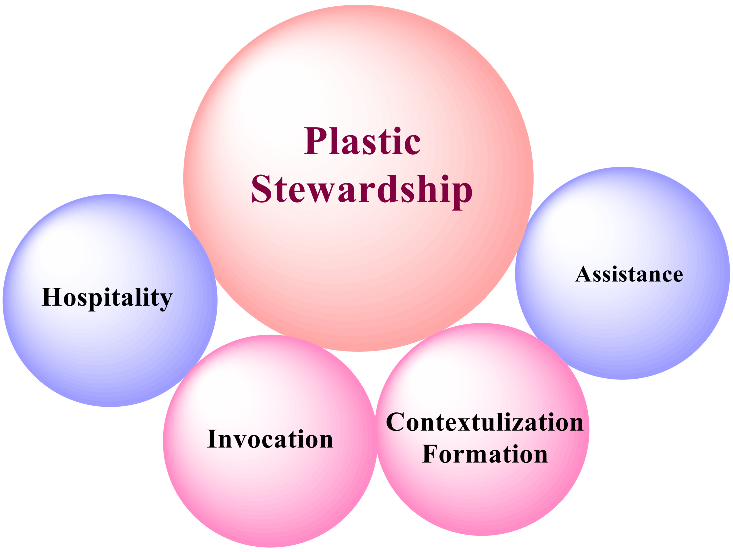

Fig. 3: Major Pillars of Plastic Stewardship

The term "plastic stewardship" describes initiatives that assist in gathering, reducing, and recycling plastic waste to lessen plastic pollution. It entails funding initiatives in order to implement waste management strategies. Over the previous few years, there has been a double growth in plastic garbage worldwide, reaching about 350 tons annually. The launch of a new plastic stewardship program by a prominent international nonprofit standard-setter and the 3R program, a coalition dedicated to reaching zero plastic waste. This initiative will create the first comprehensive framework in the world for businesses to verifiably manage and decrease plastic trash. It is essentially a pledge to continuously develop any field. This encompasses numerous programs, organizations, and centers, as well as a sizable crew that operates globally. This involves a lot of funding. Stewardship is primarily based on four pillars Figure 3 [16].

Nanotechnology

Nanotechnology has the potential to transform a number of sectors and solve environmental issues. By manipulating and controlling materials at the nanoscale, nanotechnology offers opportunities for developing innovative solutions that promote sustainability and reduce environmental impacts for example, in environmental remedies, nanotechnology offers the possibility of creating highly effective and selective methods for the removal of air, water, and soil pollution. Additionally, nanotechnology can play an important role in energy production and storage by enabling the development of high-performance batteries, photovoltaic cells, and catalytic systems. Moreover, nanotechnology can also contribute to the development of lightweight and durable materials for transportation, reducing fuel consumption and emissions [17]. Furthermore, nanotechnology can enhance the efficiency of water treatment processes by improving filtration membranes and developing advanced sensors for monitoring water quality. The field of nanotechnology has emerged as a promising solution for addressing environmental challenges. By harnessing the unique properties of nanoparticles, researchers are able to develop innovative approaches for pollution control, water purification, and sustainable energy generation. These NPscan adsorb and degrade harmful contaminants, such as heavy metals and organic pollutants, leading to cleaner and safer environments [18].

Impact of Nanotechnology on Plastic Degradation

Metal oxide NCs, particularly gold NCs, have the potential to avoid or decrease pollution at their source. Pollution control applications include air cleaning, low-light autocatalysis, and hydrogen purification for fuel cells. Gold NCs are commonly used because of their high activity rate, which reduces operating expenses for chemical plants. Gold NC has low activation energy and can increase activity with moisture. CO oxidation may occur at temperatures ranging from 90 to 400 K. Au NPshave hemispherical forms, and the particles' perimeter interfaces serve as reaction sites. Titanium dioxide (TiO_2) NPs have photocatalytic characteristics, making them ideal for creating self-cleaning surfaces that minimize pollution. When exposed to UV rays, it acts as a strong oxidizing agent [19]. This aids in the reduction of hazardous pollutants such as VOCs and nitrous oxides. Nanotechnology-enabled novel chemical degradation pathways offer targeted, efficient methods for breaking down a range of pollutants, including plastics. There are encouraging options for tackling the worldwide problem of plastic pollution thanks to nanotechnology. Although it's not a perfect answer, it offers novel ways to break down plastics more quickly.

NPs can act as catalysts to accelerate the degradation of plastics. These catalysts break down the long-chain polymers in plastics into tiny and more manageable molecules. Metals like titanium dioxide or iron oxide (NPs), and carbon nanotubes are commonly used due to their catalytic and adsorption properties. Doping of some compounds with nanoparticles needs to degrade hazardous plastic components. These additives can enhance the biodegradability of plastics by providing more surface area for microbial action or by making the material more accessible to enzymes. Graphene oxide (GO) is a kind of altered graphene that has been used for environmental cleanup by adsorbing a wide range of gaseous and aqueous pollutants, including SOx, H_2S, NH_3, volatile organic compounds, heavy metals, pesticides, and medicines [**20**]. Graphene oxides (GOs) include many oxygen-containing functional groups on their carbon surfaces, including carboxylic acids, epoxides, and hydroxyls. The layered GO structure's extreme acidity promotes acid-base interactions with basic contaminating gasses like ammonia.

Enzymes are biological catalysts that can break down specific types of plastics. By using nanotechnology, enzymes can be encapsulated in NPs, which protects them from denaturation and enhances their stability and activity. These nano-encapsulated enzymes can then be incorporated into plastic products to facilitate their degradation. NPscan be incorporated into biodegradable polymers to create nanocomposites with improved properties. These NCs can exhibit enhanced biodegradability while maintaining the structural integrity and mechanical strength required for various applications in the ecosystem. Nanotechnology can also be utilized for monitoring and assessing the degradation of plastics in the environment [21]. Nano-sized sensors can be designed to detect degradation products or changes in the physical properties of plastics, providing valuable information for waste management and pollution control efforts. Biosensors come in a variety of sizes and are capable of measuring and identifying even trace quantities of illness [22]. Analyte: lactose, glucose, and ammonia). Bioreceptors: these are molecules or elements that have the ability to detect the target substrate. For example: cells, enzymes, antibodies, DNA, RNA, etc. Additionally, it's crucial to consider the entire lifecycle of nanotechnology-based solutions to ensure they don't introduce unintended consequences or further environmental harm.

Modified NPs are becoming increasingly important in a range of industries, including infrastructure, aviation, energy generation, and medicinal applications. However, the degradation of these materials releases reactive or toxic substances in the environment, which has a negative impact on performance. The oxidation, mechanical wear, chemical and biological degradation, and loss of protective coatings are examples of potential environmental degradation mechanisms that could impact the environmental transformation and durability of NPs, nanostructured surfaces, and NCs. The ability of NPs to increase the efficiency of microplastic removal techniques is already in use [23]. Frequent landfilling, and burning of plastic trash reduces water absorption, resulting in soil sterility. Aquatic creatures congregate in streams where plastic waste is deposited, endangering aquatic life. Other degrading techniques are time-consuming and unreliable. NPscome in a variety of sizes and shapes, which can improve their physicochemical stability and degradation. The photocatalytic degradation of NPs demonstrated that adding zinc oxide NPs (ZnO) to LDPE films increases the rate of degradation after 200 hours of irradiation. Furthermore, weight loss of the polymer verified the photocatalytic activity of ZnO (NPs).

Conclusion:

Whatever problems or impacts it may have, no one can argue that plastic has become an essential component of nearly everything. Its popularity stems from its adaptability, and finding a substitute is undoubtedly a mammoth challenge. Despite a decade of research and several substitutes proposed, nothing has come close to defeating plastic on a large scale. However, this does not rule out further study into plastic substitutes. Various nanotechnology approaches have been synthesized to make materials combined with, such as milk protein, grape waste, PCL polyesters, and so on. Biopolymers are a strong contender for replacing plastics because they combine the adaptability of biomolecules with the benefits of nanoparticles. Nanotechnology brings up numerous potentials in the sphere of plastic deterioration, bringing the globe a contemporary and efficient answer to mankind's largest challenge of polymer degradation.

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ROLE OF NANOTECHNOLOGY IN THE STUDY OF MATERIALS AT AN ATOMIC OR MOLECULAR SCALE

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Abstract:

The study on basic associations between the substantial properties and different types of phenomena of production as well as determination of material's dimensions in the nanometer scale (1 to 100 nm) are referred to as Nanoscience. The Nanoscience has a distinctive dimension span, which lies between sub-nanometer to quite a few hundred nanometers. The Nanometer scaled materials may possess substantial properties uniquely different from that of massiveness material. Thus, materials in this dimension range show their unique physical and chemical properties. An alteration from atoms or molecules to massiveness form also takes place in this dimension range. When the materials are restricted to the nanometer range, they may lose their all properties. Nanotechnology is latest but investigation on nanoscaled size materials is not new at all. Nanotechnology represents the designing, production and application of materials at atomic and molecular scales, so as to produce new nanometer scaled materials. The synthesis of Nanoparticles mainly done by several different chemical, physical and biological techniques. Each technique has its own significance and Nanoparticles synthesized by a specific technique are utilized in an explicit field. On characterization, it is clinched that Nanoparticles are the superlative advanced materials to apply in nearly every arena of research and technology for routine life applications. It also includes the elementary perceptive of the substantial properties and phenomena of production of nanostructures and nanomaterials. A rapid development of Nanoscience and Nanotechnology will not be possible unless it is not supported by a strong background of theoretical study such as First Principle Study in the same area of experimental field.

Keywords: First Principle Study, Nanoscale, Nanomaterials, Substantial Properties.

Introduction:

Nanotechnology is the ability to build micro and macro materials and products with atomic precision. The Greek word "nano" which means dwarf refers to a dimension laying in one thousand times smaller than a micron. One nanometer is one billionth of a meter and it is also equivalent to ten Angstroms. One nanometer is ten thousand times lesser than the diameter of a human hair. One cubic nanometer is unevenly twenty times the volume of a discrete atom. Structures in nanoscale are known as nanostructures and are considered at the borderline of the smallest of human-made devices and the largest molecules of alive systems. Our ability to control and manipulate nanostructures will make it possible to adventure new physical, biological and chemical properties of systems that are intermediate in size, between single atoms, molecules and bulk materials.

There are some specific reasons why nanoscale has become so important. The quantum mechanical properties of electrons inside matter are influenced by variations on the nanoscale. By nanoscale design of materials, it is possible to vary their microscopic and macroscopic properties, such as charge capacity, magnetization and melting temperature without altering their chemical composition. A key feature of biological entities is the systematic organization of matter on the nanoscale. Developments in nanotechnology would allow us to place man-made nanoscale things inside living cells. It would also make it possible to make new materials using the self-assembly features of nature. This certainly will be a powerful grouping of biology with materials science. Nanoscale components have very high surface to volume ratio making them ideal for use in composite materials, reacting systems, drug delivery, and chemical energy storage (such as hydrogen and natural gas). Macroscopic systems made up of nanostructures can have much higher density than those made up of microstructures. They can also be better conductors of electricity. This can result in new electronic device concepts, smaller and faster circuits, more sophisticated functions, and greatly reduced power consumption simultaneously by controlling nanostructure interactions and complexity.

Atomic and Molecular Basis of Nanotechnology

Having worked on the molecular theory of matter one always is exposed to the quantum- mechanical Heisenberg Uncertainty Principle with the significance that the position and momentum of an object cannot simultaneously and precisely be determined [1]. Then the first questions that may come into mind is how could one be able to encounter aside the Heisenberg Uncertainty Principle to work at the atomic and molecular level, atom by atom as is the basis of nanotechnology. The Heisenberg Uncertainty Principle helps determine the size of electron clouds and hence the size of atoms. According to Heisenberg "The more precisely the position is determined, the less precisely the momentum is known". Heisenberg's Uncertainty Principal applies only to the subatomic particles like electron, positron, photon, etc. It does not forbid the possibility of nanotechnology which has to do with the position and momentum of such large particles like atoms and molecules. This is because the mass of the atoms and molecules are quite large and the quantum mechanical calculations by the Heisenberg Uncertainty Principle places no limit on how well atoms and molecules can be held in place [2].

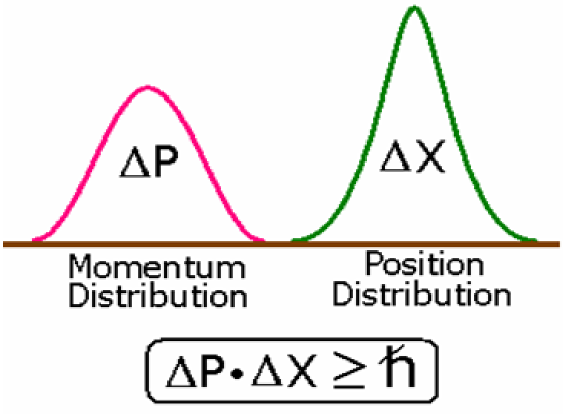

Fig. 1: Heisenberg Uncertainty Principle

Historically nanotechnology was for the first time formally recognized as a worthwhile field of research in his lecture given by Richard P. Feynman with the title "There's Plenty of Room at the Bottom" on December 29th 1959 at the annual meeting of the American Physical Society [3]. Feynman described then the advances made in this field in the past and he envisioned the future for nanotechnology. His lecture was published in the February 1960 issue of Engineering & Science quarterly magazine of California Institute of Technology**.**

In his talk Feynman described how the laws of nature do not limit our ability to work at the molecular level atom by atom. Instead, he said, it was our lack of the appropriate equipment and techniques for doing so. Feynman in his lecture talked about "How do we write small?", "Information on a small scale", possibility to have "Better electron microscopes" that could take the image of an atom, doing things small scale through the "The marvelous biological system", "Miniaturizing the computer", "Miniaturization by evaporation" example of which is thin film formation by chemical vapor deposition, solving the "Problems of lubrication" through miniaturization of machinery and nanorobotics, "Rearranging the atoms" to build various nanostructures and nanodevices, and behavior of "Atoms in a small world" which included atomic scale fabrication as a bottom-up approach as opposed to the top-down approach that we are accustomed to [4]. Bottom-up approach is self-assembly of machines from basic chemical building blocks which is considered to be an ideal through which nanotechnology will ultimately be implemented. Top-down approach is assembly by manipulating components with much larger devices which is more readily achievable using the current technology.

It is important to mention that almost all of the ideas presented in Feynman's lecture, and even more, are now under intensive research by numerous nanotechnology investigators all around the world. Later Feynman in 1983 suggested that a scale able manufacturing system could be made which will manufacture a smaller scale replica of itself [5]. That, in turn would replicate itself in smaller scale, and so on down to molecular scale.

We have made substantial progress on the fundamentals of bottom-up approach nanotechnology. Some of the important achievements include the manipulation of single atoms on a silicon surface [6], positioning single atoms with a scanning tunneling microscope [7] and the trapping of single 3 nano meter colloidal particles from solution using electrostatic methods [8]. In 1960s when Feynman recognized and recommended the importance of nanotechnology the devices necessary for nanotechnology were not invented yet. At that time, the world was fascinated with space discoveries and exploration and desire for travel to the moon.

Current Detections and Developments

Nanotechnology received its greatest momentum with the invention of scanning tunneling microscope (STM) in 1985 by Binnig and Rohrer [9]. STM allows imaging solid surfaces with atomic scale resolution. It operates based on tunneling current, which starts to flow when a sharp tip is mounted on a piezoelectric scanner approaches a conducting surface at a distance of about one nano meter. This scanning is recorded and displayed as an image of the surface topography. Actually, the individual atoms of a surface can be resolved and displayed using STM. After the Nobel prize award in 1986 to Binnig and Rohrer for the discovery of STM it was quickly followed by the development of a family of related techniques which together with STM may be classified in the general category of Scanning Probe Microscopy (SPM) techniques. Of the latter technologies, the most important is undoubtedly the atomic force microscope (AFM) developed in 1986 by Binnig, Quate and Gerber [10]. AFM is a combination of the principle of STM and the stylus profilometer. It enables us to study non- conducting surfaces, because it scans van der Waals forces with its "atomic" tips. Presently several vendors are in the market with commercial AFMs. AFM and STM possess three-dimensional resolutions up to the atomic scale which cannot be met by any other microscope. The AFMs sold by most manufacturers are generally user-friendly and they produce detailed images. AFM has found versatile applications in nanotechnology as well as other fields of science and engineering.

Figure 2 shows a schematic of the typical AFM tool. The main components of this tool are thin cantilever with extremely sharp (10 Å to 100 Å in radius) probing tip, a 3D piezo-electric scanner and optical system to measure deflection of the cantilever. When the tip is brought into the contact with the surface or in its proximity or is tapping the surface it being affected by a combination of the surface forces (attractive and repulsive). Those forces cause cantilever bending and torsion which is continuously measures via. the deflection of the reflected laser beam. 3D scanner moves the sample or in alternative designs, the cantilever, in 3 dimensions thus scanning predetermined area of the surface. A vertical resolution of this tool is extremely high reaching 0.1 Å (1 Å is on the order of atomic radius).

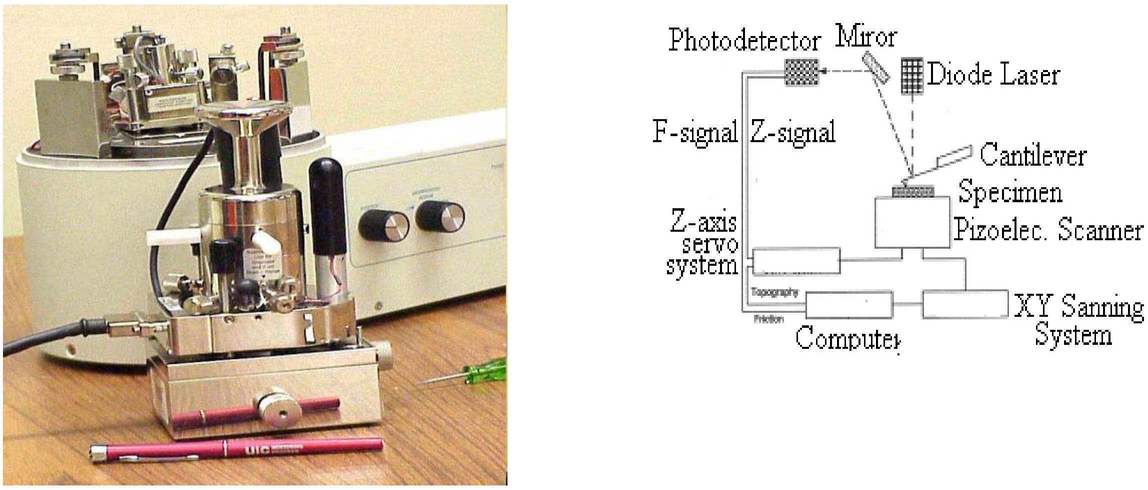

Fig. 2: Schematic of the typical AFM and its function

Buckminster fullerene (or fullerene), C60, as is shown in Figure 3 is another allotrope of carbon (after graphite and diamond), which was discovered in 1985 by Kroto and collaborators [11]. These investigators used laser evaporation of graphite and they found C_n clusters (with $n > 20$ and even-numbers) of which the most common were found to be C_{60} and C_{70}. For this discovery by Curl, Kroto and Smalley were awarded the 1996 Nobel Prize in Chemistry.

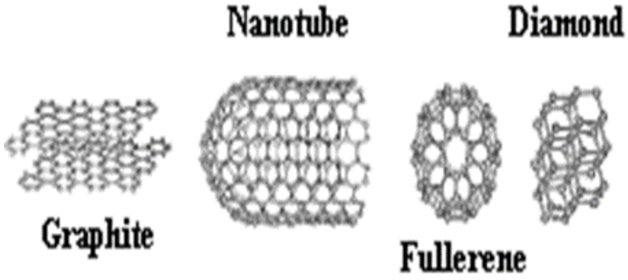

Fig. 3: Nanostructures

Carbon nanotubes were discovered by Iijima in 1991 [12] through vaporizing carbon graphite with an electric arc under an inert atmosphere and its chemical vapor deposition. The nanotubes produced by Iijima appeared to be made up of a perfect network of hexagonal graphite rolled up onto itself to form a hollow tube.

There is a great deal of interest and activity in the present day to find applications for fullerene and carbon nanotube. Considering the marvelous applications which these nanostructures could have in nanotechnology it will be necessary to understand their physical and chemical properties, their stability and behavior under stress and strain, their interactions with other molecules and nanostructures and their utility for novel applications. Another recent observation of the behavior of fluid water in a nanotube [13]. According to this the vacuum condition outside of the nanotube is not capable of removing the water droplets and bubbles out of the nanotube.

Many other impulsive advances resulting from nanotechnology are expected for different type of materials [14-17]. Thus, the future prospects for nanotechnology actually represents a revolutionary super-cutting-edge field that is expected to eventually become the foundation for such currently disparate areas as and many others that we cannot even predict at this time. It is then no sensation that it is considered to lead the humanity to the following industrial revolution.

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ROLE OF NANOTECHNOLOGY IN THE STUDY OF ELECTRONICS

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Abstract:

A nanotechnology has become a revolution that deeply affects many disciplines, especially electronics. This chapter explores the role of nanotechnology in electronics research and highlights the impact of nanotechnology on smaller devices, improved performance, and new functions. By processing materials at the nanometer scale, scientists can create electronic devices with unprecedented properties and enable advances in fields such as integrated circuits, sensors, and electronic storage devices. In addition, nanotechnology has spurred the development of nanoelectronics, and nanoscale structures have led to new phenomena and quantum effects for practical applications. This chapter focuses on the main nanomaterials used in electronics, including carbon nanotubes, graphene, and quantum dots, and discusses their unique properties and applications. In addition, it highlights the latest achievements and future prospects in the integration of nanotechnology and electronics, paving the way for future electronic devices with unparalleled performance and operation.

Introduction:

Nanotechnology has revolutionized the field of electronic devices by designing and manufacturing nanometer-scale devices that are typically less than 100 nanometers in size.This has made the production of electronic devices smaller, faster, and more efficient. A brief summary of the role of nanotechnology in electronics.

Improved Performance: Nanomaterials exhibit unique properties that can improve the performance of electronic devices. For example, carbon nanotubes and graphene are highly conductive, making them ideal for use in high-performance transistors and batteries.

Energy Efficiency Nanotechnology supports the development of energy efficient products. Nanomaterials can make technology more efficient by reducing power consumption in devices such as LEDs and solar cells.

New Possibilities: Nanotechnology opens new possibilities for electronic devices with new capabilities. Quantum dots, for example, are nanoscale semiconductor particles used to create beautiful colors in words.

Flexible Electronics: Nanotechnology supports the development of flexible and practical electronic devices. Nanomaterials, such as nanowires and nanotubes, can be combined into flexible materials, allowing the creation of electronic devices that can be repaired. Nanomaterials can be used to detect many substances, including gases, chemicals and biomolecules, with high sensitivity and selectivity. The product is more than just a path to a useful device with new features. It can only be defined as nanotechnology, which allows the integration of electronic materials, electronic materials and electronic materials. effort.

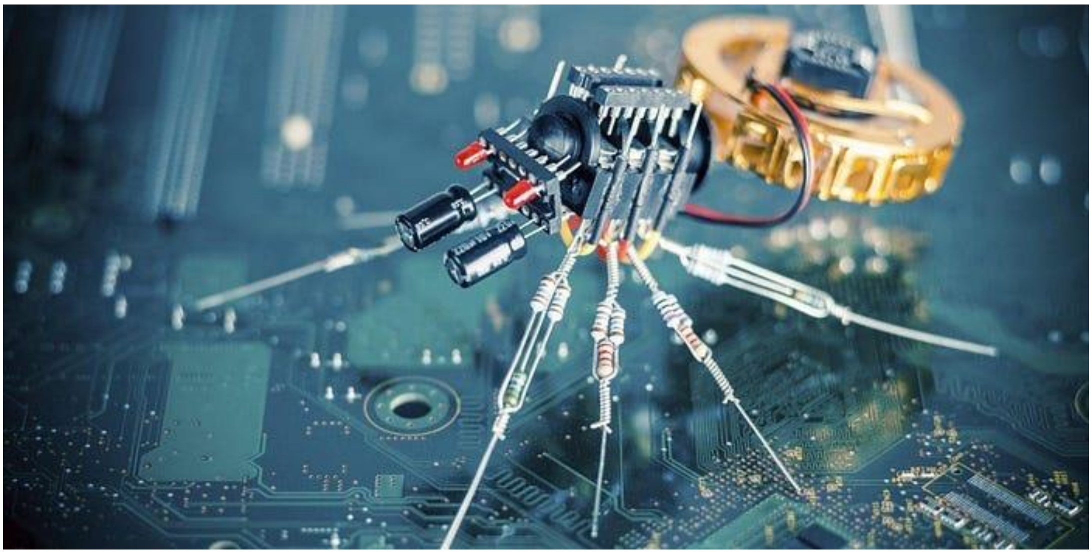


Fig. 1: Nanoelectronic components

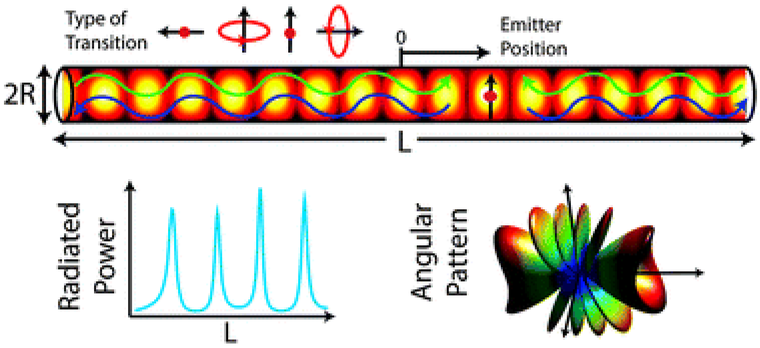
Nanoelectronics studies the electrical and magnetic properties of nanoscale systems. The major branch of nanoelectronics mainly involves the study of electrical and magnetic properties of nanoscale systems. Its main fields include hybrid inorganic-organic electronics, spintronics and quantum electronics, which combine aspects of electrical engineering, physics, chemistry, information science and nanotechnology.

Nanoscale components used in nanoelectronics are divided into two main groups:

Inorganic Nanocrystals

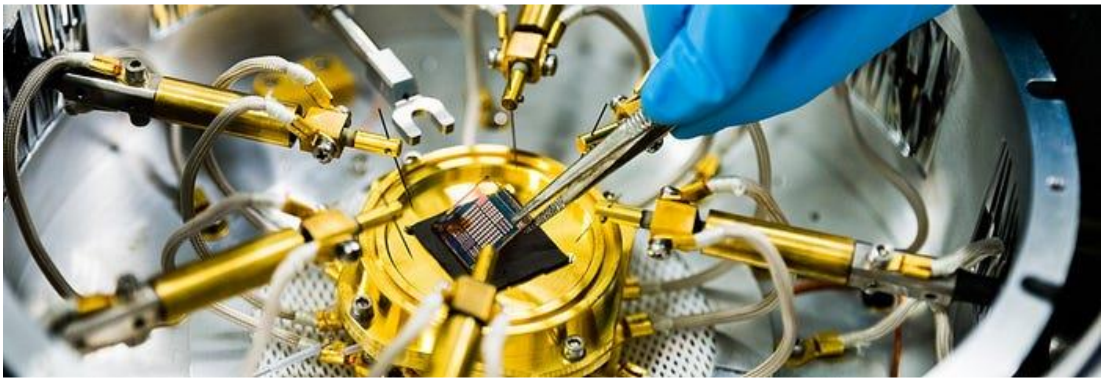
Organic Molecular Components

Inorganic nanocrystals, such as nanotubes and nanowires, are named because of their physical shape, which is generally a low-dimensional (approximately nanometer scale) structure determined by growth dynamics.



Because of this process's relevance to silicon fabrication, electronic determination, and material modification, semiconductor nanowires may find many applications in wafer technology. Molecules with different schemes, molecular monolayers and supramolecular systems.

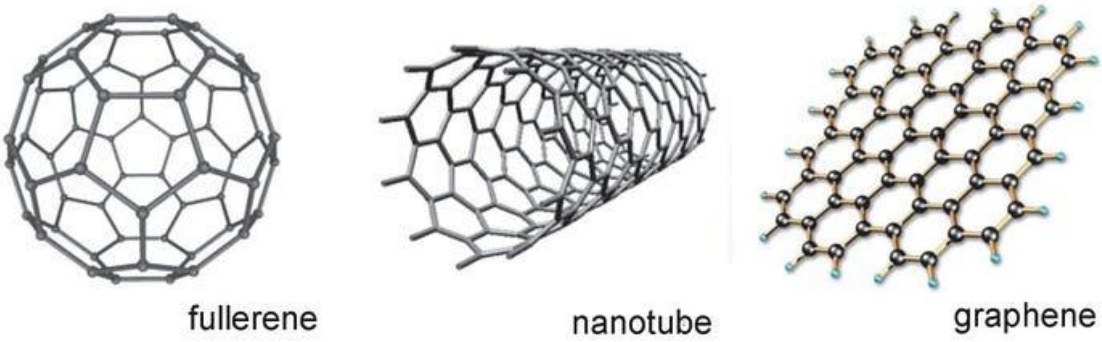
Molecular components (organic) such as molecular wires, single molecules, monolayers a nd supramolecular systems in different schemes



It is prepared with a mixture of mercury, so changes in chemical composition and adverse properties will be minor. Molecular nanocomponents have the best future in making low-energy, ultra-dense and low-end computing chips.

Materials in Nanoelectronics

Materials commonly used in nanoelectronics include zero-dimensional materials such as quantum dots, such as nanoclusters of nanotubes and nanowires, and nanocomposites, such as carbon nanotubes; fullerenes and graphene;



Carbon based materials such as carbon nanotubes, fullerenes, and graphene are often used in nanoscale processes because carbon can form bonds with other elements and these bonds can be easily modified through physical and chemical interactions. About nanosilver ink). Thin film supercapacitors are made from printed materials to form flexible materials on plastic.

Applications of Nanomaterials:

Nanoelectronics The term nanoelectronics refers to the use of nanotechnology in electronic devices. These particles are usually only a few nanometers in size. But the smaller the electronics, the more difficult they are to create.

Nanoelectronics covers a wide range of materials and devices, the special feature of which is the small size that affects the physical change of objects (nanoscale objects), in which interatomic interactions and quantum mechanical forces play an important role in their operation. equipment. At the nanoscale, new phenomena precede those governing the macroscopic world. Quantum effects, such as tunneling and atomic matter, dominate the properties of these nanoscale components. The smallest working transistor is now 7 nanometers long, which is more than 1.4 million times smaller (1 centimeter is equal to 10 million nanometers). The result of these efforts is a multi-billion-transistor processor that will bring 20 billion transistor-based circuits to a single die as the industry adopts 7-nanometer manufacturing technology.

Nanoelectronic Devices Spintronics

In addition to transistors, nanoelectronic devices also play an important role in data storage (memory). Here spintronics (the research and development of current devices for competition between electrons and their magnetic moments and electric charges) is already a mature technology. Read more: "Graphene Spintronics - From Science to Technology".

Spintronics is also playing a role in new technologies that use quantum behavior for computing (read more: â€ œQuantum Computing Moves Forward with Advances in Spintronics and The Birth of Topological Spintronicsâ).

Optoelectronics

Electronic devices that emit, capture, and control light (e.g., optoelectronics) come in many shapes and forms. Low-power (also low-power and high-power) optical communications have become important because they can solve one of the biggest problems of our information age: utility.

In the field of nanotechnology, materials such as nanofibers (e.g.: "Nanofibers paved the way for optoelectronic textiles") and carbon nanotubes have been used, and graphene in particular has shown promise for positive properties in optoelectronics.

Display

Display technology can be divided into three main technology areas: organic LEDs, electronic panels and other materials used to display important images, and equipment electricity. Read our special section on nanotechnology products for more information.

Wearable, Flexible Electronics

The age of wearable electronics has arrived, as evidenced by the rapid growth of smartwatches, fitness trackers, and other consumer monitoring devices such as e-adhesive tattoos. br> Research now shows that wearable electronics will go far beyond small electronics or portable computers. Not only will these tools be incorporated into the data in data, but electronic or mechanical devices will also become the data itself. Electronic textiles (e-textiles) will enable the creation and production of a new generation of clothing with electronic materials and electronics. Such e-textiles need to have flexibility, processing, storage, emissions and mobility (think healthcare or new human-machine connections), aim to use low-cost electronic materials (see examples such as single-walled carbon nanotube electronics) to monitor diabetes "temporary tattoos for" or "graphene nanosensor tattoos on teeth to monitor oral diseases".

Nanoelectronics in Energy

Solar cells and supercapacitors are examples of areas where nanoelectronics play an important role in energy production and storage. For more information, read our detailed articles on Nanotechnology in Energy and Graphene Nanotechnology in Energy.

Molecular Electronics

Unlike nanoelectronics, where materials are scaled to the nanoscale level, molecular electronics deals with electronic processes that occur in molecular structures, such as those found in molecular structures, from photosynthesis to signaling.

Molecular electronics aims at a fundamental understanding of charge transfer by molecules and is driven by the vision of molecular circuits to enable small, powerful and energy-saving computers (see for example: "More optoelectronic components for molecular electronics").

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ROLE OF NANOTECHNOLOGY IN THE STUDY OF SPACE EXPLORATION

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Abstract:

Nanotechnology has emerged as a pivotal enabler in the realm of space exploration, offering transformative solutions to the multifaceted challenges encountered beyond Earth's atmosphere. This abstract encapsulates the diverse roles of nanotechnology in advancing space exploration endeavours. Firstly, nanomaterials with exceptional strength-to-weight ratios revolutionize spacecraft construction, facilitating the development of lightweight yet durable components essential for efficient space missions. Secondly, nanotechnology contributes to radiation protection through the creation of advanced shielding materials capable of mitigating the deleterious effects of cosmic and solar radiation on astronauts. Furthermore, the miniaturization of instruments and sensors at the nanoscale enhances scientific capabilities for extra-terrestrial research and spacecraft monitoring. Energy generation and storage systems benefit from nanostructured materials, ensuring sustainable power sources for prolonged space missions. Nanotechnology also revolutionizes water purification and recycling systems on board spacecraft, ensuring a reliable supply of clean water for astronauts. Efficient thermal management solutions based on nanomaterials maintain optimal operating conditions within spacecraft, safeguarding sensitive equipment from thermal stress. In the realm of space medicine, nanotechnology facilitates the development of innovative biomedical technologies for monitoring and addressing health issues faced by astronauts in space. Moreover, nanotechnology holds promise for revolutionizing propulsion systems, paving the way for faster and more cost-effective space exploration missions. This abstract underscore the indispensable role of nanotechnology in enhancing the safety, sustainability, and scientific potential of space exploration, propelling humanity towards new frontiers in the cosmos.

Introduction:

Nanotechnology plays a crucial role in space exploration, offering solutions to challenges such as spacecraft miniaturization, energy production, and materials science. Here are some key areas where nanotechnology contributes to space exploration:

Miniaturization: Nanotechnology enables the development of smaller and lighter spacecraft, which reduces launch costs and allows for more efficient use of space. Nanosatellites, for example, can be deployed in constellations for various applications such as Earth observation and communication.

Materials Science: Nanomaterials exhibit unique properties that can improve the performance of spacecraft components. For example, carbon nanotubes are used to strengthen materials and improve their conductivity, which is crucial for electronics and thermal management systems in space.

Sensors and Detectors: Nanoscale sensors and detectors can be used for various purposes in space exploration, such as detecting environmental conditions, monitoring spacecraft health, and studying celestial bodies.

Energy Generation and Storage: Nanotechnology enables the development of lightweight and efficient energy generation and storage systems, such as nanoscale solar cells and Nano batteries, which are essential for long-duration space missions.

Propulsion: Nanotechnology is being explored for advanced propulsion systems, such as nanoscale thrusters and fuel additives, which could improve the efficiency and speed of spacecraft.

Radiation Protection: Nanomaterials can be used to develop lightweight and effective shielding against cosmic radiation, which is a significant concern for human space exploration beyond Earth's magnetosphere.

Space Manufacturing: Nanotechnology enables the development of advanced manufacturing techniques for producing components and structures in space, which can reduce the need for resupply missions from Earth.

Overall, nanotechnology has the potential to revolutionize space exploration by enabling the development of more efficient, reliable, and cost-effective spacecraft and technologies for exploring the cosmos.

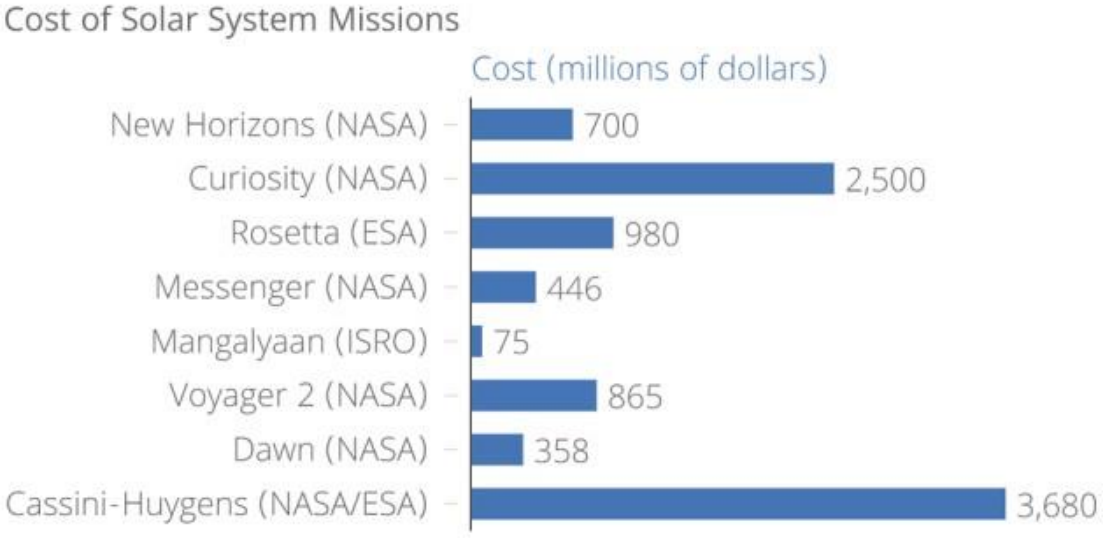

Fig. 1: Cost of Solar System Missions

Nanotechnology for Space Exploration

Space exploration is a prime candidate to take advantage of nanotechnology. It’s expensive and risky, and in many ways currently, extremely inefficient. Picture the millions spent on space missions, the satellites and astronauts lost, and the sheet investment of time needed for even the simplest endeavour.

These expenses, risks and inefficiencies are what makes nanotechnology so appealing, because the benefits and capabilities that nanotech promises could solve a lot of these problems.

Propulsion

Propulsion is one of the most significant challenges to developing fast and convenient space travel. Make no mistake, we’ve gotten pretty good at building rockets that go really fast—even fast enough to get into orbit around the planet—but that’s when things slow right down. While launch rockets are great at what they were designed to do (lift a giant tube away from the planet), they aren’t meant for the slower speed and fuel longevity required for extended travel. Once a spacecraft wants to leave orbit and journey somewhere else, a different kind of propulsion engine is required.

Solar sails could be the solution, and are one of the technologies that sees a lot of potential in nanotechnology. As a propulsion device, solar sails use the pressure of solar radiation against a highly reflective expanse of material to create thrust, and therefore don't need additional propellant fuel. However, solar sails do need to have a very large surface area that is extremely reflective, but also extremely thin and lightweight.

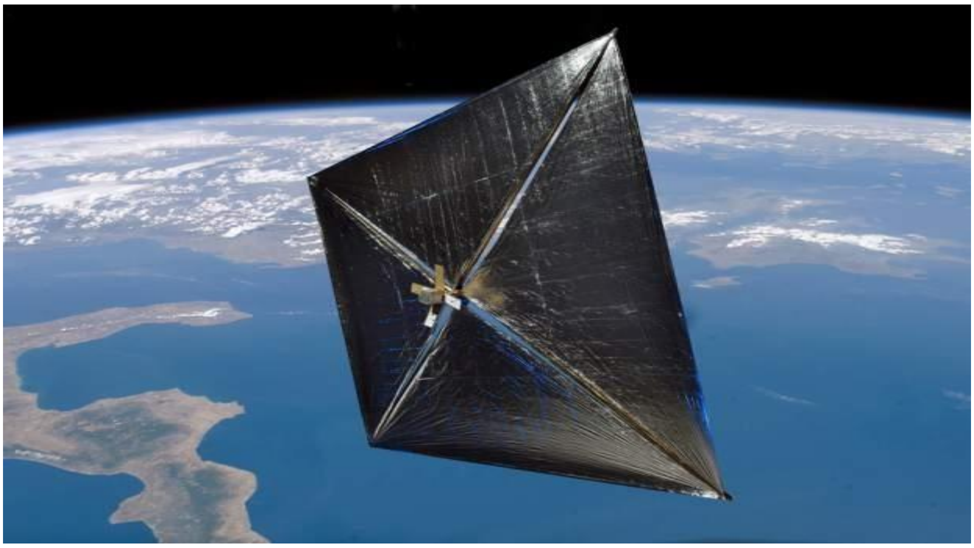

Fig. 2: The Solar Sail Demonstration mission led by NASA and L’Garde Inc. aimed to prove the viability of using ultra thin sails and sunlight for propulsion
(Image courtesy of NASA)

Materials engineered using nanotechnology can satisfy these requirements. Effective solar sails have to be hundreds of meters—or even kilometres—wide in order to have enough surface area to create the necessary propulsion to travel inter-planetary or interstellar distances. Carbon nanotube-based materials in particular are a Nano technological solution, able to be made into strong, lightweight and extremely thin sheets that could replace the polymer and aluminium solar sail materials currently used for sail prototypes. Advanced nanomaterials could also be designed to have specific properties, such as being highly reflective.

Planetary Exploration with Nano-bots and Nanos-Sensors

Exploring the surface of a distant planet using swarms of tiny Nano robots is another popular application of nanotech in space.

Currently, the Mars rovers—Spirit, Opportunity and Curiosity—have been the greatest success stories when it comes to planetary exploration. But as scientifically rich as these missions have been, each rover can only examine one small area at a time, and their movement speeds are quite slow. It's understandable, given the time lags involved in communicating between Earth and Mars, and the complexity of the instructions and data that must be relayed back and forth. Understandable, but extremely slow.

Fig. 3: Low-angle self-portrait of NASA's Curiosity Mars rover. Taken August 5th, 2015, the image is a composite showing the vehicle and the site where it performed drilling operations, dubbed "Buckskin" on lower Mount Sharpe. Future planetary exploration using nanobots would replace these types of rovers, and provide faster and more detailed mapping, chemical analysis, atmospheric composition and other vital data (Image courtesy of NASA)

This is where a Nano robot swarm could be beneficial. Imagine if a single landed rover could deploy a mass of tiny Nano bots capable of travelling across the planet's surface, or drifting on wind and through the atmosphere, to survey large swaths of a planet quickly and in great detail—even down to the molecular level.

With the development of Nano bots that operate using some form of artificial intelligence (AI) that enables them to communicate and self-organize, then the possibilities are almost limitless. A planetary surface survey mission could see Nano-bots rolling or crawling across the landscape, collecting sensor data on the minerals and compounds in the air and ground, testing for toxicity or measuring radiation, and then assembling into a communication antenna to transmit the data back to a hub station or satellite for further analysis and relay back to Earth.

Nanomaterials for Enhanced Spacesuits

Travelling to other planets, and exploring them with Nano bots, is only half the journey – eventually, humans will want to travel to these planets, and explore the surface for themselves. Spacesuits enhanced with nanotechnology will be an essential aspect of getting humans safely to other planets, and enabling them to spend time exploring—since, as of yet, there are no planetary surfaces discovered (other than Earth, of course) which have breathable atmosphere, and radiation during space travel and on an extra-terrestrial planet's surface is a constant concern.

Fig. 4: Spacesuits made from nanomaterials will be lighter and more flexible, allowing astronauts to explore and maneuver easily

The potential for self-repairing nanomaterials is once again a key element, as one of the most significant threats facing astronauts is the possibility of puncturing their suit and creating a breach that lets oxygen escape, or lets a toxic atmosphere inside.

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NANOTECHNOLOGY AND ITS ROLE IN BIOLOGICAL, CHEMICAL, AND PHYSICAL SCIENCES

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