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Elucidating the Morphological Characteristics of Nanoparticles Entities: A Comprehensive Review

Nabeela Ikram[1], Nimra Shahid[1], Ayesha Khalid[2], Nida Fatima[2], Maryam Iqbal[1], Aiza Rafique[2], Nor ul Huda Yasin[1], Quratulain Awan[1], Arooj Ajmal[1] and Qurban Ali[3]

[1]Department of Chemistry, University of Agriculture Faisalabad, 31000
[2]Department of Physics, University of Agriculture Faisalabad, 31000
[3]Department of Botany, University of Agriculture Faisalabad, 31000

Abstract: This paper offered a comprehensive examination of nanoparticles, categorizing them by composition and discussing synthesis methods, morphological characteristics, and applications across sectors. Carbon-based, ceramic, polymeric, and metallic nanoparticles were explored, with a focus on silver oxide, zinc oxide, nickel oxide, and gold nanoparticles. Synthesis techniques and resulting morphologies were detailed, highlighting the influence of morphology on properties like optical and catalytic behavior. The paper underscored the significance of nanoparticles in fields such as healthcare, catalysis, and photonics, emphasizing their versatility and potential for innovation. Pharmaceuticals, semiconductors, environmental protection, and other sectors all heavily depend on nanoparticles (NPs). To characterize NPs concerning size, order, and surface properties, methods such as SEM, XRD, and FTIR are crucial. Such uses as medication delivery, antibacterial therapies, and energy solutions present enormous promise for these NPs. The regulation of synthesis, the effect on the environment, and large-scale production still present difficulties, notwithstanding their potential.

Keywords: Nanoparticles, SEM, XRD, FTIR, photonics

INTRODUCTION

"There is plenty of room at the bottom''(Feynman, 2018) was delivered by Richard Feynman which is related to nanotechnology. There are different materials which are produced through nanotechnology. Nanotechnology is defined as "understanding and control of matter at nano scale at dimension between 1 and 100nm''. Nano is a prefix means 10^{-9}. 1 nanometer is one billionth of meter (Thakur *et al*; 2018). Nano particles are one of them. Nano particles have one dimensions less than 100nm (Khan *et al.*, 2019). Different dimensions are present according to their shapes; 0D,1D,2D,3D. Different nano particles are present including silver (Rauwel *et al.*, 2015), platinum, copper, magnesium (Abinaya *et al.*, 2021; Al-Hakkani, 2020; Ameh *et al.*, 2019; Jan *et al.*, 2021; Jeevanandam *et al.*, 2019; Jeyaraj *et al.*, 2019; Masindi *et al.*, 2023; Padilla Espinosa *et al.*, 2022; Shih *et al.*, 2020) They have yellow, brownish red, deep red and black color respectively.

To create the nano structures to the shape, morphology, size and composition, production system exists. Two approaches are used for the synthesis of nanoparticles; bottom up and top down (Imran Din, 2016). In bottom up, complex structures are produced from simpler ones and in top down, simple and nano sized structures are produced.

The extensive usage of nanoparticles in an assortment of sectors, like cosmetics, electronics (Chavali and Nikolova 2019; He *et al.*, 2020; Chiari-Andreo *et al.*, 2019; Mu and Sprando, 2020), and both diagnostic and therapeutic medical applications, is because of their small size and vast surface area. The ability to study nanomaterials using techniques with atomic resolution, like tandem electron microscopy, scanning tunneling microscopy, and scanning electron microscopy by transmission has boosted the field's exponential expansion and expanding interest (Sharma *et al.*, 2019).

In this paper, one main goal is to review the morphological behavior of different nanoparticles (Aziz *et al.*, 2019; Rana *et al.*, 2020; Abudayyak *et al.*, 2017; Arya *et al.*, 2020).

The Nanoparticles are classified into different types such as carbon based nano particles, metal nanoparticles, ceramic nanoparticles, polymeric nano particles on the basis of size, morphology, physical, and chemical properties (Ealia *et al.*, 2017; Khan and Hossain, 2022; Ijaz *et al.*, 2020; Shnoudeh *et al.*, 2019; Zielińska *et al.*, 2020).

Carbon based nanoparticles

The two major classes of carbon based Nano particles are fullerene and carbon nanotube. Fullerene is the third allotrope of carbon. A fullerene is any molecule made entirely of carbon atoms, which might be hollow or have other configurations like an ellipsoid or tube. Fullerenes are the series of hollow carbon molecules that forms either Bucky balls of carbon nanotube.

***Corresponding Author:** Qurban Ali

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Pentagonal and hexagonal carbon units are presented and is sp2 hybridized (Yadav, 2018).

The unique structure of fullerenes contributes to their specific applications, posing challenges in spectroscopic testing, purification, separation, and assessing purity due to their limited solubility in common organic solvents. Overcoming the hydrophobic barriers inherent in fullerenes for biological purposes often involves conjugating them with bio-molecules. Fullerenes continue to be extensively researched for their applications in various physicochemical and pharmacological fields, with continuous discoveries and applications emerging. The high cost and limited supply of fullerenes often confine research to small scales. In one study, Researchers have explored various nanoparticle formulations, aiming for compatibility with biological systems and efficient penetration of cell membranes to facilitate therapeutic molecule delivery. Among these, fullerenes stand out as a pioneering class of carbon-based nanoparticles with distinctive structural characteristics and favorable properties for engaging with cellular environments (Kazemzadeh and Mozafari, 2019).

Carbon nanotubes, characterized by flawless crystalline concentric cylinders formed by spirally organized carbon atoms, are thinner than graphite whiskers and represent a significant material in nanotechnology due to their unique properties and sp2 hybridization (Mishra *et al.,* 2020; Tran and Mulchandani, 2016). They can be single, double or multi walled (Li and Maruyama, 2019; Cao *et al.,* 2019; Arunkumar *et al.,* 2020). CNT have great properties like mechanical, optical and electrical (Sa'aya *et al.,* 2019; Morsi *et al.,* 2019).

A single graphene layer makes up a CNT. Carbon nanotubes can be further classified into chiral, armchair, and zigzag crystallographic forms based on the way the graphene sheet is linked together. The pair of indices (n, m) is employed to denote the chiral vector, which plays a significant role in determining the electrical properties of carbon nanotubes. These indices represent the manner in which a sheet of graphene is rolled up into a tube. The integer’s n and m represent the amount of vectors of units within the graphene honeycomb crystal lattice that are aligned along two particular orientations (Wei *et al.,* 2015). These structural characteristics provide insights into the degree of strain experienced by a nanotube. Nanotubes are classified as zigzag if the index m equals 0; alternatively, they are termed armchair if the indices n and m are equal. Examples of armchair nanotubes include those denoted by indices such as (1, 1), (2, 2), (3, 3), and so forth. Based on chirality, one can have metallic or semiconducting single-walled carbon nanotubes and have a band gap between 0.4 and 2 eV (Preciado-Rivas *et al.,* 2019).

The phrase "multi-walled carbon nanotubes" describes a collection of concentric cylinders made of single-walled nanotubes (SWNT) with varying sizes. These multi-walled nanotubes (MWNT) can be conceptualized in two structural models. Firstly, the Russian Doll model portrays MWNT as carbon nanotubes containing concentric tubes of different diameters within them. Secondly, the Parchment model occurs when a single sheet of graphene is continuously wrapped around itself in a spiral shape, forming multiple layers (Natrayan *et al.,* 2022; Ali *et al.,* 2021). Particles that are cylindrical, spherical, elliptical, or tube-shaped can all be found in carbon nanostructures. Carbon nanotubes are formed like tubes, nano horns are horn-shaped particles, and spheres or ellipsoids are members of the fullerene group of nanoparticles.

In one study, multiwall carbon nanotubes underwent oxidative ultra-sonication in a sulfuric acid and nitric acid mixture (3:1) at room temperature. The treatment duration influenced the development of functional groups, with longer durations resulting in increased carboxylic acid group concentration. The extended oxidation enhanced the colloidal stability of aqueous fMWCNT dispersions, preventing precipitation for at least 24 hours. Zeta potential measurements revealed a change from negative to positive charge upon self-assembly of cationic polyelectrolytes on fMWCNTs. Multilayer self-assembly is consistent with the charge reversal generated by the addition of anionic polyelectrolytes. Functional groups were highlighted by the complex formation that resulted from the electrostatic interaction between negatively charged fMWCNTs and positively charged gold nanoparticles. This complex creation raises the possibility of using positively charged colloids to find carbon nanotube defect locations. The layer-by-layer method of gold nanoparticles are as follows:

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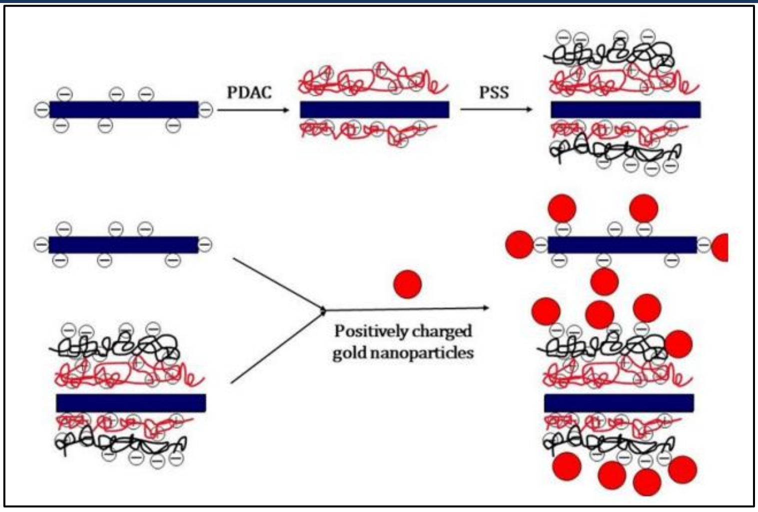

Figure 1. The layer by layer method of gold nanoparticles (Saboor and Ataei, 2024).

Ceramic nano particles

Ceramic nanoparticles are heat- and successively-cooled inorganic nonmetallic solids. They come in amorphous, polycrystalline, dense, porous, hollow, and other variations (Khan *et al.*, 2019). Due to their role in processes such as catalysis, photo catalysis, the breakdown of dyes, and imaging applications, these nano particles are therefore attracting an array of researchers (Thomas *et al.*, 2015). Ceramic nanoparticles may be spherical, rod-shaped, core-shell, and nanotube-shaped. Examples of ceramic nanoparticles are calcium, titanium, and silicon (Thomas *et al.*, 2015).

(Wang *et al.*, 2021) reviewed the functions and applications of ceramic nanoparticles in bone tissue engineering, specifically focusing on their incorporation into 3D printed scaffolds and bioinks. It explored how nanoparticles enhance antimicrobial ability, mechanical strength, and accelerate bone formation while facilitating drug delivery and bio-imaging. The combination of advanced manufacturing techniques and nanoparticle properties aimed to create integrated bone substitutes. Ultimately, the study concluded that nanoparticles offer significant benefits and potential in bone tissue engineering and broader biomedical applications.

Polymeric nanoparticles

The tiny particles known as polymeric nanoparticles, which usually range in shape from 1 towards 1000 nanometers, have attracted increasing attention in recent years because of their special qualities resulting from their tiny scale. These nanoparticles possess the capability to carry active substances or have them surface-adsorbed onto their polymeric core (Cano *et al.*, 2020; Cano *et al.*, 2019). The term "nanoparticles" encompasses two main types: Nano spheres and Nano capsules. Nano capsules consist of a polymeric shell enclosing an oily core, typically containing dissolved medication. This structure controls drug's release profile from the core. On the other hand, Nano spheres utilize a continuous polymeric network as their foundation. Within Nano spheres, medication can either be contained inside the structure or adsorbed onto their surface (Mansha *et al.*, 2017; Crucho and Barros, 2017).

Polymeric nanoparticles appeared as an exciting means to improve drug absorption and achieve a particular supply to the target site; the adaptability of polymers proved them especially ideal for meeting the demands of various systems for drug delivery. Begines et al. (2020) conducted a study in which the inherent toxicology of some drugs combined with the complicated nature of certain diseases sparked an increasing demand for creating and improving drug delivery processes.

Metal nanoparticles

The noble metals which are employed for the synthesis of nanoparticles are appointed as metallic nanoparticles. Nowadays the main focus of researchers is on metallic nanoparticles because of their properties useful for catalysis, composite-like polymer preparation, treatment, Disease diagnosis, and sensor technology (Moura *et al.*, 2017; Banerjee *et al.*, 2017; Shaikh *et al.*, 2016; Jamkhande *et al.*, 2019). Different methods are used for the preparation of metallic nanoparticles. The method by which stabilizing agents follow metal nanoparticles, the mechanism of metal ions' reaction with reducing compounds, and other experimental techniques all have a significant impact on the strength, physical characteristics, and shape of the nanoparticles, making choosing the type of metallic tiny particles preparation technique critical (Cele,

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2020). Examples of metal oxide nanoparticles are silver oxide, zinc oxide, nickel oxide, magnesium, and gold nanoparticles Now, we will explain the morphology of different metallic nanoparticles one by one (Fakhari *et al.*, 2019; Narender *et al.*, 2022; Abinaya *et al.*, 2021; Fernandes *et al.*, 2020; Prasanth *et al.*, 2019; Giljohann *et al.*, 2020; Hammami and Alabdallah, 2021).

Morphology of Silver oxide nanoparticles

Ag NPs are defined as nanomaterials where most of their dimensions fall between 1 and 100 nm. They demonstrated a greater surface (area-to-volume ratio) as well as capacity when compared to bulk silver (Yaqoob *et al.*, 2020). The creation of devices for specific drug delivery, testing, detection, and imaging has been sparked by this substance's unusual nanoscale electricity, optics, and catalytic abilities. Silver nanoparticles (AgNPs) have become highly sought after in many fields, including medical, industrial, and health care, due to their unique physical and chemical properties. Particles of silver are already in high demand across a range of fields, including medical treatment, medicine, and industrial uses, because of their unique physical and chemical properties. One of the most intriguing features of these nanoparticles is their biological activity, which is defined by their size distribution, physical properties of the surface, shape, and chemical composition; additionally, agglomeration is influenced by capping agents, particles reaction in mediums, ion release, and reducing agents used during AgNPs synthesis.

Flower like Ag Nano particles

Various shapes of silver micro particles, such as flower-like silver microstructures, have been synthesized using wet chemical procedures (Khodashenas and Ghorbani, 2019). The three-dimensional structure resembles a flower, and its petals are made of bunches of silver particle fibers that are each covered in a polymer wrap. The silver nitrate ($AgNO_3$) mixture is reduced with the addition of polyvinylpyrrolidone (PVP) with vitamin C to create these particles. Utilizing scanning electron microscopy (SEM), the structure was examined. The wet-chemical process demonstrated the creation of small silver crystals resembling flowers. To produce well-defined particles, a solution of iron (II) sulfate heptahydrate and silver nitrate is vigorously stirred at high speed with various modifiers. By employing suitable modifiers and experimental conditions, it is possible to generate micro-sized silver crystals with diverse morphologies. In a study conducted by (Ponsanti *et al.*, 2020) , A green method was used to create flower-shaped silver nanoparticles by reducing starch. The average particle diameters of the silver nanoparticles made from various starches, such as corn, cassava, and sago, were 48 nm, 108.1 nm, and 114.5 nm, respectively. These nanoparticles displayed varied sizes of flower-shaped structures. X-ray diffraction analysis verified the nanoparticles' face-centered cubic (fcc) structure. Furthermore, a surface plasmon peak measured between 420 and 430 nm suggested that starch had a role in the creation of silver nanoparticles. These flower-shaped nanoparticles of silver have a distinctive morphology that makes them useful in a variety of applications.

Cube like Ag nanoparticles

Silver nitrate can be reduced with polyvinylpyrrolidone (PVP) and ethylene glycol together to create cubic silver nanoparticles. The study's findings demonstrate how important variables like temperature, the concentration of silver nitrate, and the molar concentration of PVP to nitrate of silver are in determining the final product's shape. For example, variations in between 161°C and 120°C or between 120°C and 190°C in temperature resulted in asymmetrical morphologies in the produced silver nanoparticles. Furthermore, the input concentration of silver nitrate ($AgNO_3$) should exceed 0.1 M to ensure optimal outcomes. Otherwise, the predominant output would be silver nanowires. Another significant factor is the molar proportion to the unit of repetition of polyvinylpyrrolidone to silver nitrate. Increasing this ratio from 1.5 to 3 leads to the formation of doubly twinned particles as the major outcome (Dawadi *et al.*, 2021). Metal sulfides were introduced into the process to aid in the synthesis of silver nano cubes. In aqueous systems, when silver is present alongside trace amounts of sulfides exceeding the micromole threshold, sulfide ions strongly react with silver, resulting in the creation of silver sulfide (Ag_2S).

Khodashenas and Ghorbani, (2019) used leaf extracts from Poplar macro Carpa to produce tiny silver cubes at room temperature. The leaf extract served as a stabilizing and reducing agent throughout the synthesis process. Both round and cubic-shaped particles of silver were visible in TEM micrographs; the spherical Ag NPs ranged from 10 to 100 nm, while the cubic-shaped Ag NPs were between 10 and 50 nm. After a few hours, cubic nanoparticles with sizes ranging from 50 nm to 1 μm were the most common shapes in

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the synthesis, according to three-dimensional pictures captured with a FESEM. The image is as follows (Khodashenas and Ghorbani, 2019).

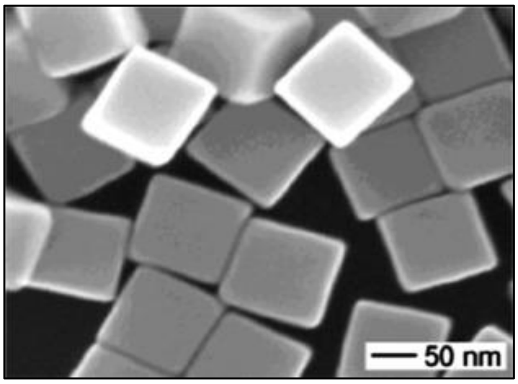

Figure2. Cubical shape of silver nanoparticles (Khodashenas and Ghorbani, 2019).

Nano wire morphology

It is believed that one-dimensional nanostructures will be crucial to the manufacturing of nano scale devices. Because of the metal's exceptional optical properties, great electrical conductivity, and high thermal conductivity, the creation and research of Ag Nanorods and Nanowires with precisely established dimensions and proportions has become crucial (Garnett *et al.*, 2019). At a temperature of 160°C, silver nitrate can be reduced using ethylene glycol (EG). Upon Including an order containing silver nitrate and polyvinylpyrrolidone to the mixture, silver nanowires are formed, with diameters typically ranging from 30 to 40 nanometers and lengths of approximately 50 micrometers (Hamans *et al.*, 2022).

Nghia *et al*., (2012) designed silver nanowires using the polyol process in ethylene glycol with PVP in the role of stabilizer, employing microwave heating. Sodium chloride presence facilitated nanowire production, with formation occurring rapidly (approximately 3 minutes). The silver nanostructures' dimensions and form were influenced by factors like PVP concentration, NaCl concentration, $AgNO_3$ concentration, and heating duration. Optimal conditions for silver nanowire production were identified as low PVP concentration (50 mM), 3 mM NaCl, and a 3-minute heating period. Notably, the study's advantage lay in the use of cost-effective NaCl over H_2PtCl_6. The nanowire morphology of silver nanoparticles are as follows:

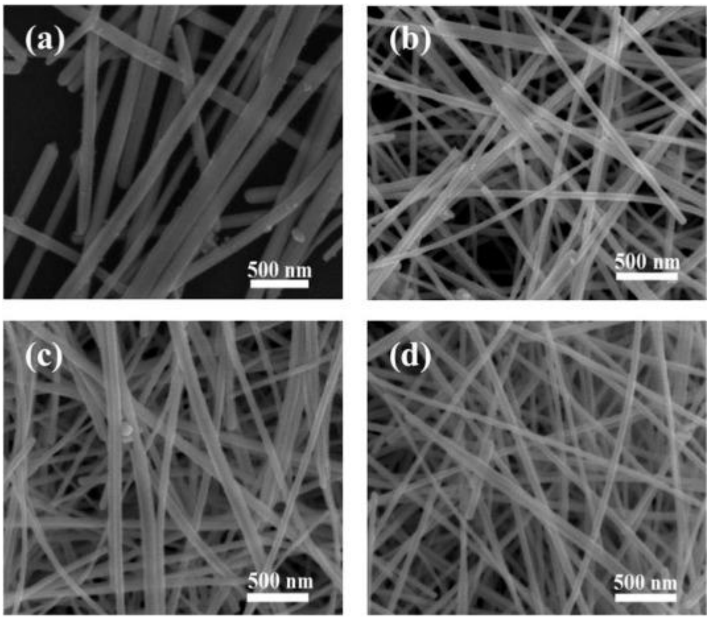

Figure 3. Nanowire morphology of silver nanoparticles (Zhang *et al.,* 2017).

Morphology of Zinc oxide nanoparticles

ZnO are inorganic materials with an array of uses that is practical, strategic, promising, and adaptable. It is sometimes referred to as a semiconductor II-VI (Mohan and Renjanadevi, 2016; Sajjad *et al.,* 2018). Zinc dioxide

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nanoparticles (ZnO-NPs) are the most widespread category of metal oxide nanoparticles. They have a broadband gap (3.37 eV), a high excited binding energy (60 meV), and are easily modified in shape (Al Jabri *et al.*, 2022). This makes it possible for the simulation of ZnO-NPs to be a powerful photo-catalytic and photo-oxidizing moiety against chemical and biological species (Shaba *et al.*, 2021).

Researchers have reported discovering zinc oxide nanoparticles with various shapes. Nano plates (Abinaya *et al.*, 2016), NanoTetrapods (Paulowicz *et al.*, 2018), Nano Spheres (Lavand and Malghe, 2015), Nano Rods (Ghannam *et al.*, 2019), Nano Flowers (El-Shafai *et al.*, 2018), Nano Tubes, are some of these.

A nanotube is a structure that looks like a tube and is a component of the one-dimensional (1D) nanostructure group. NanoTetrapods are dimensional structures formed from nanomaterials that measure four feet. NanoTetrapods have the benefit of spontaneously aligning to the plane with one standard "arm" over other nanocrystalline geometric structures of nanomaterials (Srivastava *et al.*, 2022). The spatial distribution of the ZnO NanoTetrapods legs has an angle of 109.5° (Modi, 2015). The simplest type of nanoparticle is the Nano sphere, which has just one volatile geometric parameter (radius) and shows resonant responses to optical stimulation (Ahmadivand *et al.*, 2019).

Solid rod-like structures are called nanowires, comparable to regular wires (Waqar *et al.*, 2015), with a thickness or diameter restricted to tens of nanometers or less (1 nm = 109 m) (Nasrollahzadeh *et al.*, 2019). Due to the significant disparity in the diameter and length of nanowires, they are regarded as 1D materials. It has been claimed that compared to bulk wires, nanowires have fewer structural defects (Erchard and Holleitner.2015). Nano flowers are microscopic structures that resemble plant blossoms. They are frequently produced in extreme conditions, such as between 80 and 550°C (Shende *et al.*, 2018). Additionally, High volume-to-surface ratios in nanoflowers have been found to improve surface adsorption and enhance reaction kinetics (Goryacheva, 2016).

Nano plates are nanomaterials with two-dimensional nanostructures or a plate-like shape. Nanostructures with rod-like forms are known as Nano rods. The one dimension that Nano rods have is not on the nanoscale. In opposition to nanotubes and nanowires, which may be created from a limited number of elements (including metals and nonmetals), Nano rods offer a unique benefit over other one-dimensional nanostructures (Ghassan *et al.*, 2019).

(Droepenu *et al.*, 2022) investigated the effects of pH, precursor concentration, growing period, and temperature on ZnO nanostructure shape. They observed the formation of tetrapod-like and, flower-like structures within a pH range of 8 to 12.5. Conversely, decreasing the pH from 8 to 4.6 resulted in the gradual erosion of rod-like structures into wire-like nanostructures.

Zhu *et al*. (2018) investigated the impact of surfactants on the morphology of ZnO nanocrystals. They found that increasing the concentration of CTAB (0.03-0.1 M) led to the aggregation of plate-like nanostructures, forming flower-like structures. However, a further increase in CTAB to 0.3 M resulted in the collapse of the flower-like structures. The synthesis conditions included a reaction time of 3 hours, autoclave temperature of 150°C for 16 hours, and calcination temperature of 500°C for 2 hours. These flower-like nanostructures have been explored for their potential applications in sulfur dioxide gas detection and ethanol sensing.

Large band gaps of 3.6–4.0 eV are found in NiO nanostructures and P-type semiconductors, Catalysts, battery cathodes, electrochromic films, battery electrodes, gas detectors, photovoltaic devices, electrochromic films, batteries cathodes, and magnetic materials are just a few of the applications for NiO nanoparticles. NiO nanoparticles are further researched for use in dye-sensitized photocathodes, smart windows and electrochemical super-capacitors. The electrical (Mansour and EI Mir, 2019), optical (Anand *et al.*, 2020), and magnetic properties of NiO nanoparticles are greatly influenced by their particle size, shape, and method of fabrication. Recently, there has been a lot of interest in nickel-based oxide nanoparticles due to their special optical signals electrical power, magnetic, heating, and mechanical properties. It was made possible to develop nickel nanoparticles in the following forms: nanotubes, Nano rods, hollow spheres, nanobelts, nano prisms, nanostars and hexagonal flakes (Danjumma *et al.*, 2019; Salim and Tarabiah, 2023; Akinkuade *et al.*, 2018; Oliva-Ramirez *et al.*, 2018).

The procedure for generating nanostars, micro flowers, and spherical nickel particles is described

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below. Spherical nickel-metal nanoparticles were synthesized by thermally decomposing Ni-hydrazine complexes and subsequently reducing the resulting Ni ions. The synthesis process for nickel nanoparticles is detailed as follows. Initially, a nickel acetate aqueous solution (0.1 mole) was warmed up to 50 °C with the incorporation of 0.25 mole of hydrazine ($N_2H_4H_2O$) with vigorous stirring. Upon reaching 65 °C, a light violet precipitate formed. Subsequently, an aqueous solution of sodium hydroxide (0.3 mole) was added to the solution after it cooled to 50 °C. The mixture was then warmed up to 55 °C and kept up for an additional hour to facilitate the formation of spherical nanoparticles.

To produce nanosize nickel stars, an aqueous sodium hydroxide solution (0.1 mole) was introduced to the N-hydrazine complex. The solution was heated to 70 °C and kept at that temperature for 3 hours. After allowing the solution to mature for 24 hours at 70 °C, a small nickel blossom was obtained. The precipitated particles were removed through centrifugation. The overall synthesis had a yield of 60%, determined by the amount of Ni acetate used. The resultant black Ni precipitates were washed five times using distilled water and afterward dried continuously in an oven at 40 °C (Mun *et al.*, 2019).

As the level of sodium hydroxide is boosted a discernible change in the form of the nanoparticles is observed. Particularly, when using 1 M sodium hydroxide, needle-like crystal sets with usual dimensions that vary from 100 to 500 nm are now formed; a different shift in shape is noticed with a further raise in NaOH concentration in order to 2 M, during which the precipitate includes nanoparticles organized in a chain-like form, with a typical particle diameter within 100 and 500 nm. These results are typical when aerogel is set up employing the lowest quantity of NaOH (0.5 M). NaOH is known to play a catalyst role in the polyol process when creating nickel nanostructures, significantly accelerating the rate of metal precipitation. Furthermore, the shape and size of metal nanoparticles can be significantly influenced by the rate at which they nucleate and develop.

In one study conducted by (Narender *et al.*, 2022), Researchers created nickel oxide tiny particles, nanorods in particular and nanoworms using water-based nickel chloride, sodium oxalate, as well as ethylene glycol as their solvents, and they showed how effective these materials were in photodegrading 4-NP. The same materials were used in another study to create nickel oxide nanowires that are nanosheets. Furthermore, utilizing nickel sulfate as a precursor, a scientist created nickel oxide nanoparticles and evaluated their antibacterial efficacy against gram-positive and gram-negative bacteria. Microwave-assisted oxidation was used to create nickel oxyhydroxide, which was then converted into spherical-shaped nanoparticles through thermal breakdown. The spherical and rod shaped nickel oxide nanoparticles are as follows.

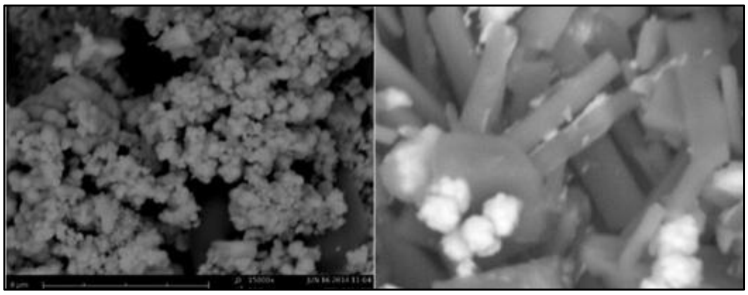

Figure 4. Nickel oxide nanoparticles (a) spherical (b) rod shaped follows (Narender *et al.*, 2022)

Morphology of Gold Nanoparticles

Gold nanoparticles (Au NPs) are of great interest due to their ability to interact with light through Surface Plasmon Resonance (SPR). Recent advancements in nanotechnology have demonstrated that Au NPs have potential to serve as basic building blocks for plasmonic and photonic devices. Most of the research on bio-molecular conjugates has been focused on Au NPs (Abdelghany *et al.*, 2017).

Colloidal gold is another name for solution of metals such as gold nanoparticles; it is also occasionally used interchangeably with the term gold particles. The Romans used these colloidal solutions to apply stains to glass, and their use dates back a long way. But colloidal gold was first studied scientifically in the 1850s when Michael Faraday noticed that the properties of colloidal gold solutions differed from those of bulk gold. As

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a result, the color of a colloidal solution is either intensely red (for particles smaller than 100 nm) or impure yellowish (for larger particles). The fascinating optical properties of these gold nanoparticles are caused by a unique interaction they have with light: the electrons that are free of the metal nanoparticles fluctuate about the lattice structure in the presence of the fluctuating electromagnetic field of light.

Spherical Gold Nanoparticles

Dong *et al.,* (2020) pioneered the most widely used method for synthesizing monodisperse spherical gold nanoparticles. This approach involves the utilization of citrates as an agent that chemically minimize gold salts such as hydrogen tetrachloroaurate (HAuCl4). By employing this technique, it is possible to create monodisperse spherical gold nanoparticles that range in diameter from 10 to 20 nm. However, Brown and Natan reported the creation of bigger gold nanoparticles using hydroxylamine to seed Au3+, with dimensions that vary from 30 to 100 nm. The shape of their gold nanoparticles was changed by further studies, leading to the creation of spherical, polygonal, triangular, and rod-shaped.

Nano star shaped Gold nanoparticles

Based on Murphy's synthetic process, a novel surfactant-based synthetic technique claimed to have produced the first nano star-shaped AuNPs. This process results in a modest yield (9% yield) of gold nanostars (AuNSs). The synthesis of AuNSs has undergone several optimizations to increase controllability over the final shape. The yield of AuNSs production has increased to approximately 100% thanks to the use of polyvinylpyrrolidone (PVP) as a stabilizer. Pallavicini et al. enhanced seed-based methods by using surfactants that adhere weakly, such as lauryl sulfobetaine, to facilitate a later functionalization step using thiolated PEG. This process involves the complete displacement of the surfactant.

The synthesis approach presented here has the benefit of yielding five-branched gold tiny stars (AuNSs) with controllable generation and morphology, even in the presence of additional coating agents that bond weakly, like Triton X-100. The three isolated surface Plasmon resonant structures (LSPRs) of these penta-twinned AuNSs, two of which are located in the nearly infrared (NIR) range, provide them with exceptional photothermal responsiveness. Modern techniques combine the Turkevich method for seed solution preparation with an additional step that synthesizes AuNSs utilizing CTAB, AgNO3, HAuCl4, and ascorbic acid. It has been proposed that the morphology of AuNS tips can be altered by lowering the CTAB level from 5.3 to 3.7 mM

Additionally, AuNSs containing long and short spikes were successfully constructed by using a hexagon-shaped lyotropic liquid crystallographic (LLC) state as a template, which was obtained by combining TX-100 and water. This is important for controlling spike length (Chirico *et al.,* 2015; Khan *et al.,* 2018; Chatterjee *et al.,* 2018; Sheen mers *et al.,* 2017).

Three distinct methyl polyethylene glycol-coated, anisotropic gold nanoparticle shapes; stars, rods, and triangles—were created in a single study by Xie *et al.,* (2017). The analysis of these nanoparticles' cellular uptake by RAW264.7 cells yielded a parametric assessment of the shape effect. Stars, rods, and triangles were found to have the highest, lowest, and most efficient cellular absorption of the gold nanoparticles. Examining the potential cellular uptake methods of the three different forms of gold nanoparticles, it was discovered that the varied shapes tended to employ the different endocytosis pathways in varying amounts. The results of this study, which showed that shape can affect how well nanoparticles are absorbed by cells of RAW264.7 and that triangles had the best cellular uptake, help guide the development of nanoparticles for drug delivery.

Characterization techniques of nanoparticles

One of the most essential and basic statistics for the characterization of nanoparticles is particle size. This element establishes the particle's size, distribution, & whether it is on the nano- or micro-scale (Khan *et al.,* 2022). One of the methods most frequently used to characterize NPs is X-ray diffraction (XRD). XRD typically yields data on the crystalline grain size, lattice parameters, phase nature, and crystalline structure. The latter parameter is determined for a given sample employing the Scherrer equation and the broadening of the measurement's most intense peak from XRD analysis. One benefit of using XRD techniques is that they produce statistically representative volume-averaged values. These techniques are typically applied to powdered samples, following the drying of their respective colloidal solutions. One can ascertain the composition of the particles by comparing the position and strength of the peaks with the reference patterns obtained from the Worldwide Center for Diffraction Data database. The XRD

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peaks are vast for particles smaller than 3 nm, thus it is not appropriate for amorphous materials (Mourdikoudis *et al.*, 2018). Applying X-ray line broadening, (Upadhyay *et al.*, 2016) calculated the typical size of the crystallite of magnetite NPs, finding it to be between 9 and 53 nm. Other than instrumental broadening, the size of the particles and crystallites as well as lattice stresses were the main causes of the XRD peak broadening.

The surface imaging method known as the scanning electron or SEM, uses an electron beam to interact with a sample and produce various signals that show the atomic makeup and surface shape. SEM builds a three-dimensional view of the studied material from these emissions, including secondary electrons and backscattered electrons. An Everhart Thornley scintillator-photomultiplier monitor is usually used to detect these electrons once they have left the sample surface. However, because they cannot properly deflect an electron beam, many PNPs are almost undetectable to the naked eye because of their organic composition. For this reason, a 200–300 Å thin coating of metal must be coated on the sample during sample preparation to produce a conductive layer. This process lessens heat damage, prevents surface charge, and enhances the additional electron signal needed for the SE (Crucho and Barros, 2017). T-SEM imaging yields a somewhat broader size distribution than TEM imaging. The decreased spatial resolution obtained in comparison to traditional TEM is undoubtedly a constraint on the exact separation of the particulates in the T-SEM phase for small SiO2 NPs. Furthermore, it's possible that the upper layer of particles won't always be visible using the T-SEM.

The basis of FTIR, also known as Fourier transform infrared is the measurement of electromagnetic radiation absorption at wavelengths in the mid-infrared range (4000–400 cm^{-1}). A molecular structure becomes IR active when it absorbs infrared radiation because it modifies its dipole moment somehow. A recorded spectrum reveals the locations of bands associated with the type and strength of bonds and certain functional groups, revealing details on molecular interactions and structures. Changes in functional group variations can be used via the Fourier transform infrared (FTIR) technique for spectroscopy to identify changes in the overall composition of biomolecules. FTIR measures how much infrared light at a certain wavelength affects the vibrations and rotations of molecules. By using this approach, one can determine specifics regarding the existence of interactions between entities by analyzing differences in structure in molecular binding. FTIR-based techniques for characterization that are most commonly used are transmittance, attenuated total reflectance, as well as micro-spectroscopy (Eid, 2022). Feliu and colleagues used a hybrid technique combining in situ ATR-FTIR and distinct electrochemical mass spectral analysis to investigate the effects of Pt nanostructures on ethanol oxidation. These methods aid in the electrochemical probing of adsorbates and detecting volatile reaction products. The favored outcomes of breakdown were linked to their outer structures, with COads forming on (100) regions and acetaldehyde/acetic acid-forming on (111) domains, according to their results, which were consistent with earlier research (Buso-Rogero *et al.*, 2016).

Application of nanoparticles

Nanoparticles in semiconductor production

Silver nanoparticle suspensions were effectively created by chemically reducing silver nitrate using formaldehyde reductant & PVP stabilizer, using two distinct organic bases as the promoter: triethylamine and pyridine. About 20–30 nm was the size of the silver particles made from the simpler triethylamine. The lesser amount of basic pyridine used to make the silver particles had smaller diameters (10–20 nm) as a result of the reaction rate decreasing. Silver nanoparticle suspensions made using these two approaches are appropriate for use in the semiconductor sector and do not contain any metal ions. A photoelectrochemical system was constructed using a multilayer architecture of Au nanoparticles. Using a progressive crosslinking technique, a complex structure made of several layers of tiny gold particles was built on an ITO support. In this procedure, an electrostatic crosslinker known as a bis-bipyridinium ZnII-protoporphyrin IX dyad 7 interacted with citrate-capped gold nanoparticles. The structure's absorption spectra proved that it was composed of light-responsive porphyrin and cyclic voltammetry was used to confirm the crosslinker and gold nanoparticle coverage. Electrons moved from the porphyrin component to the pendant bipyridinium group when it was exposed to light (Hossain *et al.*, 2023).

Nanoparticles in medicine

Drug delivery

There is growing recognition of the efficacy of nanoparticles as dosage enhancers, radio sensitizers, and contrast agents. Radiation therapy

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incorporates nanoparticles, which build up inside the tumor. Gold nanoparticles have been observed to assemble due to interactions with the cytosolic glutathione (GSH). More gold nanoparticles (NP) are reported to collect in the tumor as opposed to the normal tissues in cancer cells because their GSH levels are significantly higher than those of normal cells. This boosts the effectiveness of radiation therapy, which is considerably reduced in tumors because of multiple medication resistance and the antiapoptotic properties of the protein survivin. When the tumor is exposed to photon beams during treatment, nanoparticles (NP) within the tumor interact with the photons, producing additional secondary electrons. These electrons boost the radiation the tumor absorbs by causing more harm to cancer cells near the NP (Abdulle and Chow, 2019).

Excellent clinical performance, good therapeutic efficacy, and reduced toxicity to healthy tissue are all displayed by nanomedicine. Au NP-based drug transport has drawn a lot of interest due to its outstanding results. Even though Au NPs have not received pharmacological approval for use in officially marketed nanomedicines, numerous investigations are being conducted in this area. Many Au NP-based nano-drugs in combination with other biomedical uses are under investigation, such as drug-conjugated Au NPs made for tumor-targeting and cancer therapy. Small interfering RNAs, proteins, plasmid DNA deoxynucleic acids, peptides, and chemotherapeutic medicines are among the pharmaceuticals for which Au NPs are believed to be an efficient nano-carrier. To enhance the outermost area or ratio of surface to volume for drug delivery, cationic polymers or functional groups like carboxyl, amine, or thiol groups are typically added to the surface of Au NPs. The medication can be immobilized on the Au NPs stably and efficiently because to the designed surface area. Serum proteins inside the bloodstream shield the medication enclosed in Au NP complexes from enzyme breakdown. medication-Au NP complexes can also be modified to include cell-specific targeting molecules, which will allow the medication to be delivered to certain target cells (Siddique and Chow, 2020).

Antimicrobial

Hospital wallpapers contain ZnO nanoparticles as antimicrobials. Because of its antibacterial qualities, zinc oxide powder is used as an active ingredient in creams, lotions, and ointments for dermatological purposes. Certain nanoparticles (NPs), such as copper nanoparticles (CuNPs) and silver nanoparticles (AgNPs), possess potent antibacterial characteristics and are being investigated for application in a range of medical goods, including bandages and medical equipment (Hoseinzadeh *et al.*, 2017).

An eco-friendly process has been used to create silver nanoparticles from safflower. This has the potential to be utilized as an antibacterial agent in therapy and to combat food spoiling since it was discovered to be good against the germs that cause food to go bad. Increased dosage and targeting made possible by nanocarriers help to avoid toxicity and unfavorable side effects, such as those associated with the cancer medication Doxil. It has also been used with great accuracy to administer imaging agents (Rodríguez-Félix *et al.*, 2021).

All things considered, NPs are being actively explored for a variety of applications and have a great deal of potential for usage in the medical field. To guarantee their secure and accountable usage, it is crucial to thoroughly weigh the advantages and disadvantages of employing NPs in medicine.

Future aspects and challenges

A key challenge is producing and handling metal nanoparticles with exact control over their size and form. It can be difficult to scale up many processes to create metal nanoparticles for large-scale manufacturing since they call for extreme heat and toxic chemicals. Furthermore, it's critical to precisely manage the size and form of metal nanoparticles during synthesis to minimize any negative effects on the NPs' properties and possible uses. The effects of metal NPs on the environment present another difficulty. A few metal nanoparticles, including silver NPs, have the potential to harm aquatic life and have further effects on the ecosystem. Further studies on the effects of metal nanoparticles on the environment are necessary, as is the creation of greener synthesis and processing techniques. Utilizing metal nanoparticles (NPs) for energy conversion, storage, and environmental protection is one field that shows promise for the future. For instance, using metal nanoparticles could help create more effective solar cells or enhance the performance of batteries. Metal nanoparticles may also be utilized in catalysis to increase the effectiveness of chemical reactions. In medicine, studies on metal nanoparticles are also being conducted in the areas of cancer treatment and drug delivery (Altammar, 2023).

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CONCLUSION

The diverse morphologies of metal oxide and metal nanoparticles offer a wide array of applications across various sectors. Silver oxide nanoparticles, zinc oxide nanoparticles, nickel oxide nanoparticles, and gold nanoparticles each exhibit distinct shapes with specific uses ranging from medication delivery to catalysis and photonic devices. Mastering the synthesis techniques to control their morphology is crucial for unlocking their full potential. Continued exploration of nanoscience promises innovative solutions to complex challenges in science and engineering, fostering a landscape ripe for transformative advancement. Nanoparticles offer diverse applications across sectors, with their properties shaped by precise synthesis and characterization. From drug delivery to catalysis, their potential is vast, though challenges like environmental impact and scalable production persist. Continued research in nanoscience is crucial for advancing these technologies and addressing global challenges.

REFERENCES

1. Abdulle, A., and J. C. Chow. "Contrast Enhancement for Portal Imaging in Nanoparticle-Enhanced Radiotherapy: A Monte Carlo Phantom Evaluation Using Flattening-Filter-Free Photon Beams." *Nanomaterials* 9.1 (2019): 920.
2. Abinaya, C., et al. "Structural and Optical Characterization and Efficacy of Hydrothermal Synthesized Cu and Ag Doped Zinc Oxide Nanoplate Bactericides." *Materials Chemistry and Physics* 184.1 (2016): 172-182.
3. Abinaya, S., et al. "Green Synthesis of Magnesium Oxide Nanoparticles and Its Applications: A Review." *Sustainable Chemistry and Pharmacy* 19.1 (2021): 100368.
4. Abudayyak, M., E. Guzel, and G. Özhan. "Nickel Oxide Nanoparticles Are Highly Toxic to SH-SY5Y Neuronal Cells." *Neurochemistry International* 108.1 (2017): 7-14.
5. Ahmadivand, A., B. Gerislioglu, and Z. Ramezani. "Generation of Magnetoelectric Photocurrents Using Toroidal Resonances: A New Class of Infrared Plasmonic Photodetectors." *Nanoscale* 11.1 (2019): 13108-13116.
6. Akinkuade, S., et al. "Structural, Optical and Electrical Characteristics of Nickel Oxide Thin Films Synthesised through Chemical Processing Method." *Physica B: Condensed Matter* 535.1 (2018): 24-28.
7. Al-Hakkani, M. F. "Biogenic Copper Nanoparticles and Their Applications: A Review." *SN Applied Sciences* 2.1 (2020): 505.
8. Al Jabri, H., et al. "Zinc Oxide Nanoparticles and Their Biosynthesis: Overview." *Life* 12.1 (2022): 594.
9. Alaqad, K., and T. A. Saleh. "Gold and Silver Nanoparticles: Synthesis Methods, Characterization Routes and Applications Towards Drugs." *Journal of Environmental Analytical Toxicology* 6.1 (2016): 525-2161.
10. Ali, N., A. Taha, and D. S. Ahmed. "Characterization of Treated Multi-Walled Carbon Nanotubes and Antibacterial Properties." *Journal of Applied Sciences and Nanotechnology* 1.1 (2021): 1-9.
11. Alrebdi, T. A., et al. "Structural, Linear and Nonlinear Optical Properties of NiO Nanoparticles–Multi-Walled Carbon Nanotubes Nanocomposite for Optoelectronic Applications." *Radiation Physics and Chemistry* 195.1 (2022): 110088.
12. Altammar, K. A. "A Review on Nanoparticles: Characteristics, Synthesis, Applications, and Challenges." *Frontiers in Microbiology* 14.1 (2023): 1155622.
13. Ameh, T., and C. M. Sayes. "The Potential Exposure and Hazards of Copper Nanoparticles: A Review." *Environmental Toxicology and Pharmacology* 71.1 (2019): 103220.
14. Anand, G. T., et al. "Structural and Optical Properties of Nickel Oxide Nanoparticles: Investigation of Antimicrobial Applications." *Surfaces and Interfaces* 18.1 (2020): 100460.
15. Arunkumar, T., et al. "Synthesis and Characterisation of Multi-Walled Carbon Nanotubes (MWCNTs)." *International Journal of Ambient Energy* 41.1 (2020): 452-456.
16. Arya, S., et al. "Influence of Processing Parameters to Control Morphology and Optical Properties of Sol-Gel Synthesized ZnO Nanoparticles." *ECS Journal of Solid State Science and Technology* 10.1 (2021): 023002.
17. Aziz, S. B., et al. "Structural, Thermal, Morphological and Optical Properties of PEO Filled with Biosynthesized Ag Nanoparticles: New Insights to Band Gap Study." *Results in Physics* 13.1 (2019): 102220.
18. Banerjee, K., et al. "A Novel Approach of Synthesizing and Evaluating the Anticancer

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Potential of Silver Oxide Nanoparticles in Vitro." *Chemotherapy* 62.1 (2017): 279-289.
19. Begines, B., et al. "Polymeric Nanoparticles for Drug Delivery: Recent Developments and Future Prospects." *Nanomaterials* 10.1 (2020): 1403.
20. Buso-Rogero, C., et al. "Ethanol Oxidation on Shape-Controlled Platinum Nanoparticles at Different pHs: A Combined In Situ IR Spectroscopy and Online Mass Spectrometry Study." *Journal of Electroanalytical Chemistry* 763.1 (2016): 116-124.
21. Thomas, C., P. Kumar Mishra, and S. Talegaonkar. "Ceramic Nanoparticles: Fabrication Methods and Applications in Drug Delivery." *Current Pharmaceutical Design* 21 (2015): 6165-6188.
22. Cano, A., M. Ettcheto, J.-H. Chang, E. Barroso, M. Espina, B. A. Kühne, M. Barenys, C. Auladell, J. Folch, and E. B. Souto. "Dual-Drug Loaded Nanoparticles of Epigallocatechin-3-Gallate (EGCG)/Ascorbic Acid Enhance Therapeutic Efficacy of EGCG in a APPswe/PS1dE9 Alzheimer's Disease Mice Model." *Journal of Controlled Release* 301 (2019): 62-75.
23. Cano, A., E. Sanchez-Lopez, M. Ettcheto, A. Lopez-Machado, M. Espina, E. B. Souto, R. Galindo, A. Camins, M. L. García, and P. Turowski. "Current Advances in the Development of Novel Polymeric Nanoparticles for the Treatment of Neurodegenerative Diseases." *Nanomedicine* 15 (2020): 1239-1261.
24. Cao, Y., S. Cong, X. Cao, F. Wu, Q. Liu, M. R. Amer, and C. Zhou. "Review of Electronics Based on Single-Walled Carbon Nanotubes." *Single-Walled Carbon Nanotubes: Preparation, Properties and Applications* (2019): 189-224.
25. Cele, T. "Preparation of Nanoparticles." *Engineered Nanomaterials-Health and Safety* 12 (2020): 1-14.
26. Chavali, M. S., and M. P. Nikolova. "Metal Oxide Nanoparticles and Their Applications in Nanotechnology." *SN Applied Sciences* 1 (2019): 607.
27. Chiari-Andréo, B. G., M. G. J. De Almeida-Cincotto, J. A. Oshiro Jr, C. Y. Y. Taniguchi, L. A. Chiavacci, and V. L. B. Isaac. "Nanoparticles for Cosmetic Use and Its Application." *Nanoparticles in Pharmacotherapy*. Eds. Elsevier, 2019.
28. Crucho, C. I., and M. T. Barros. "Polymeric Nanoparticles: A Study on the Preparation Variables and Characterization Methods." *Materials Science and Engineering: C* 80 (2017): 771-784.
29. Danjumma, S. G., Y. Abubakar, and S. Suleiman. "Nickel Oxide (NiO) Devices and Applications: A Review." *Journal of Engineering Research and Technology* 8 (2019): 12-21.
30. Dawadi, S., S. Katuwal, A. Gupta, U. Lamichhane, R. Thapa, S. Jaisi, G. Lamichhane, D. P. Bhattarai, and N. Parajuli. "Current Research on Silver Nanoparticles: Synthesis, Characterization, and Applications." *Journal of Nanomaterials* 2021 (2021): 6687290.
31. Demetzos, C., and C. Demetzos. "Introduction to Nanotechnology." *Pharmaceutical Nanotechnology: Fundamentals and Practical Applications* (2016): 3-15.
32. Droepenu, E. K., B. S. Wee, S. F. Chin, K. Y. Kok, and M. F. Maligan. "Zinc Oxide Nanoparticles Synthesis Methods and Its Effect on Morphology: A Review." *Biointerface Research in Applied Chemistry* 12 (2022): 4261-4292.
33. Ealia, S. A. M., and M. P. Saravanakumar. "A Review on the Classification, Characterisation, Synthesis of Nanoparticles and Their Application." *IOP Conference Series: Materials Science and Engineering*. IOP Publishing, 2017.
34. Eid, M. M. "Characterization of Nanoparticles by FTIR and FTIR-Microscopy." *Handbook of Consumer Nanoproducts*. Springer, 2022.
35. El-Shafai, N., M. E. El-Khouly, M. El-Kemary, M. Ramadan, I. Eldesoukey, and M. Masoud. "Graphene Oxide Decorated with Zinc Oxide Nanoflower, Silver and Titanium Dioxide Nanoparticles: Fabrication, Characterization, DNA Interaction, and Antibacterial Activity." *RSC Advances* 9 (2019): 3704-3714.
36. Erhard, N., and A. Holleitner. "Semiconductor Nanowires Studied by Photocurrent Spectroscopy." *Semiconductor Nanowires*. Elsevier, 2015.
37. Fakhari, S., M. Jamzad, and H. Kabiri Fard. "Green Synthesis of Zinc Oxide Nanoparticles: A Comparison." *Green Chemistry Letters and Reviews* 12 (2019): 19-24.
38. Fernandes, M., K. R. Singh, T. Sarkar, P. Singh, and R. Pratap Singh. "Recent Applications of Magnesium Oxide (MgO) Nanoparticles in Various Domains." *Advanced Materials Letters* 11 (2020): 1-10.

Publisher: SARC Publisher

39. Feynman, R. "There's Plenty of Room at the Bottom." *Feynman and Computation*. CRC Press, 2018.
40. Garnett, E., L. Mai, and P. Yang. "Introduction: 1D Nanomaterials/Nanowires." *Chemical Reviews* 119 (2019): 8955-8957.
41. Ghannam, H., A. Chahboun, and M. Turmine. "Wettability of Zinc Oxide Nanorod Surfaces." *RSC Advances* 9 (2019): 38289-38297.
42. Ghassan, A. A., N.-A. Mijan, and Y. H. Taufiq-Yap. "Nanomaterials: An Overview of Nanorods Synthesis and Optimization." *Nanorods and Nanocomposites* 11 (2019): 8-33.
43. Giljohann, D. A., D. S. Seferos, W. L. Daniel, M. D. Massich, P. C. Patel, and C. A. Mirkin. "Gold Nanoparticles for Biology and Medicine." *Spherical Nucleic Acids* (2020): 55-90.
44. Goryacheva, I. "Labels for Optical Immunotests." *Comprehensive Analytical Chemistry*. Elsevier, 2016.
45. Hamans, R. F., M. Parente, A. Garcia-Etxarri, and A. Baldi. "Optical Properties of Colloidal Silver Nanowires." *The Journal of Physical Chemistry C* 126 (2022): 8703-8709.
46. Hammami, I., and N. M. Alabdallah. "Gold Nanoparticles: Synthesis Properties and Applications." *Journal of King Saud University-Science* 33 (2021): 101560.
47. He, Z., Z. Zhang, and S. Bi. "Nanoparticles for Organic Electronics Applications." *Materials Research Express* 7 (2020): 012004.
48. Hoseinzadeh, E., P. Makhdoumi, P. Taha, H. Hossini, J. Stelling, M. Amjad Kamal, and G. Md Ashraf. "A Review on Nano-Antimicrobials: Metal Nanoparticles, Methods and Mechanisms." *Current Drug Metabolism* 18 (2017): 120-128.
49. Khodashenas, B., and H. R. Ghorbani. "Synthesis of silver nanoparticles with different shapes." *Arabian Journal of Chemistry* 12 (2019): 1823-1838.
50. Lavand, A. B., and Y. S. Malghe. "Synthesis, characterization and visible light photocatalytic activity of nitrogen-doped zinc oxide nanospheres." *Journal of Asian Ceramic Societies* 3 (2015): 305-310.
51. Li, Y., and S. Maruyama. *Single-walled carbon nanotubes: preparation, properties and applications*. Springer, 2019.
52. Lu, J., J. Wang, K. T. Hassan, A. Talmantaite, Z. Xiao, M. R. Hunt, and L. Šiller. "Morphology control of nickel nanoparticles prepared in situ within silica aerogels produced by novel ambient pressure drying." *Scientific Reports* 10 (2020): 11743.
53. Mansha, M., I. Khan, N. Ullah, and A. Qurashi. "Synthesis, characterization and visible-light-driven photoelectrochemical hydrogen evolution reaction of carbazole-containing conjugated polymers." *International Journal of Hydrogen Energy* 42 (2017): 10952-10961.
54. Masindi, V., M. Tekere, and S. Foteinis. "Treatment of real tannery wastewater using facile synthesized magnesium oxide nanoparticles: Experimental results and geochemical modeling." *Water Resources and Industry* 29 (2023): 100205.
55. Modi, G. "Zinc oxide tetrapod: a morphology with multifunctional applications." *Advances in Natural Sciences: Nanoscience and Nanotechnology* 6 (2015): 033002.
56. Mohan, A. C., and B. Renjanadevi. "Preparation of zinc oxide nanoparticles and its characterization using scanning electron microscopy (SEM) and X-ray diffraction (XRD)." *Procedia Technology* 24 (2016): 761-766.
57. Morsi, M., A. Rajeh, and A. Al-Muntaser. "Reinforcement of the optical, thermal and electrical properties of PEO based on MWCNTs/Au hybrid fillers: Nanodielectric materials for organoelectronic devices." *Composites Part B: Engineering* 173 (2019): 106957.
58. Moura, D., M. Souza, L. Liverani, G. Rella, G. Luz, J. Mano, and A. Boccaccini. "Development of a bioactive glass-polymer composite for wound healing applications." *Materials Science and Engineering: C* 76 (2017): 224-232.
59. Mourdikoudis, S., R. M. Pallares, and N. T. Thanh. "Characterization techniques for nanoparticles: comparison and complementarity upon studying nanoparticle properties." *Nanoscale* 10 (2018): 12871-12934.
60. Mun, C.-H., C. V. M. Gopi, R. Vinodh, S. Sambasivam, I. M. Obaidat, and H.-J. Kim. "Microflower-like nickel sulfide-lead sulfide hierarchical composites as binder-free electrodes for high-performance supercapacitors." *Journal of Energy Storage* 26 (2019): 100925.
61. Narender, S. S., V. V. S. Varma, C. S. Srikar, J. Ruchitha, P. A. Varma, and B. V. S. Praveen. "Nickel oxide nanoparticles: a brief review of their synthesis, characterization, and

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applications." *Chemical Engineering & Technology* 45 (2022): 397-409.
62. Nasrollahzadeh, M., Z. Issaabadi, M. Sajjadi, S. M. Sajadi, and M. Atarod. "Types of nanostructures." *Interface Science and Technology* 28 (2019): 29-80.
63. Natrayan, L., P. Arul Kumar, J. A. Dhanraj, S. Kaliappan, N. Sivakumar, P. P. Patil, S. Sekar, and P. Paramasivam. "Synthesis and analysis of impregnation on activated carbon in multiwalled carbon nanotube for Cu adsorption from wastewater." *Bioinorganic Chemistry and Applications* (2022): 7470263.
64. Padilla Espinosa, I. M., S. Azadehranjbar, R. Ding, A. J. Baker, T. D. Jacobs, and A. Martini. "Platinum nanoparticle compression: Combining in situ TEM and atomistic modeling." *Applied Physics Letters* 120 (2022).
65. Paulowicz, I., V. Postica, O. Lupan, N. Wolff, S. Shree, A. Cojocaru, M. Deng, Y. K. Mishra, I. Tiginyanu, and L. Kienle. "Zinc oxide nanotetrapods with four different arm morphologies for versatile nanosensors." *Sensors and Actuators B: Chemical* 262 (2018): 425-435.
66. Ponsanti, K., B. Tangnorawich, N. Ngernyuang, and C. Pechyen. "A flower shape-green synthesis and characterization of silver nanoparticles (AgNPs) with different starch as a reducing agent." *Journal of Materials Research and Technology* 9 (2020): 11003-11012.
67. Prasanth, R., S. D. Kumar, A. Jayalakshmi, G. Singaravelu, K. Govindaraju, and V. G. Kumar. "Green synthesis of magnesium oxide nanoparticles and their antibacterial activity."
68. Preciado-Rivas, M. R., V. A. Torres-Sánchez, and D. J. Mowbray. "Optical absorption and energy loss spectroscopy of single-walled carbon nanotubes." *Physical Review B* 100 (2019): 235429.
69. Rana, A., K. Yadav, and S. Jagadevan. "A comprehensive review on green synthesis of nature-inspired metal nanoparticles: Mechanism, application and toxicity." *Journal of Cleaner Production* 272 (2020): 122880.
70. Rauwel, P., S. Küünal, S. Ferdov, and E. Rauwel. "A review on the green synthesis of silver nanoparticles and their morphologies studied via TEM." *Advances in Materials Science and Engineering* 2015 (2015): 682749.
71. Razak, N. A. A., N. H. Othman, M. S. M. Shayuti, A. Jumahat, N. Sapiai, and W. J. Lau. "Agricultural and industrial waste-derived mesoporous silica nanoparticles: A review on chemical synthesis route." *Journal of Environmental Chemical Engineering* 10 (2022): 107322.
72. Rodríguez-Félix, F., A. G. López-Cota, M. J. Moreno-Vásquez, A. Z. Graciano-Verdugo, I. E. Quintero-Reyes, C. L. Del-Toro-Sánchez, and J. A. Tapia-Hernández. "Sustainable-green synthesis of silver nanoparticles using safflower (*Carthamus tinctorius* L.) waste extract and its antibacterial activity." *Heliyon* 7 (2021).
73. Sa'aya, N. S. N., S. Z. N. Demon, N. Abdullah, A. Shatar, V. F. K. Ernest, and N. A. Halim. "Optical and morphological studies of multiwalled carbon nanotube-incorporated poly (3-hexylthiophene-2, 5-diyl) nanocomposites." *Sensors & Materials* 31 (2019).
74. Saboor, F. H., and A. Ataei. "Decoration of metal nanoparticles and metal oxide nanoparticles on carbon nanotubes." *Advanced Journal of Chemistry, Section A* 7 (2024): 122.
75. Sagadevan, S., and J. Podder. "Investigations on structural, optical, morphological and electrical properties of nickel oxide nanoparticles." *International Journal of Nanoparticles* 8 (2015): 289-301.
76. Sajjad, M., I. Ullah, M. Khan, J. Khan, M. Y. Khan, and M. T. Qureshi. "Structural and optical properties of pure and copper-doped zinc oxide nanoparticles." *Results in Physics* 9 (2018): 1301-1309.
77. Salim, E., and A. Tarabiah. "The influence of NiO nanoparticles on structural, optical and dielectric properties of CMC/PVA/PEDOT: PSS nanocomposites." *Journal of Inorganic and Organometallic Polymers and Materials* 33 (2023): 1638-1645.
78. Santos, C. S., B. Gabriel, M. Blanchy, O. Menes, D. García, M. Blanco, N. Arconada, and V. Neto. "Industrial applications of nanoparticles–a prospective overview." *Materials Today: Proceedings* 2 (2015): 456-465.
79. Shaba, E. Y., J. O. Jacob, J. O. Tijani, and M. A. T. Suleiman. "A critical review of synthesis parameters affecting the properties of zinc oxide nanoparticles and its application in wastewater treatment." *Applied Water Science* 11 (2021): 48.
80. Shaikh, S. F., R. S. Mane, B. K. Min, Y. J. Hwang, and O.-S. Joo. "D-sorbitol-induced phase control of TiO_2 nanoparticles and its

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application for dye-sensitized solar cells." *Scientific Reports* 6 (2016): 20103.
81. Sharma, S., S. Jaiswal, B. Duffy, and A. K. Jaiswal. "Nanostructured materials for food applications: spectroscopy, microscopy and physical properties." *Bioengineering* 6 (2019): 26.
82. Shende, P., P. Kasture, and R. Gaud. "Nanoflowers: The future trend of nanotechnology for multi-applications." *Artificial Cells, Nanomedicine, and Biotechnology* 46 (2018): 413-422.
83. Shi, L.-E., Z.-H. Li, W. Zheng, Y.-F. Zhao, Y.-F. Jin, and Z.-X. Tang. "Synthesis, antibacterial activity, antibacterial mechanism and food applications of ZnO nanoparticles: a review." *Food Additives & Contaminants: Part A* 31 (2014): 173-186.
84. Shih, Y.-J., Z.-L. Wu, Y.-H. Huang, and C.-P. Huang. "Electrochemical nitrate reduction as affected by the crystal morphology and facet of copper nanoparticles supported on nickel foam electrodes (Cu/Ni)." *Chemical Engineering Journal* 383 (2020): 123157.
85. Shnoudeh, A. J., I. Hamad, R. W. Abdo, L. Qadumii, A. Y. Jaber, H. S. Surchi, and S. Z. Alkelany. "Synthesis, characterization, and applications of metal nanoparticles." *Biomaterials and Bionanotechnology*. Elsevier (2019).
86. Siddique, S., and J. C. Chow. "Gold nanoparticles for drug delivery and cancer therapy." *Applied Sciences* 10 (2020): 3824.
87. Sirelkhatim, A., S. Mahmud, A. Seeni, N. H. M. Kaus, L. C. Ann, S. K. M. Bakhori, H. Hasan, and D. Mohamad. "Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism." *Nano-Micro Letters* 7 (2015): 219-242.

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