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The Comprehensive Features, Current Aspects, Synthesis, Characterization and Role of Nanomaterials in Modern Industries through Nanotechnology

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Abstract

Nanotechnology has attained the valuable significant attention throughout time because to its compelling and pioneering uses in the forthcoming industrial age, particularly in relation to nanomaterials. Nanomaterials find applications in several areas, including agriculture, biomedicine, electronics, energy, transportation, communications, cosmetics, coatings, materials, and mechanical engineering. Numerous techniques have been used to fabricate nanoparticles (NPs) with precise control over their form, size, dimensions, and structure. There may be exist two primary methodologies for the synthesis of nanoparticles, namely the top-down and bottom-up techniques. These nanoparticles include core/shell (CS) nanoparticles, gold nanoparticles (Au-NPs), nickel nanoparticles (Ni-NPs), platinum nanoparticles (Pt-NPs), copper oxide nanoparticles (CuO-NPs), zinc oxide nanoparticles (ZnO-NPs), palladium nanoparticles (Pd-NPs), and silicon nanoparticles (Si). The physicochemical qualities may vary depending on the size and form of the object. There are many categories of nanocomposites, including ceramic matrix nanocomposites, metal matrix nanocomposites, and polymer matrix nanocomposites. Semiconductor materials have characteristics that lie between those of metals and nonmetals, making them very versatile and widely used in numerous applications, as documented in the literature. Semiconductor nanoparticles have broad bandgaps, resulting in notable modifications to their characteristics via bandgap tuning. Carbon nanotubes (CNTs) and graphene are widely recognized as prominent constituents within the carbon-based nanomaterials category. There are many aspects of the functional nanomaterial needed to explore their chemical and physical potentials for the use in the sub valuable industries areas.

Keywords: Nanotechnology, applications, food engineering, transportation, communications, cosmetics, coatings, materials.

INTRODUCTION

The key distinguishing trait of all nanomaterials is their size. The concept of size is readily comprehensible, yet its application is challenging due to the absence of inherent, tangible or chemical demarcations that define the "nanoscale." Conventionally, nanomaterials are referred to as falling within the size range of 1-100 nm, although there lacks a distinct threshold that definitively distinguishes the nanoscale from a chemical or biological standpoint. Nanotechnology encompasses the processes of synthesizing, developing, and using nanoparticles within the realm of scientific inquiry. Nanotechnology has valuable significant attention throughout time because to its compelling and pioneering uses in the forthcoming industrial age, particularly in relation to nanomaterials.

Nanomaterials find applications in several areas, including agriculture, biomedicine, electronics, energy, pollution abatement, food engineering, transportation, communications, cosmetics, coatings, materials, and mechanical engineering [1, 2]. Numerous studies have examined the effectiveness of exposure control techniques, including confinement, ventilation, replacement, process improvements, and the use of personal protective equipment. Furthermore, the use of control banding has been proposed as a valuable approach for assessing the potential hazards associated with engineered nanomaterials. The determination of the need and nature of exposure control measures is contingent upon the accurate assessment of the hazards associated with exposure to engineered nanomaterials (ENMs). Accurate identification of the pathways of exposure is crucial, as it dictates the approach to be taken in assessing exposure and the methods used for managing the associated risks [3, 4].

Nanoscience advancements have significantly impacted several scientific disciplines, leading to the development of nanotechnologies that have greatly facilitated daily living in the contemporary period. The field of nanoscience and nanotechnology is seeing significant growth since it encompasses the study of structures, devices, and systems that possess unique features and functionalities resulting from the precise arrangement of their constituent atoms. The advent of diverse spectroscopic methods has accelerated scientific inquiry and advancements within the realm of nanotechnology. The researchers much focused the development of scanning tunneling microscopy (STM), a technique that enabled the visualization of individual atoms on planar surfaces. Subsequently, atomic force microscopy (AFM) was invented and has since emerged as the most significant scanning probe microscope technique. The enhance the storage capacity of hard disks prompted the exploration of electrostatic and magnetic forces through these microscopy methods. As a result, the field progressed to include the emergence of Kelvin-probe microscopy, electrostatic microscopy, and magnetic-force microscopy. At now, nanotechnology is undergoing significant advancements and is increasingly integrated into several domains associated with materials chemistry. The area of nanotechnology is continuously advancing, with the emergence of more sophisticated characterization and synthesis techniques that enable the production of nanomaterials with enhanced dimensional control [5,6]. The field of nanoscale science and engineering provides a novel opportunity to enhance our comprehension and manipulation of matter at the atomic and molecular scales. The exceptional electrical, optical, and magnetic characteristics of nanoscale particles have garnered significant interest. These nanoscale particles possess the physical characteristics that provide them viable options for use in the field of nanoengineering. The pursuit of innovative technological advancements in the fields of data storage, biological sciences, and drug delivery has been a driving force behind the extensive study on nanoparticles. These nanoparticles include core/shell (CS) nanoparticles, polymer-coated nanoparticles, silver nanoparticles (Ag-NPs), copper nanoparticles (Cu-NPs), gold nanoparticles (Au-NPs), nickel nanoparticles (Ni-NPs), platinum nanoparticles (Pt-NPs), copper oxide nanoparticles (CuO-NPs), zinc oxide nanoparticles (ZnO-NPs), palladium nanoparticles (Pd-NPs), and silicon nanoparticles (Si) [7-10].

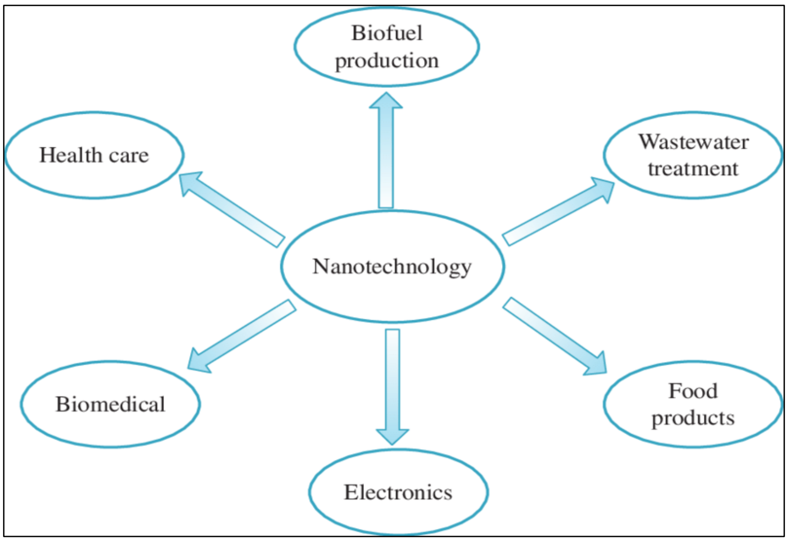

Fig-1: Shows the applications of the nanotechnology in different fields

Several categories of the functional nanomaterials

Nanomaterials have garnered significant attention from scientists due to their nanoscale dimensions, expansive surface area, adjustable band gaps, surface morphology, and promising prospects in diverse fields such as medicine, medical devices, textile industries, electrical devices, coating industries, and other industrial sectors. The nanocomposite refers to a solid substance consisting of many phases, whereby at least one of the phases has one, two, or three dimensions that are less than 100 nm. Nanocomposites have a significantly elevated surface-to-volume ratio in contrast to conventional composites. The physicochemical qualities may vary depending on the size and form of the object. Various categories of nanocomposites exist, including those composed of nanoparticles. There are many categories of nanocomposites, including Ceramic Matrix Nanocomposites (CMNC), Metal Matrix Nanocomposites (MMNC), and Polymer Matrix Nanocomposites (PMNC). Semiconductor materials have characteristics that lie between those of metals and nonmetals, making them very versatile and widely used in numerous applications, as documented in the literature. Semiconductor nanoparticles have broad bandgaps, resulting in notable modifications to their characteristics via bandgap tuning. Hence, these materials have significant importance in the fields of photocatalysis, photo optics, and electrical devices. For instance, a diverse range of semiconductor nanoparticles have shown remarkable efficacy in applications involving water splitting. This may be attributed to their appropriate bandgap and band edge locations [10, 11]. Bimetallic nanoparticles (NPs) may be synthesized by the use of alloys or by using a layered structure, known as core-shell configuration. The unusual optical and electrical features of these nanoparticles are attributed to their localized surface plasmon resonance characteristics. Furthermore, several metallic nanoparticles exhibit distinctive thermal, magnetic, and biological characteristics. This renders them progressively significant substances for the advancement of nanodevices that may be used in various physical, chemical, biological, biomedical, and pharmacological contexts. The controlled synthesis of metal nanoparticles with precise size, shape, and facets is a crucial aspect in the development of advanced materials in contemporary times [12, 13].

Metal nanoparticles may be synthesized via chemical, electrochemical, or photochemical methods. Metal nanoparticles may be created by chemical means by reducing metal-ion precursors in solution using chemical reducing agents. These materials possess the ability to adsorb molecules of tiny size and exhibit a high surface energy. Biomolecules are often used in several research domains, including the detection and imaging of biomolecules, as well as in environmental and bioanalytical applications. The process of nanoparticle production by chemical reduction involves the dissolution of metal-containing salts, referred to as precursors, which are then chemically reduced inside a suitable solvent. During the first phase of nucleation, the metal salt undergoes reduction, resulting in the formation of zerovalent metal atoms. The method of electrochemical deposition has been extensively used in the creation of metal nanoparticles. Electrochemical deposition takes place at the boundary between an electrolyte solution that contains the metal to be deposited and a metal substrate that has electrical conductivity [14-16].

Functional nanomaterials synthesis

Numerous techniques have been used to fabricate nanoparticles (NPs) with precise control over their form, size, dimensions, and structure. There exist two primary methodologies for the synthesis of nanoparticles, namely the top-down and bottom-up techniques. These approaches may be further classified into many groups depending on the specific operations and reaction circumstances [17, 18]. The bottom-up or constructive technique is an alternate strategy that utilizes a build-up approach, whereby nanoparticles are formed by assembling clusters, which are in turn derived from individual atoms. Plant extracts play a crucial role in the process of nanoparticle production. This particular procedure is sometimes referred to as green synthesis or a sustainable method of producing nanoparticles. Gold nanoparticles have been synthesized using leaves from the geranium plant, scientifically known as *Pelargonium graveolens*. The valuable 1 milliliter volume of a 1 millimolar aqueous solution of silver nitrate is introduced into a 5 milliliter volume of plant extract in order to facilitate the synthesis of silver nanoparticles. The synthesis from an alcoholic extract involves following a similar technique. The plant extract is combined with silver nitrate and placed in a shaker operating at a speed of 150 revolutions per minute in a light-restricted environment. Sonochemistry is a field of study that investigates the phenomenon of chemical reactions occurring in molecules as a result of the application of intense ultrasonic radiation. Acoustic cavitation, including the phenomena of bubble formation, development, and collapse inside a liquid subjected to ultrasonic irradiation, serves as the principal driving force behind the sonochemical process. While it is often recommended to prevent cavitation in reactor design to minimize erosion damage, acoustic cavitation plays a crucial role in sonochemical processing as it allows for the controlled and limited application of its effects specifically to the reaction, rather than the reactor itself. The utilization of this approach has been widely employed for the synthesis of nanoscale materials possessing exceptional characteristics. This is primarily attributed to the distinctive operating parameters, including exceedingly elevated temperatures (5000 K), pressures surpassing 20 MPa, and rapid cooling rates exceeding 109 K s−1. These specific conditions promote the generation of smaller particles and diverse morphologies of the resultant products, distinguishing this method from alternative techniques [19, 20]. One of the primary benefits associated with the implementation of sonochemical studies is their cost-effectiveness.

The assessment of magnetization saturation may be conducted by using a vibrating sample magnetometer. The Vibrating Sample Magnetometer (VSM) operates on the principles of Faraday's law, which asserts that a coil will experience an electromagnetic force when there is a variation in the magnetic flux that links the coil. The experimental configuration involves the movement of a magnetic sample in close proximity to two pickup coils. When a sample material is subjected to a homogeneous magnetic field, it results in the induction of a dipole moment in the sample. This dipole moment is directly proportional to the product of the sample's susceptibility and the applied magnetic field. If the sample is subjected to sinusoidal motion, it will result in the generation of an electrical signal in stationary pick-coils that are appropriately positioned. The aforementioned signal, which exhibits a frequency of vibration, demonstrates a direct correlation with the magnetic moment, amplitude of vibration, and frequency of vibration. The device displays the magnetic moment in units of electromagnetic measurement. The measurement of the magnetic moment should be conducted at the magnetic field that corresponds to it. Based on the available data, it is possible to construct the hysteresis loop for magnetic nanoparticles [21, 22].

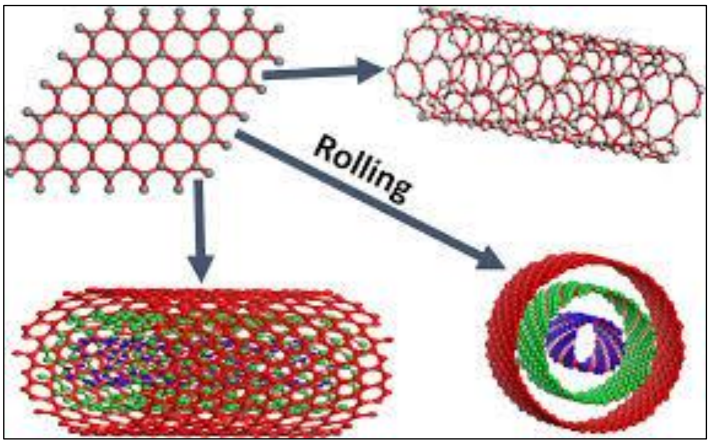

Fig-2: Shows the functional materials in different rotations

Applications of advanced functional nanomaterials

The use of nanotechnology in the agricultural sector serves to augment food production while concurrently enhancing the nutritional composition, quality, and safety of food products. Fertilizers, insecticides, herbicides, and plant growth factors/regulators are used in agricultural practices to augment crop productivity. Nanotechnology is increasingly being used in the advancement of techniques aimed at promoting seed germination, enhancing plant growth, and fortifying plant defense mechanisms. Metal nanoparticles, namely silver nanoparticles (Ag NPs) and copper nanoparticles (Cu NPs), have been the subject of much research in the field of plant science. The cost of organic synthesis is high and it entails the use of hazardous chemicals. Nevertheless, the process of nanoparticle surface functionalization enables the incorporation of a greater quantity of micronutrients into a single nanoparticle, hence facilitating effective transport to plants. The incorporation of these micronutrients has the potential to augment production and elevate the nutritional composition of agricultural goods. Carbon nanoparticles are often used in the field of agriculture due to their ability to impact the metabolic processes of plants, hence affecting their development. Hence, the use of nanomaterials at minimal concentrations has the potential to infiltrate plant cells, thereby offering a promising solution for augmenting crop output and fruit production [22, 23]. Nanomaterials exhibit notable characteristics such as substantial surface areas, magnetism, quantum phenomena, antibacterial properties, as well as elevated thermal and electrical conductivities. Metal-based materials at the nanoscale exhibit significantly elevated catalytic activity. To enhance the dispersion of these catalysts, they may be dispersed across two-dimensional sheets of other nanomaterials. This approach enhances the overall performance of metal-based catalysts. The category of nanomaterials encompasses several types such as carbon-based nanomaterials, nanoporous materials, core–shell materials, ultrathin 2-dimensional nanomaterials, and metal-based nanomaterials. Within this group, carbon-based nanomaterials are an intriguing category of nanomaterials that include many types such as fullerenes, carbon nanotubes, carbon-based quantum dots, graphene, and carbon nanohorns. Furthermore, it is possible to enhance the capabilities of carbon-based nanomaterials by further functionalizing their surfaces, hence allowing for tailored applications. Carbon nanotubes (CNTs) and graphene are widely recognized as prominent constituents within the carbon-based nanomaterials category. These materials have undergone significant investigation across many fields owing to their notable attributes, including substantial surface areas, efficient charge transfer capabilities, and exceptional mechanical robustness. The use of carbon quantum dots has garnered significant interest within the domains of sensing, nanomedicine, and bioimaging. Following the successful extraction of graphene from graphite in 2004, there was a significant surge of interest in ultrathin two-dimensional (2D) materials, owing to their remarkable and unparalleled characteristics. Consequently, a number of ultrathin nanomaterials have been documented in scientific literature, such as silicene, borophene, antimonene, MXenes, 2D MOF nanosheets, and boron nitride nanosheets. In addition to the remarkable attributes shown by ultrathin 2D materials, the current stage of experimental assessment for these materials remains in its nascent phase. Nevertheless, there is a swift and extensive exploration of these materials for their potential practical applications [23, 24].

Several research projects conducted on nanomaterials have yielded significant outcomes. Certain nanoparticles have been used in the context of industrial manufacturing. Nevertheless, there is a scarcity of literature pertaining to the molding mechanism and strengthening process of nanoparticles' microstructure. Consequently, several aspects within this field remain unexplored and need further investigation. The distinctive characteristics shown by nanoparticles confer upon them extensive possibilities for use and significant potential worth in forthcoming times. Hence, it is essential to persist in the exploration of nanomaterials and enhance our comprehension of their molding mechanism, strengthening process, and modification techniques in order to enhance their qualities. Nanoparticles (NPs) possess unique electrical and optical characteristics, making them very versatile for many applications in the fields of imaging methods and electronics. For example, the use of Gd-based nanoparticles (NPs) has been shown to enhance both the imaging resolution and the efficiency of contrast agent delivery in magnetic resonance imaging (MRI). The use of gadolinium oxide nanoparticles (Gd2O3 NPs) as a contrast agent was shown to exhibit higher efficacy compared to the conventional agent (Gd-DOTA) at equivalent concentrations. Simultaneously, Gadolinium Phosphate Nanoparticles (GdPO4 NPs) were effectively used for tumor identification by Magnetic Resonance Imaging (MRI) at a dosage that is one-tenth of the regularly administered amount of Gd-DTPA agent. An illustration of the use of Eu3+-doped oxide nanoparticles (NPs) is shown in the tracking of a solitary toxin receptor, achieving a localization accuracy of 30 nm [24, 25].

The use of microarray methodologies that rely on the identification of particular biomolecular interactions has emerged as a crucial technique in the fields of disease diagnosis, pattern analysis, and pharmaceutical exploration. The little bars are affixed at one end and designed to selectively interact with cancer-associated chemicals. These compounds have the capability to bind to modified polymer proteins that are present in some types of cancer. During the process of detection, when there are biospecific interactions between a receptor that is immobilized on one side of a cantilever and a material in a solution, the cantilever undergoes bending. By using optical detection methods, it becomes possible to determine the presence of cancer molecules [26, 27].

Quantum dots, also known as QDs, are semiconductor nanoparticles that exhibit luminescence in a specific color when illuminated by light. The luminescent properties of nanoparticles are contingent upon their dimensional characteristics. After being illuminated by actinic ray light, the quantum dots experience an increase in energy that enables some electrons to get liberated from their respective atoms. The capacity of quantum dots (QDs) to navigate inside the nanoparticle enables the formation of an electrical conduction band, facilitating the unrestricted movement of electrons across a material, hence facilitating electrical conductivity. The researchers conducted a search for innovative and cost-effective approaches to enhance energy provision and improve energy use in response to the growing energy demand resulting from population growth, urbanization, and the restricted accessibility of fuel resources. Research in the field of oil upstream mostly focuses on optimizing activities related to exploration, drilling, production, recovery, and the identification of untapped reserves. Wood has a fibrous nature, making it highly suited and versatile as a raw material for a wide range of applications. Nevertheless, the use of this material is limited in many applications owing to two distinct attributes: alterations in dimensions resulting from fluctuations in humidity, and its vulnerability to microbial biodegradation. The moisture content of wood exhibits variability, leading to instability in terms of dimensions and structural properties. This phenomenon has the potential to influence the compatibility and efficacy of many materials, including adhesives and surface coatings, when interacting with wood substrates. The manufacture of value-added wood products from low-quality resources using contemporary technology has the ability to effectively enhance the value of forest resources. This approach also contributes to the competitiveness of the wood sector in international markets. The integration of nanotechnology with a chemical impregnation method presents an enticing opportunity to augment several value-added wood qualities, such as wood surface hardness, abrasion resistance, and dimensional stability. The integration of nanotechnology with the traditional impregnation process has facilitated the development of a novel approach aimed at improving the essential wood quality attributes necessary for value-added applications. The advent of nanotechnology has lately instigated a paradigm shift in several domains of scientific research and engineering. The field of study encompasses the processes of fabrication, experimentation, manufacturing, and application of materials and technologies that operate at the nanoscale, namely within the range of 1 to 100 nm [28-35].

CONCLUSION

Different types of nanoparticles are organized in the form of complex materials and functional nanomaterials that are used for the physical and functional biomaterials. Nanoparticles (NPs) also provide the capability to see and monitor each individual molecule, so unveiling significant insights into physiological mechanisms such as the arrangement of membrane proteins and their interactions with other proteins. There are many aspects of the functional nanomaterial needed to explore their chemical and physical potentials for the use in the sub valuable industries areas.

REFERENCES

1. Pal, S. L., Jana, U., Manna, P. K., Mohanta, G. P., & Manavalan, R. (2011). Nanoparticle: An overview of preparation and characterization. *Journal of applied pharmaceutical science*, (Issue), 228-234.
2. Buzea, C., Pacheco, I. I., & Robbie, K. (2007). Nanomaterials and nanoparticles: sources and toxicity. *Biointerphases*, *2*(4), MR17-MR71.
3. Sadhra, S. S. (2008). Principles of risk assessment. In Gardiner, K., Harrington, J. M., editors. Occupational hygiene. Oxford, UK: Blackwell Publishing Ltd. pp. 105–123.
4. Sánchez Jiménez, A., Varet, J., Poland, C., Fern, G. J., Hankin, S. M., & van Tongeren, M. (2016). A comparison of control banding tools for nanomaterials. *Journal of occupational and environmental hygiene*, *13*(12), 936-949.
5. Sudha, P. N., Sangeetha, K., Vijayalakshmi, K., & Barhoum, A. (2018). Emerging Applications of Nanoparticles and Architecture Nanostructures, Elsevier, pp. 341–384.
6. Bayda, S., Adeel, M., Tuccinardi, T., Cordani, M., & Rizzolio, F. (2019). The history of nanoscience and nanotechnology: from chemical–physical applications to nanomedicine. *Molecules*, *25*(1), 112.
7. Qiu, L., Zhu, N., Feng, Y., Michaelides, E. E., Żyła, G., Jing, D., ... & Mahian, O. (2020). A review of recent advances in thermophysical properties at the nanoscale: From solid state to colloids. *Physics Reports*, *843*, 1-81.
8. Chivere, V. T., Kondiah, P. P., Choonara, Y. E., & Pillay, V. (2020). Nanotechnology-based biopolymeric oral delivery platforms for advanced cancer treatment. *Cancers*, *12*(2), 522.
9. El-Naggar, M. E., Hasanin, M., & Hashem, A. H. (2022). Eco-friendly synthesis of superhydrophobic antimicrobial film based on cellulose acetate/polycaprolactone loaded with the green biosynthesized copper nanoparticles for food packaging application. *Journal of Polymers and the Environment*, 1-13.
10. Hisatomi, T., Kubota, J., & Domen, K. (2014). Recent advances in semiconductors for photocatalytic and photoelectrochemical water splitting. *Chemical Society Reviews*, *43*(22), 7520-7535.
11. Khan, I., Abdalla, A., & Qurashi, A. (2017). Synthesis of hierarchical WO3 and Bi2O3/WO3 nanocomposite for solar-driven water splitting applications. *International Journal of Hydrogen Energy*, *42*(5), 3431-3439.
12. Dreaden, E. C., Alkilany, A. M., Huang, X., Murphy, C. J., & El-Sayed, M. A. (2012). The golden age: gold nanoparticles for biomedicine. *Chemical Society Reviews*, *41*(7), 2740-2779.
13. Mody, V. V., Siwale, R., Singh, A., & Mody, H. R. (2010). Introduction to metallic nanoparticles. *Journal of Pharmacy and bioallied sciences*, *2*(4), 282.
14. Gazi, A. S., & Sailaja, A. K. (2018). Preparation and Characterization of Paracetamol Loaded Eudragit S100 Nanoparticles by Salting Out Technique. *J Dev Drugs*, *7*(01), 3-6.
15. Tiruwa, R. (2016). A review on nanoparticles-preparation and evaluation parameters. *Indian journal of pharmaceutical and biological research*, *4*(2), 27-31.
16. Mohanraj, V. J., & Chen, Y. J. T. J. O. P. R. (2006). Nanoparticles-a review. *Tropical journal of pharmaceutical research*, *5*(1), 561-573.
17. Tiwari, J. N., Tiwari, R. N., & Kim, K. S. (2012). Zerodimenstional, one- dimensional, two-dimensaional and threedimensional nanostructured materials for advanced electrochemical energy devices, *Progress in Materials Science*, 57, 724-803.
18. Veziroglu, S., Hwang, J., Drewes, J., Barg, I., Shondo, J., Strunskus, T., & Aktas, O. C. (2020). PdO nanoparticles decorated TiO2 film with enhanced photocatalytic and selfcleaning properties. *Materials Today Chemistry*, 16, 100251.
19. Mirkin, C., & Tuominen, M. (2011). Nanotechnology research directions for societal needs in 2020, Springer, The Netherlands.
20. Zha, J., & Roggendorf, H. (1990). In Sol-gel science, Brinker, C. J., & Sherer, G. W. (Eds.), Academic Press, New York.
21. Yang, H., & Clegg, C. M. (2013). STM Study of Self-assembly of Quantum Dot Formed by Selective Laser Heating. *MRS Online Proceedings Library (OPL)*, *1527*, mrsf12-1527, 1-6.
22. Aljabali, A. A. A., Obeid, M. A., Al Zoubi, M. S., Charbe, N. B., Chellappan, D. K., Mishra, V., Dureja, H., Gupta, G., Prasher, P., & Dua, K. (2021). Handbook of Nanocelluloses. Springer; Cham, Switzerland. Nanocelluloses in Sensing Technology; pp. 1–30.
23. Xue, J., Pisignano, D., & Xia, Y. (2020). Maneuvering the migration and differentiation of stem cells with electrospun nanofibers. *Advanced Science*, *7*(15), 2000735.

24. Türkcan, S., Masson, J. B., Casanova, D., Mialon, G., Gacoin, T., Boilot, J. P., ... & Alexandrou, A. (2012). Observing the confinement potential of bacterial pore-forming toxin receptors inside rafts with nonblinking Eu3+-doped oxide nanoparticles. *Biophysical Journal*, *102*(10), 2299-2308.
25. Zou, B., Huang, C. Z., Wang, J., & Liu, B. Q. (2006). Effect of nano-scale TiN on the mechanical properties and microstructure of Si3N4 based ceramic tool materials. *Key Engineering Materials*, *315*, 154-158.
26. Lei, Q., & Juan, P. H. (2003). Application of nanotechnology for high-performance textiles, pp. 1-5.
27. Joshi, M., & Bhattacharya, A. (2011). Nanotechnology- a new route to high-performance functional textiles, *Textile Program, 43*(3), 155-233.
28. Park, B., Hurley, F., Ayres, J., Krug, H. H., Allen, G., Crutzen, P., ... & Aitken, R. (2007). *Nanotechnology: consequences for human health and the environment*. Royal Society of Chemistry.
29. Xu, W., Wang, X., Sandler, N., Willfor, S., & Xu, C. (2018). Three-dimensional printing of woodderived biopolymers: a review focused on biomedical applications. *ACS sustainable chemistry & Engineering, 6*(5), 5663-5680.
30. Kamel, S. (2007). Nanotechnology and its applications in lignocellulosic composites, a minireview. *Express Polymer Letters, 1*(9), 546-575.
31. Ali, J. A., Kalhury, A. M., Sabir, A. N., Ahmed, R. N., Ali, N. H., & Abdullah, A. D. (2020). A state-of-the-art review of the application of nanotechnology in the oil and gas industry with a focus on drilling engineering. *Journal of Petroleum Science and Engineering*, *191*, 107118.
32. Al-Shargabi, M., Davoodi, S., Wood, D. A., Al-Musai, A., Rukavishnikov, V. S., & Minaev, K. M. (2022). Nanoparticle applications as beneficial oil and gas drilling fluid additives: A review. *Journal of Molecular Liquids*, *352*, 118725.
33. Afzali, A., & Maghsoodlou, S. H. (2016). Modern application of nanotechnology in textile. *Nanostructured Polymer Blends and Composites in Textiles*, 41-85.
34. Malik, S., Muhammad, K., & Waheed, Y. (2023). Nanotechnology: A revolution in modern industry. *Molecules*, *28*(2), 661.
35. Sarvalkar, P. D., Barawkar, S. D., Karvekar, O. S., Patil, P. D., Prasad, S. R., Sharma, K. K., ... & Vhatkar, R. S. (2022). A review on multifunctional nanotechnological aspects in modern textile. *The Journal of the Textile Institute*, *114*(3), 470-487.