OPEN ACCESS
Scholars Bulletin
Abbreviated Key Title: Sch Bull
ISSN 2412-9771 (Print) | ISSN 2412-897X (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Subject Category: Chemistry

Innovative Aspect Towards the Synthesis, Characterization of Nanoparticles and Advanced Applications for Development in Various Industries

Tahira Batool[1], Saeed Ahmad[2], Muhammad Sheeraz Javed[3*], Muhammad Anees Ramzan[4], Tayyaba Riaz[5], Nimra Shahzad[6], Muhammad Jamil Khan[7], Waqas Ahmad[8], Naseem Abbas[9]

[1]Institute of Chemistry, The Islamia University of Bahawalpur
[2]School of Chemistry and Chemical Engineering, Hainan Normal University, China
[3]School of Life Sciences, Hainan Normal University, China
[4]Department of Chemistry, Government College University Faisalabad
[5]Faculty of Biosciences, Cholistan University of Veterinary and Animal Sciences Bahawalpur
[6]Laser and Optronics Centre, Department of Physics, University of Engineering and Technology, Lahore, Pakistan
[7]Department of Chemistry, Abbottabad University of Science and Technology, Abbottabad, Pakistan
[8]Department of Zoology, University of Malakand
[9]Department of Chemistry and Chemical engineering, Institute of Molecular Science, Shanxi University Taiyuan 030006, China

DOI: https://doi.org/10.36348/sb.2024.v10i07.001 | **Received:** 12.06.2024 | **Accepted:** 16.07.2024 | **Published:** 12.08.2024

***Corresponding author:** Muhammad Sheeraz Javed
School of Life Sciences, Hainan Normal University, China

Abstract

The remarkable progress in nanotechnology in the last several decades has drawn attention to nanoparticles (NPs) and their characterization, synthesis, and applications. This phenomenon is caused by changes in the mechanical, chemical, and physical properties of the materials on this scale, including their optical properties, thermal conductivity, and melting point. Since many procedures for producing metal nanoparticles need high temperatures and harsh chemical conditions, scaling them up for large-scale manufacture can be challenging. Generally, there are two primary methods for synthesizing nanomaterials: the bottom-up method and the top-down method. A spinning disc reactor (SDR) is used in the spinning-assisted production of nanoparticles. Carbon fullerenes are spherical cages that contain anything from 28 to over 100 carbon atoms. Because of the way they interact with carbon to generate hexagons and pentagons, which result in hollow balls, they resemble soccer balls. The chemical or elemental makeup of nanoparticles directly affects their purity and functionality. The efficiency of the nanoparticle may decline if there is a rise in secondary or undesired materials present, since this might also result in secondary reactions and contamination throughout the process. Although they are commonly supplied as dispersions in different media, including glasses or liquid solvents, they may also be produced in the gas phase to create aerosols. When gold nanoparticles are exposed to a particular wavelength of light, the light's oscillating electromagnetic field causes the free electrons to collectively oscillate coherently. The nanoadsorbents are particularly effective in reducing pollutants, and very little nanoadsorbent is needed to absorb the pollutants' components.

Keywords: Carbon fullerenes, spherical, hexagons, nanoparticle, secondary reactions, contamination.

INTRODUCTION

The scientific achievement of nanotechnology came to light in the twenty-first century. This multidisciplinary topic deals with the creation, manipulation, and use of materials smaller than 100 nm. Numerous industries, including biotechnology, biomedicine, food, agriculture, and the environment, heavily rely on nanoparticles. Wastewater treatment, environmental monitoring, functional food additives, antimicrobial agents are used nanoparticles [1-2]. Because of their cutting-edge properties such as nature, biocompatibility, anti-inflammatory and antibacterial activity, effective drug delivery, bioactivity, bioavailability, tumor targeting, and bio-absorption, nanoparticles (NPs) have found increasing applications in biotechnology and applied microbiology. One major issue is the production and manipulation of metal nanoparticles with precise control over their size and structure. Since many procedures for producing metal nanoparticles need high temperatures and harsh chemical conditions, scaling them up for large-scale manufacture can be challenging. To maximize the properties and potential applications of metal nanoparticles, it is also essential to carefully control the size and shape of the particles during production. There is a larger degree of interdependence between the optical and electrical characteristics of NPs. Noble metal nanoparticles (NPs) possess size-dependent optical characteristics and have a prominent UV-visible extinction band that is absent from the bulk metal's spectra [3-4]. The localized surface plasma resonance (LSPR) is the name given to this excitation band that arises when the input photon frequency remains constant due to the collective excitation of the conduction electrons. The wavelength selection absorption with very high molar excitation coefficient resonance is the outcome of LSPR excitation. Ray light scattering along the surface of NPs improved spectroscopies and increased local electromagnetic fields with an efficiency comparable to 10 fluorophores. It is commonly known that the LSPR spectrum's peak wavelength depends on the size [1,3,4].

Generally, there are two primary methods for synthesizing nanomaterials: the bottom-up method and the top-down method. Physical vapor deposition, chemical vapor deposition, electrospinning, 3D printing, biological synthesis, and supercritical fluid synthesis are some of the technologies that have gained prominence in the synthesis of nanomaterials recently. These methods are combined with other techniques to increase the efficiency of the synthesis. When compared to their bulk counterparts, nanomaterials exhibit a number of intriguing properties, including greater mechanical performance, the potential for surface functionalization, a high surface area, and variable porosity. These exceptional qualities explain why nanomaterials are the ideal choices in the biomedical industry for the creation of wound dressings, chemical sensors, biosensors, gene therapy, and drug delivery systems [5-6].

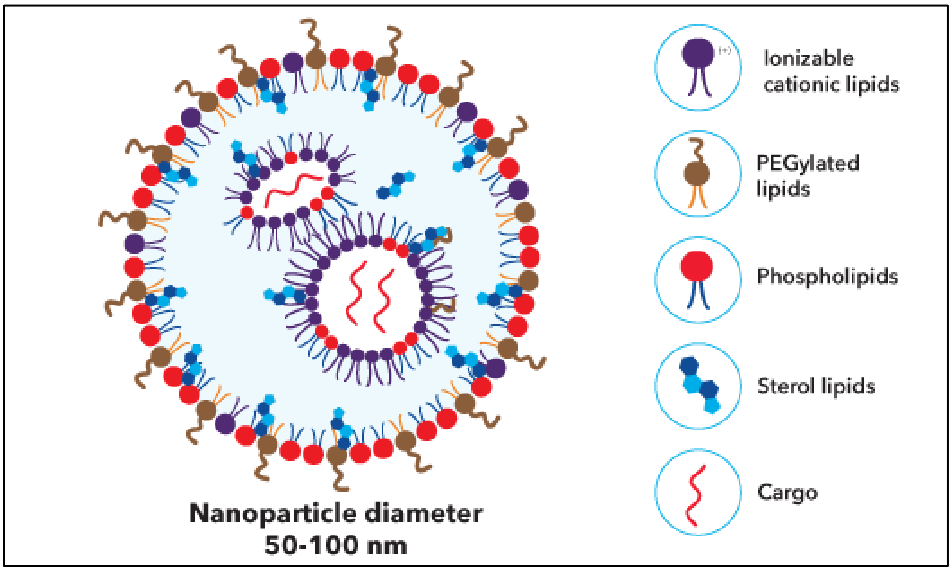

Fig-1: Shows the structure of nanoparticles with potential types

For the past fifty years, material scientists have been thoroughly studying the applications of nanoparticles and nanostructured materials across a range of industries. Nanotechnology is the use of a material's unique properties at the nanoscale. As scientific breakthroughs are debated, nanotechnology has always taken center stage and garnered a lot of attention. Because nanotechnologies enable the development of better-designed, more durable, safer, cleaner, and intelligent goods for use in everyday life, health, agriculture, communications, and other industries, they have had a significant influence on almost every aspect of society and industry [7-9]. Numerous fields have adopted the name "nanotechnology," which is quickly developing as a result of the creation of nanoproducts with unique size-related physicochemical characteristics that set them apart from bigger matter. The main objective of nanotechnology is to process, divide, and combine different materials. Because of their tiny sizes, nanoparticles can pass through living things' physiological barriers and trigger undesirable biological responses. It is known that nanoparticles may enter the human body through the skin, gastrointestinal system, or lungs. They can also induce cardiac issues, inflammation in the lungs, and brain toxicity. In fact, because of their size and makeup, certain nanoparticles have been discovered to permanently harm cells through oxidative stress and organ injury. The harmful impact of carbon-based nanoparticles on lung cancer cells. It has been proposed that variables like the nanoparticle's size, surface area, and composition how hazardous radiations can affect it [10-11].

Table1: Shows types nanoparticles with structural nature and applications

Nanoparticles type	Roles	mechanism	Usage/applications
Fullerenes based	spherical cages, their physical characteristics make them more valuable.	They expand when exposed to high pressure, but they return to their original structure when the pressure is released.	Because of their eminent properties, it is used in the electrical field.
Carbon nanotubes	Carbon nanotubes, often known as CNTs, long hexagonal networks of carbon atoms.	Highly stable are carbon nanotubes	Their compact size and unique physical, mechanical, and electrical characteristics set them apart from others.
Magnetic based	Cell destiny regulation and molecular level cell signaling have been shown to benefit from the capacity to apply a mechanical stress inside the cells.	heat-induced magnetic field generation or externally controlled	Applications for medication release, illness treatment, and remote control of single cell operations have made advantage of these capabilities

Structural organization of typical nanoparticles

The remarkable progress in nanotechnology in the last several decades has drawn attention to nanoparticles (NPs) and their characterization, synthesis, and applications. This phenomenon is caused by changes in the mechanical, chemical, and physical properties of the materials on this scale, including their optical properties, thermal conductivity, and melting point [12-13]. As per the definition of a nanoscale, nanomaterials (NMs) are described as "materials with small dimensions with building units sized between 1 and 1000 nm in at least one dimension. Beyond only a few dimensions, nanoparticles vary in forms and sizes as well. One nanoparticle can be dimensional, meaning that its length, breadth, and peak are all constant at a single factor. Examples dimensional nanoparticles are nano dots. One dimensional nanoparticle can have only one parameter, like graphene. Two dimensional nanoparticles have size and breadth, like carbon nanotubes. Three dimensional nanoparticles have all the parameters, like length, breadth, and peak, like gold nanoparticles [13-15].

Methods and developmental synthesis

A spinning disc reactor (SDR) is used in the spinning-assisted production of nanoparticles. It has a revolving disk within a chamber or reactor that can adjust body temperature and other factors. Nitrogen or other inert gases are usually pumped into the reactor to eliminate internal oxygen and prevent chemical reactions. The liquid, or precursor and water, is poured into the disc as it is rotating at a distinct speed. The atoms or molecules are driven to fuse together by the spinning, which causes them to precipitate, accumulate, and dry [16-17]. The characteristics of the nanoparticles synthesized from SDR are determined by a variety of operating factors, including the liquid glide rate, disc rotation speed, liquid/precursor ratio, proximity to feed, disc surface, etc. One economical way to convert bulk materials into nanoscale materials is by mechanical milling. Blends of various phases may be produced efficiently using mechanical milling, which also aids in the creation of nanocomposites. Aluminum alloys enhanced by oxide and carbide, wear-resistant spray coatings, aluminum, nickel, magnesium, and copper-based nanoalloys, and several other nanocomposite materials are all made via mechanical milling. Ball-milled carbon nanomaterials are thought to be a unique kind of nanomaterial that offers the chance to meet the needs of energy conversion, energy storage, and environmental cleanup [17-18].

Carbon fullerenes are spherical cages that contain particles from 28 to over 100 carbon atoms. Because of the way they interact with carbon to generate hexagons and pentagons, which result in hollow balls, they resemble soccer balls. Their physical characteristics make them more valuable than others in the class. They expand when exposed to high pressure, but they return to their original structure when the pressure is released. Those molecules were not thought of as lubricants since they lacked affinity with one another. Because of its electrical properties, it is used in the electrical field. Thus, solar cells are utilized in data storage. Comparably sized biologically active molecules inserted into its empty structure [19-20]. Carbon nanotubes, often known as CNTs, are 1 nm to 100 nm long hexagonal networks of carbon atoms. There are two varieties of carbon nanotubes (CNTs): multi-walled carbon nanotubes (MWCNTs) and single-walled carbon nanotubes (SWCNTs). Their compact size and unique physical, mechanical, and electrical characteristics set them apart from others. The molecular absorption capacity of carbon nanotubes is greater. Highly stable are carbon nanotubes [21-22].

For nanoparticles used in heat-induced magnetic field generation or externally controlled hyperthermia, magnetic characteristics are crucial. Biological items can be moved and transported by use of the magnetic force. Cell destiny regulation and molecular level cell signaling have been shown to benefit from the capacity to apply a mechanical stress inside the cells. Applications for medication release, illness treatment, and remote control of single cell operations have made advantage of these capabilities [23-24]. In the past, producing magnetic nanoparticles was an essential first step in any research aimed at enhancing their characteristics and determining if they could be used in real-world applications. Many of these nanomaterials are now readily accessible commercially, eliminating the need for individual teams or laboratories to synthesis these particles, which guarantees greater repeatability of conducted studies. In spite of this, the synthesis of nanoparticles continues to be a crucial stage in research aimed at deeper analysis, and it is unquestionably essential for the creation of novel particle kinds and synthesis techniques. One of the main physical characteristics of magnetic nanoparticles that may be used to customize other characteristics like magnetism and surface area is their size [24-25]. For instance, smaller particles have been produced via organic-phase synthesis.

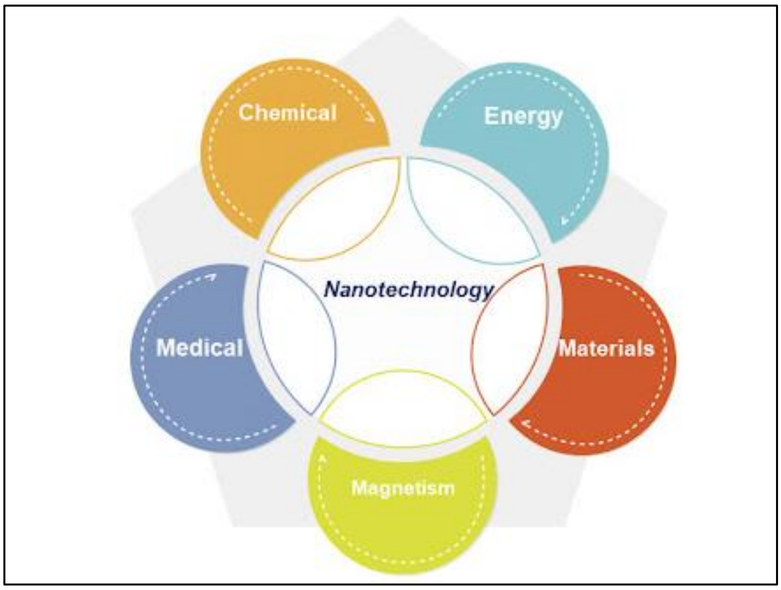

Fig-2: Applications targeted the field of nanotechnology emphasizes different potentials

The chemical or elemental makeup of nanoparticles directly affects their purity and functionality. The efficiency of the nanoparticle may decline if there is a rise in secondary or undesired materials present, since this might also result in secondary reactions and contamination throughout the process. Composition measurements are frequently performed using the X-ray photoelectron spectroscopy (XPS) method [26-28]. Under certain techniques, the particles undergo chemical digestion first, followed by a wet chemical analysis using techniques including mass spectrometry, atomic emission spectroscopy, and ion chromatography. Particles in the gaseous phase can be collected using wet chemical procedures, spectrometric methods, filtration, or electrostatic methods. The amount of nanoparticles scattered throughout the gaseous phase must be measured in order to determine the air or gas concentration required for the operation. By taking into account variables like the concentration, size, and dispersion of nanoparticles in a certain volume of air or gas, performance may be evaluated in terms of its efficacy. To perform the concentration measurements, a condensation particle counter is often used (CPC) [28-29].

Novel applications and usage in various industrialization

Nanoparticles are potential prospects for a variety of applications due to their special qualities [11]. In addition to their capacity to scatter and absorb light, gold nanoparticles (AuNPs) also use surface chemistry and nonradiative electron relaxation dynamics to transform optical energy into heat. Furthermore, gold nanoparticles are highly desirable and adaptable since they may be utilized as medication carriers. AuNPs have several desirable properties in biomedicine, including good stability and biocompatibility, low toxicity, ease of surface functionalization, and drug transferability. Additional characteristics, such size and form adaptability, have undoubtedly attracted attention to the application of gold nanoparticles in several industries. These nanoparticles are similar in size to a large number of biomolecules [30-31]. When gold nanoparticles are exposed to a particular wavelength of light, the light's oscillating electromagnetic field causes the free electrons to collectively oscillate coherently. This leads to a charge separation with respect to the ionic lattice and the formation of a dipole oscillation that runs parallel to the direction of the light's electric field. The oscillation's greatest amplitude occurs at a particular frequency known as surface plasmon resonance (SPR). The maximum extinction of the SPR Band varies from 517 nm to 532 nm in the visible range as the size of gold nanoparticles increases from 10 nm to 50 nm. This suggests that the concentration and particle size of gold nanoparticles affect both the fluorescence intensity and the absorption band. Furthermore, SPR amplifies the radiative [31-32].

Supported bimetallic gold-silver nanoparticles have been documented in phenol degradation photoreaction and a variety of CO oxidation processes. When it comes to mixed oxides, the amounts of the mesoporous support have a significant impact on the catalytic activity in addition to the chemical interaction between the metals. Numerous studies that altering the shape or structure of the support surface can enhance the catalytic activity while CO is being oxidized. The processes involved in altering nanoparticle systems with these features necessitate a thorough examination of the physicochemical characteristics of the relevant materials, Au-Ag nanoparticle alloys, which are a system that is now being investigated for oxidation system [33-34]. The silver nanoparticles (AgNPs) can boost agricultural yields, plant growth, and seed germination. They also affect how the plant grows in response to both positive and negative influences. The addition of AgNPs alters the bacterial diversity in the soil and has an impact on plant development. The functional variety of bacteria varies according to AgNP concentrations. The complex interactions between microorganisms and plants with silver nanoparticles may be simplified by controlling the concentration of AgNPs, which can boost plant growth potential without negatively impacting the environment. Furthermore, AgNPs dramatically improve fresh and dried seedling weights as well as the potential for seed germination, index, mean germination time, and seed vigor index. The colloidal AgNPs contain significant characteristics of stabilized and well-dispersed characteristics showing more adhesive agents [35-36].

For the final quality assessment, thermogravimetric analysis (TG), X-ray photoelectron spectroscopy (XPS), and infrared spectroscopy are often employed to specifically confirm the existence of the functionalization processes of carbon nanotubes. Therefore, by adjusting the CVD preparation parameters and reactants, such as time, pressure, temperature, substrate, catalyst, carbon precursor, and gas flow rate assisted with various characterization and functionalization techniques, one can obtain the optimized carbon nanotubes for numerous practical applications [37-38]. In the treatment of water and wastewater, nanoadsorbents such as carbon nanotubes and nanocomposites have been created to remove organic and biological pollutants, heavy metals, and other contaminants from the water. The nanoadsorbents are particularly effective in reducing pollutants, and very little nanoadsorbent is needed to absorb the pollutants' components. Therefore, nanoadsorbents be used as novel purifying techniques as nanotechnology advances. It is feasible to select the best adsorbent by comparing the effectiveness of nanoadsorbents and assessing how they work to remove contaminants. It should be mentioned that the wide range of uses for nanoadsorbents in water treatment stems from their high specific active surface and selectivity for absorbing the components of pollutants and poisons [38-39].

Ever since their discovery, fullerenes have drawn interest from scientists in a variety of domains. Their peculiar qualities and attributes are what set them apart from other materials and give them significance. Different applications of fullerene have been found in the industry. It may be used to create molecular networks, conductive devices, and surface coatings, among other things. Furthermore, in the sphere of medicine, a water-soluble fullerene has demonstrated efficacy against is even useful as an antioxidant [40-41]. The remarkable structure of fullerenes accounts for their particular uses. It will become challenging to do spectroscopic examination of products, purification, separation, and purity evaluation due to its limited solubility in typical organic solvents. In order to exploit fullerene-based macromolecules for biological applications, conjugation has emerged as a key tactic for getting beyond the innate hydrophobic barriers that fullerenes face. There is still a lot of research being done on the use of fullerenes in many physicochemical and pharmacological domains, and new developments and uses are always being found. Working on a small scale is a result of fullerenes' high cost and limited availability. Nanotubes with concentric cylinders made of spirally organized carbon atoms are flawless crystals that are thinner than the whiskers of graphite [42-43].

Since it permits further reactions with biomolecules, linkers, or dyes that have been functionalized with aldehyde or NHS ester, amine modification is frequently employed. For amine surface treatment, aminopropyltrimethoxysilane (APTMS) and aminopropyltriethoxysilane (APTES) are the most widely used, reasonably priced, and readily accessible chemicals. When the nuclei are produced, the aminoalkoxysilane is added during the final stages of polymerization within the Stöber process, allowing for in situ NP surface treatment. The aminoalkoxysilane reagent is usually employed excessively in these situations, and any unreacted molecules are eliminated during the purification processes [44-45]. Researchers now have fresh hope for curing hazardous dyes because of nanotechnology. Since dyes are one of the pollutants that must be removed from water bodies, nanoparticles such as zinc oxide, titanium, iron oxide, and silver are ideal for treating dyes present in water because they exhibit fast oxidation, photocatalytic activity, and antibacterial activity. Because of the distinct physiochemical characteristics of nanoparticles, the quickly expanding field of nanotechnology has demonstrated potential in the treatment of waste water over time [44-46].

CONCLUSION

The scientific community realized the need for innovative chemistries for nanoparticle synthesis, purification, and post synthetic alterations since many basic investigations and technology applications required nanoparticles with homogeneous sizes and shapes. Numerous techniques may be used to create nanoparticles. Although they are commonly supplied as dispersions in different media, including glasses or liquid solvents, they may also be produced in the gas phase to create aerosols. Using several characterization methods, including TEM, XRD, and SEM, it was discovered that NPs varied in size from a few nanometers. Moreover, control over the morphology is possible, NPs have a vast surface area because of their small size.

REFERENCES

1. Ahmad, T., Wani, I. A., Ahmed, J., & Al-Hartomy, O. A. (2014). Effect of gold ion concentration on size and properties of gold nanoparticles in TritonX-100 based inverse microemulsions. *Appl. Nanosci*. 4, 491–498.
2. Ajitha, B., Reddy, Y. A. K., & Reddy, P. S. (2015). Green synthesis and characterization of silver nanoparticles using Lantana camara leaf extract. *Mater. Sci. Eng*. C 49, 373–381.
3. Al-Dhabi, N. A., Mohammed Ghilan, A.-K., & Arasu, M. V. (2018). Characterization of silver nanomaterials derived from marine Streptomyces sp. al-dhabi-87 and its in vitro application against multidrug resistant and extended-spectrum beta-lactamase clinical pathogens. *Nanomaterials* 8:279.
4. Ganesh, M., Hemalatha, P., Peng, M. M., & Jang, H. T. (2017). One pot synthesized Li, Zr doped porous silica nanoparticle for low temperature CO2 adsorption. *Arabian Journal of Chemistry*, *10*, S1501-S1505.
5. Garrigue, P., & Delville, M. H. (2004). C. Labrug re, E. Cloutet, PJ Kulesza, JP Morand, A. Kuhn. *Chem. Mater*, *16*, 2984-2986.
6. Jiao, L., & Barakat, N. (2011). Balanced depth and breadth in a new interdisciplinary nanotechnology course. *Journal of Educational Technology Systems*, *40*(1), 75-87.
7. Khan, I., Saeed, K., & Khan, I. (2019). Nanoparticles: Properties, applications and toxicities. *Arabian journal of chemistry*, *12*(7), 908-931.
8. Abid, N., Khan, A. M., Shujait, S., Chaudhary, K., Ikram, M., Imran, M., ... & Maqbool, M. (2022). Synthesis of nanomaterials using various top-down and bottom-up approaches, influencing factors, advantages, and disadvantages: A review. *Advances in Colloid and Interface Science*, *300*, 102597.
9. Winterer, M., & Hahn, H. (2022). Nanoceramics by chemical vapour synthesis. *International Journal of Materials Research*, *94*(10), 1084-1090.
10. Zhou, M., Bao, S., & Bard, A. J. (2019). Probing size and substrate effects on the hydrogen evolution reaction by single isolated Pt atoms, atomic clusters, and nanoparticles. *Journal of the American Chemical Society*, *141*(18), 7327-7332.
11. Mi, J. L., Liang, J. H., Yang, L. P., Wu, B., & Liu, L. (2019). Effect of Zn on size control and oxygen reduction reaction activity of Co nanoparticles supported on N-doped carbon nanotubes. *Chemistry of Materials*, *31*(21), 8864-8874.
12. Nimesh, S., & Chandra, R. (2022). *Theory, techniques and applications of nanotechnology in gene silencing*. River Publishers.
13. Wang, B., Zhao, M., Mehdi, M., Wang, G., Gao, P., & Zhang, K. Q. (2019). Biomolecule-assisted synthesis and functionality of metal nanoclusters for biological sensing: a review. *Materials Chemistry Frontiers*, *3*(9), 1722-1735.
14. Viljoen, J. P., & Viljoen, R. (2021). Embracing Industrial Revolutions.
15. Vishwanath, R., & Negi, B. (2021). Conventional and green methods of synthesis of silver nanoparticles and their antimicrobial properties. *Current Research in Green and Sustainable Chemistry*, *4*, 100205.
16. Freese, S., Glasser, G., Susewind, M., Lieberwirth, I., Hofe, T., & Jonas, U. (2024). Morphological design of PDVB-based particles. *Nano Select*, *5*(3), 2300064.
17. Mekuye, B., Höfer, R., & Mebratie, G. (2024). Computational Study of the Effect of the Size-Dependent Dielectric Functions of Gold Nanomaterials on Optical Properties. *Advances in Condensed Matter Physics*, *2024*(1), 8846112.
18. Tan, C. H., Low, S. S., Cheah, W. Y., Singh, J., Chai, W. S., Tiong, S. K., & Show, P. L. (2024). Futuristic opportunities for pretreatment processes in biofuel production from microalgae. *GCB Bioenergy*, *16*(5), e13136.
19. Lombardo, D., Kiselev, M. A., & Caccamo, M. T. (2019). Smart nanoparticles for drug delivery application: development of versatile nanocarrier platforms in biotechnology and nanomedicine. *Journal of nanomaterials*, *2019*(1), 3702518.
20. Mousavi, S. Z., Nafisi, S., & Maibach, H. I. (2017). Fullerene nanoparticle in dermatological and cosmetic applications. *Nanomedicine: Nanotechnology, Biology and Medicine*, *13*(3), 1071-1087.
21. Yamaguchi, T., Bandow, S., & Iijima, S. (2004). Synthesis of carbon nanohorn particles by simple pulsed arc discharge ignited between pre-heated

carbon rods. *Chemical physics letters*, *389*(1-3), 181-185.

22. Wu, W., He, Q., & Jiang, C. (2008). Magnetic iron oxide nanoparticles: synthesis and surface functionalization strategies. *Nanoscale research letters*, *3*, 397-415.
23. Sun, C., Lee, J. S., & Zhang, M. (2008). Magnetic nanoparticles in MR imaging and drug delivery. *Advanced drug delivery reviews*, *60*(11), 1252-1265.
24. Veiseh, O., Gunn, J. W., & Zhang, M. (2010). Design and fabrication of magnetic nanoparticles for targeted drug delivery and imaging. *Advanced drug delivery reviews*, *62*(3), 284-304.
25. Chomoucka, J., Drbohlavova, J., Huska, D., Adam, V., Kizek, R., & Hubalek, J. (2010). Magnetic nanoparticles and targeted drug delivering. *Pharmacological research*, *62*(2), 144-149.
26. Chaurasiya, A., Gorajiya, A., & Nirmal, J. (2022). Stability testing parameters of nanoscaled product development. In *Multifunctional Nanocarriers* (pp. 475-500). Elsevier.
27. Marsalek, R., Kotyrba, M., Volna, E., & Jarusek, R. (2021). Neural network modelling for prediction of zeta potential. *Mathematics*, *9*(23), 3089.
28. Meng, C., Das, P., Shi, X., Fu, Q., Müllen, K., & Wu, Z. S. (2021). In situ and operando characterizations of 2D materials in electrochemical energy storage devices. *Small Science*, *1*(4), 2000076.
29. Crooks, R. M., Zhao, M., Sun, L., Chechik, V., & Yeung, L. K. (2001). Dendrimer-encapsulated metal nanoparticles: synthesis, characterization, and applications to catalysis. *Accounts of chemical research*, *34*(3), 181-190.
30. Amina, S. J., & Guo, B. (2020). A review on the synthesis and functionalization of gold nanoparticles as a drug delivery vehicle. *International journal of nanomedicine*, 9823-9857.
31. Elahi, N., Kamali, M., & Baghersad, M. H. (2018). Recent biomedical applications of gold nanoparticles: A review. *Talanta*, *184*, 537-556.
32. Ghosh, P., Han, G., De, M., Kim, C. K., & Rotello, V. M. (2008). Gold nanoparticles in delivery applications. *Advanced drug delivery reviews*, *60*(11), 1307-1315.
33. Wang, A., Hsieh, Y. P., Chen, Y. F., & Mou, C. Y. (2006). Au–Ag alloy nanoparticle as catalyst for CO oxidation: Effect of Si/Al ratio of mesoporous support. *Journal of Catalysis*, *237*(1), 197-206.
34. Liu, J. H., Wang, A. Q., Chi, Y. S., Lin, H. P., & Mou, C. Y. (2005). Synergistic effect in an Au− Ag alloy nanocatalyst: CO oxidation. *The Journal of Physical Chemistry B*, *109*(1), 40-43.
35. Wang, J., Zhu, W., He, X., & Yang, S. (2008). Catalytic wet air oxidation of acetic acid over different ruthenium catalysts. *Catalysis Communications*, *9*(13), 2163-2167.
36. Pallavi, Mehta, C. M., Srivastava, R., Arora, S., & Sharma, A. K. (2016). Impact assessment of silver nanoparticles on plant growth and soil bacterial diversity. *3 Biotech*, *6*, 1-10.
37. Omidi, S., & Kakanejadifard, A. (2018). Eco-friendly synthesis of graphene–chitosan composite hydrogel as efficient adsorbent for Congo red. *RSC advances*, *8*(22), 12179-12189.
38. Atyaa, A. I., Radhy, N. D., & Jasim, L. S. (2019, July). Synthesis and characterization of Graphene Oxide/hydrogel composites and their applications to adsorptive removal Congo Red from aqueous solution. In *Journal of Physics: Conference Series* (Vol. 1234, No. 1, p. 012095). IOP Publishing.
39. Li, H., Fan, J., Shi, Z., Lian, M., Tian, M., & Yin, J. (2015). Preparation and characterization of sulfonated graphene-enhanced poly (vinyl alcohol) composite hydrogel and its application as dye absorbent. *Polymer*, *60*, 96-106.
40. Baati, T., Bourasset, F., Gharbi, N., Njim, L., Abderrabba, M., Kerkeni, A., ... & Moussa, F. (2012). The prolongation of the lifespan of rats by repeated oral administration of [60] fullerene. *Biomaterials*, *33*(19), 4936-4946.
41. Szunerits, S., Barras, A., Khanal, M., Pagneux, Q., & Boukherroub, R. (2015). Nanostructures for the inhibition of viral infections. *Molecules*, *20*(8), 14051-14081.
42. Beg, S., Rizwan, M., Sheikh, A. M., Hasnain, M. S., Anwer, K., & Kohli, K. (2011). Advancement in carbon nanotubes: basics, biomedical applications and toxicity. *Journal of pharmacy and pharmacology*, *63*(2), 141-163.
43. Burakov, A. E., Galunin, E. V., Burakova, I. V., Kucherova, A. E., Agarwal, S., Tkachev, A. G., & Gupta, V. K. (2018). Adsorption of heavy metals on conventional and nanostructured materials for wastewater treatment purposes: A review. *Ecotoxicology and environmental safety*, *148*, 702-712.
44. Patel, S. (2011). Harmful and beneficial aspects of Parthenium hysterophorus: an update. *3 Biotech*, *1*(1), 1-9.
45. Perez, H., Jorda, V., Bonville, P., Vigneron, J., Frégnaux, M., Etcheberry, A., ... & Leconte, Y. (2018). Synthesis and characterization of Carbon/Nitrogen/Iron based nanoparticles by laser pyrolysis as non-noble metal electrocatalysts for oxygen reduction. *C*, *4*(3), 43.
46. Halamoda-Kenzaoui, B., Ceridono, M., Urbán, P., Bogni, A., Ponti, J., Gioria, S., & Kinsner-Ovaskainen, A. (2017). The agglomeration state of nanoparticles can influence the mechanism of their cellular internalisation. *Journal of nanobiotechnology*, *15*, 1-15.