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Review Article

A review of the synthesis, characterizations, and applications of inorganic nanoparticles

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Abstract:

Due to their exceptional chemical, physical and biological properties, the synthesis of inorganic nanoparticles has received significant attention, enabling diverse applications across various industries. This review highlights research that has focused on developing efficient methods for the synthesis of inorganic nanoparticles, including various metals, metal oxides and semiconductors. In addition to elucidating different synthesis techniques, such as sol-gel processes, hydrothermal methods, and chemical reduction, the role of synthesis agents in controlling the size, shape and surface properties of nanoparticles is demonstrated. Since nanoparticles have unique electronic, optical and mechanical properties, they are suitable for applications in medicine such as cancer imaging and therapy, agriculture, energy and food industry. Therefore, a discussion of the potential applications of these nanoparticles in areas such as targeted drug delivery, biosensors, antimicrobial packaging and environmental remediation is provided. These findings contribute to the advancement and understanding of the synthesis of inorganic nanoparticles, paving the way for innovations in the field of nanotechnology.

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1. Introduction:

The coming into view of nanoscale science and technology has driven significant efforts to devise a new grand design strategy for synthesizing nanomaterials with controlled sizes and shapes. In particular, nanoparticles have caught the attention. Due to their small size, typically ranging from 1 to 100 nm, they are very suitable for advanced technological applications. In addition, the permit their use in studying biological processes, as well as in sensing and treating the disease. In the past few years, inorganic nanomaterials, containing nanoparticles, nanotubes, and nanowires, have been arranged, developed, and modified to enhance and expand their properties and functionality. [1]

2. The importance of nanotechnology

Research in this field has witnessed tremendous development, as is evident from the increasing number of scientific researches on the subject of nanoparticles during the period 1996- 2009, and this trend shows the growing use of their technological and scientific applications. One Nobel Prize was awarded during the work period of the past years in the field of nanotechnology, following their discovery of fullerenes in 1996, to Robert F. Curl, Jr., Sir Harold
W. Kroto, and Richard E. Smalley, figure (1). [2]

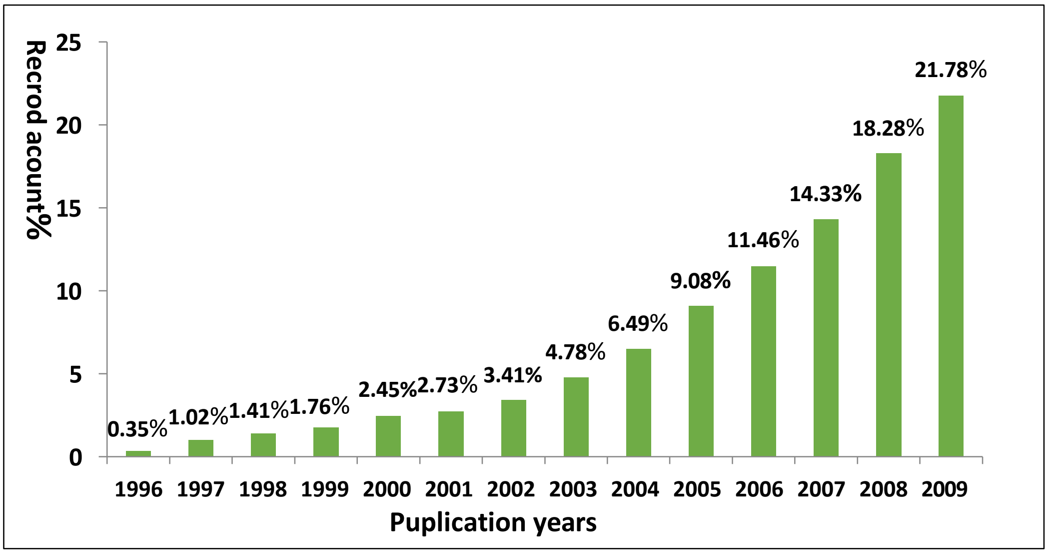


Figure 1. Chronologically, the number of scientific papers published on the subject of inorganic NPs for the period from 1996 to 2009.

It is worth noting that nanotechnology is not a modern invention; its roots date back to ancient times. In a region called Attica in Greece during the sixth century BC, craftsmen invented an advanced firing method to create the red and black effects that decorate Greek vases. It was later discovered that these effects were the result of spinel-like nanoparticles embedded in a thin glass layer, formed by carefully controlling oxidation and reduction during the firing technique. [3] used. Additionally, nanotechnology was utilized in lustrous ceramics, where transmission electron microscopy (TEM) revealed the presence of thin metallic films with a nanostructure. These artifacts, characterized by a colorful metallic luster, were created through an experimental method that originated in Iraq during the ninth century and later gained fame throughout the Middle East, Egypt, Persia, and in cities such as Italy and Spain. [4]

The process of color production using

metallic nanoparticles has been studied using various methods, including absorption, reflection, and diffraction. Researchers were able to distinguish between fake and original artifacts through a specific vision they relied on, which was provided to them by many different techniques such as advanced microscopy and Raman scattering, which provided them with insights into the nanostructure and methods used by ancient craftsmen. This review highlights the development and application of nanotechnology from its inception to its transformation into a field of science. [5]

Nanoparticles have unique chemical and physical properties. At the nanoscale, these materials exhibit behavior that is different from their larger counterparts. At most, their chemical, electronic, and optical properties differ significantly from those of the bulk material components. This is due to the increase in surface area relative to volume, which increases the influence of surface atoms. This transformation not only changes the properties of the nanoparticle, but also has a significant impact on its interactions with its surrounding environment. [6,7] The behavior of nanoparticles changes from classical physics to quantum mechanics when the particles are small enough. In this regime, the particle behaves like an artificial atom with discrete electronic states, a behavior similar to that of natural atoms. The quantum wave function of the electron in such a regime is expressed coherently throughout the atomic lattice. When the crystal size shrinks to the nanometer range, distinct changes occur in its properties. The electronic structure shifts from continuous bands to discrete quantum levels, leading to a change in optical transitions and making the thermal, electrical, and optical properties of the material dependent on size and shape (Fig. 4). [7]

In general, surface atomic effects or quantum mechanics do not give us a complete prediction of all the properties of nanoparticles. For example, silicon nanoparticles of (20-100) nm can be compared to ruby and diamond, which exhibit very high hardness in the range of (30-50) GPa. [8] Nanoparticles are produced by three different scientific methods, including physical methods such as pulsed laser ablation, which has proven to be a very effective method for producing highly purified nanoparticles or nanofilms, chemical, and mechanical processes such as grinding. [9, 10]

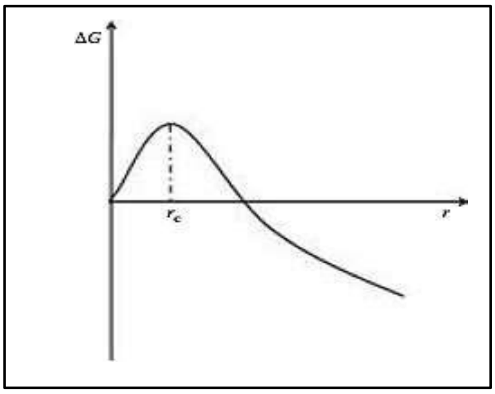


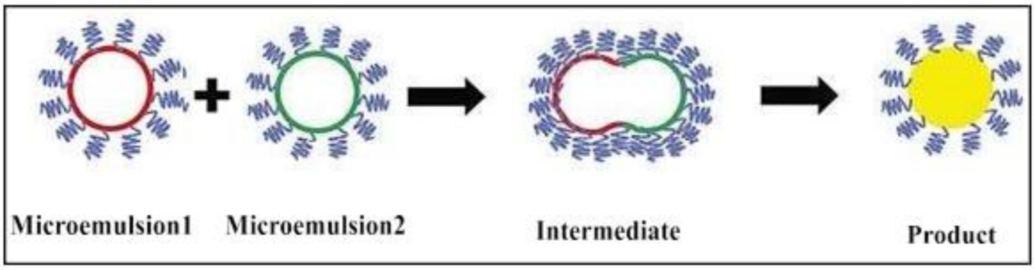
Figure 2: ΔG (free energy) as a function for the radius of particle; critical radius size rc.[7].

3. Synthetic methods:

Three basic and various methods have been used to prepare nanoparticles: chemical methods, including: (co-precipitation, organic solvents, supercritical fluids, and the use of an inorganic matrix as a support), physical methods, including: (thermolytic (thermal decomposition), microwave radiation, ultraviolet radiation, sonochemistry, laser ablation, induced by free radicals, and photochemistry), and biological methods (using bacteria, algae, plants, or fungi). In this article, we will explain a group of them. The methods commonly used in the manufacture of nanoparticles have a significant impact on the size and shape of small particles [11].

3.1. Microemulsions:

They consist of three basic components: oil, water, and a mixture of surface-active agents. Micelles are formed when the critical micelle concentration (CMC) is exceeded. They are aggregates of molecules of surfactants that increase the solubility of organic compounds in water (oil-in-water emulsions) or hydrophilic compounds in the oil phase (water-in-oil emulsions). This principle has been exploited in the preparation of nanoparticles (NPs) by linking two microemulsions containing suitable reactants, as in Scheme 1. [12]



Scheme.1: The microemulsion mechanism that proposed for the formation of nanoparticles.

Similar methods have prepared different types of inorganic nanoparticles. For example, silver nanoparticles (Ag NPs) were produced by mixing reverse micellar solutions of Na(AOT), and $NaBH_4$. Similarly, gold nanoparticles (Au NPs) were synthesized using NaCN– BH_3 in a water–hexane microemulsion of sodium AOT (1,4-bis(2-ethylhexoxy)-1,4- 1,4-dioxobutane-2-sulfonate), where $HAuCl_4$ was reduced to yield Au NPs. Palladium nanoparticles (Pd NPs) were also prepared in reverse micelles formed by AOT in isooctane, with the addition of coating agents to the suspension. Copper nanoparticles (Cu NPs) were synthesized by the reduction of a micellar solution formed by mixing $Cu(DS)_2$ (dodecyl sulfate) with $NaBH_4$. Below the critical micelle concentration (CMC), a mixture of CuO and metallic nanoparticles is formed, while above the CMC, only metallic nanostructures are generated. Another type of bimetallic nanoparticles, such as gold and silver, were prepared by the co-reduction of AgNO3 and HAuCl4 salts with hydrazine in a microemulsion of water, AOT, and isooctane at room temperature. Tin oxide (SnO_2) nanoparticles were prepared by heating the precipitate formed by mixing microemulsions of $SnCl_4.5H_2O$, CTAB, 1-butanol, isooctane and ammonia at 500 °C. Other techniques include the use of mixed micelles of $Co(DS)_2$ and $Fe(DS)_2$ in aqueous methylamine to produce bimetallic nanoparticles of cobalt and iron $CoFe_2O_4$, and the reaction of copper ammonia complex with thiourea in a microemulsion of Triton-X 100-cyclohexane to produce Cu_2S nanoparticles. [13]

3.2. Thermal decomposition process:

Another approach to synthesize inorganic nanoparticles NPs is by the thermal decomposition of metal-surfactant complexes and organometallic compounds. Bimetallic nanoparticles such as CoPt and FePt are prepared at high temperatures by reacting trioctylphosphine oxide and $Co_2(CO)_8$ or $Fe(CO)_5$ with 1,2-hexadecanediol and $Pt(acac)_2$. Metallic nanoparticles are obtained by the thermal decomposition of metal carbonyls (metallic compounds with zero oxidation state), for example, by high-temperature decomposition of the Co2(CO)8 complex in the presence of oleic acid and triphenylphosphine at 220 °C, resulting in monodisperse cobalt (Co) nanoparticles. [10]

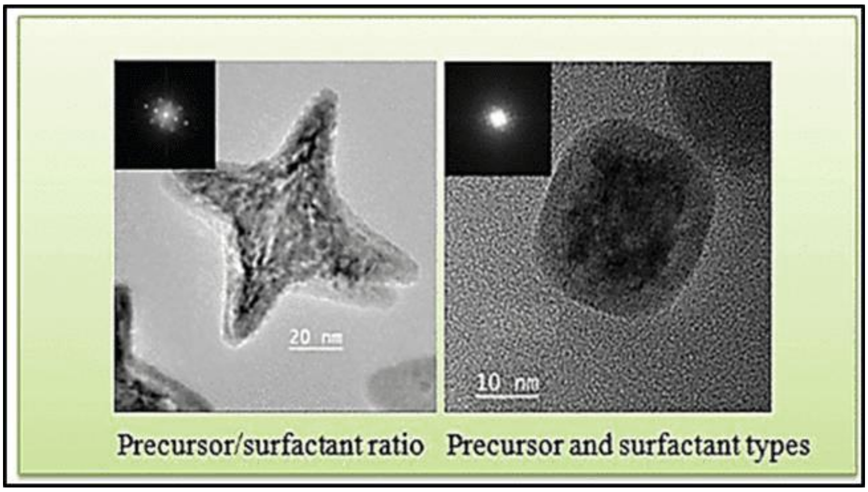


Figure 3: The comprehensive scheme of transmission electron microscopy of magnetite and ultra-large-scale structure of monodisperse nanoparticles

Slow heating at 320 °C of the iron-oleate complex with octadecene and maintaining this temperature for 30 min helps generate iron oxide nanoparticles. The thermal decomposition of long chains of iron carboxylates. Palmitate can also produce the Iron oxide NPs that ranging, such as Fe(III) oleate, myristate [14] figure5 showed the TEM. Palmitate can also produce the Iron oxide NPs that range in shape from spherical to nanostars. Thermal decomposition at 250 °C for 10 min of copper sulfate on a silicon substrate produces copper nanoparticles (Cu NPs), which are subsequently oxidized to Cu2O while retaining their original composition. Other examples include: the production of CdSe and CdS nanoparticles **(Figures 6 and 7)** at 200 °C from cadmium complexes in TOP and hexadecylamine, the output of Fe_2P nanoclusters from $Fe(CO)_4[PPh_2CH_2CH_2–Si(OMe)_3]$ within a dry silica gel matrix, and GaP nanoparticles from $Cl_2GaP(SiMe_3)_2$ at 300 °C. Moreover, the burning method has been primarily used to synthesize nanoparticles of bimetallic oxides, like $CoFe_2O_4$, using Co and $Fe(acac)_3$ predecessors. [15] at 300 °C. Palladium nanoparticles with sizes ranging from (3.5-7) nm were obtained by thermal decomposition of palladium-trioctylphosphine complex for 30 min. **(Figure 8)** [16] Monodisperse cobalt nanoparticles (NPs) are synthesized via a high-temperature thermal decomposition method in the presence of oleic acid and triphenylphosphine. [17]

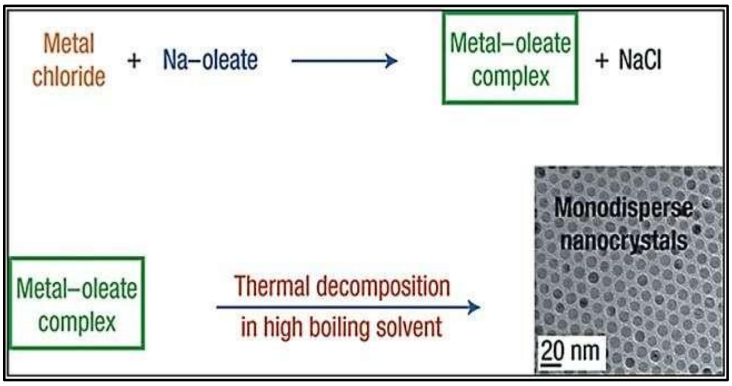


Figure 4: The comprehensive scheme of transmission electron microscopy of magnetite and ultra-large-scale structure of monodisperse nanoparticles.

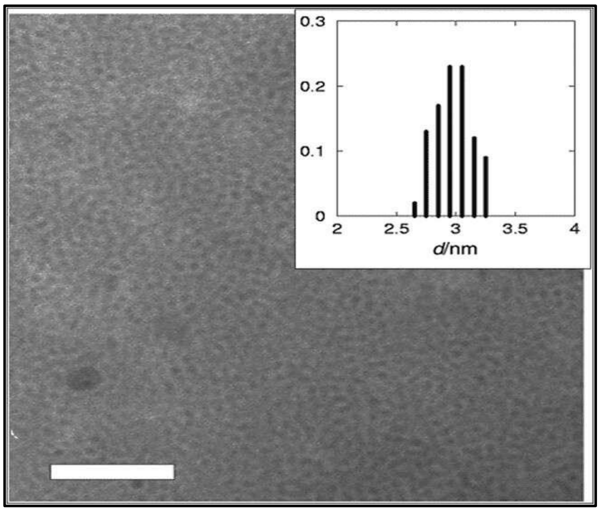


Figure 5: An image under transmission electron microscope for a relatively dense arrangement of CdSe nanoparticles showing a tendency to close-pack in the plane (bar=50 nm).

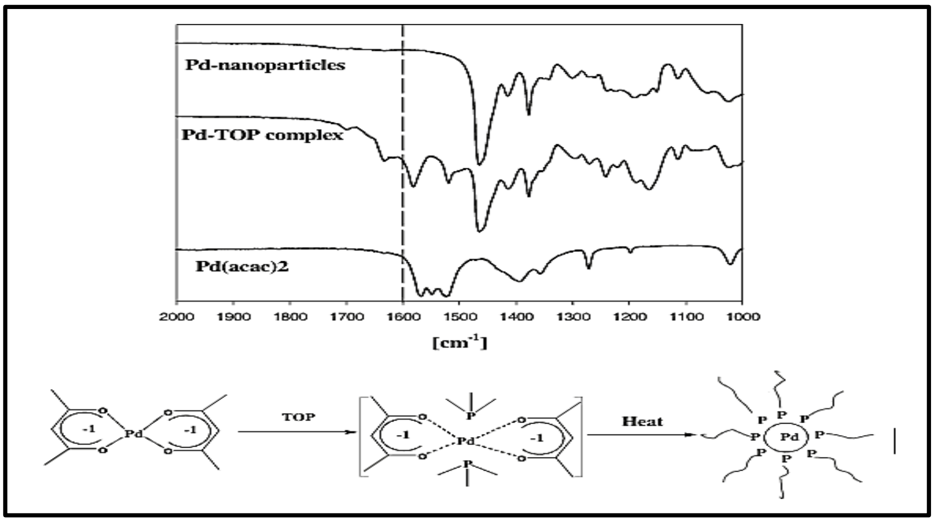


Figure 6: IR Spectrum of Pd NPS, Pd-TOP complex, and Pd(OAc)$_2$ predecessor

3.3. Hydrothermal and solvothermal methods:

These techniques are . They trade on the change in the reactivity of reactants and the solubility in water or the solvent below risewidely applied to generate inorganic nanoparticles (NPs). They trade on the change in the reactivity of reactants and the solubility in water or the solvent at elevated pressures and temperatures. Inorganic nanoparticles can be synthesized at temperatures much lower than those required for solid-state reactions by taking advantage of the high reactivity of complexes and metal salts below these conditions. Different reaction parameters, such as the temperature, pressure, time, pH, reactant concentration, and the volume of the reaction cell, can be set to obtain the nucleation rates and particle size distributions that are desirable. [15]

This route has been used to produce nanoparticles of metal oxides, pnictides, chalcogenides, and other materials. For example, heating an aqueous solution of trisodium citrate, $HAuCl_4$, and CTAB at 110 °C for different time periods (6, 12, 24, 48, and 72 h) yields octahedral gold nanoparticles with sizes of 30, 60, 90, 120, and 150 nm, respectively. In a similar manner, nanoanatase TiO_2 can be synthesized at 100 °C using anhydrous diethyl ether as a solvent, tetrabutyl titanate as a titanium source, and acetic acid as an inhibitor. [19]

At 200 °C for 4 hours, ReO_3 metal oxide nanoparticles, with sizes ranging from (8.5-32.5) nm, are prepared by decomposing the Re_2O_7–dioxane complex under solvothermal conditions. Also molecular precursors such as 2,2′-bipyridyl($Pb(SC(O)(C_6H_5)_2)$) and 2,2′-bipyridyl ($Cd(SC(O)(C_6H_5)_2)$), are heated in aqueous media at 100 °C for 30 minutes, to produce PbS and CdS nanoparticles respectively, the ZnO nanorods Monodispersed with an average diameter under 50nm are gained by solvothermally reacting zinc nitrate, ethylenediamine, ethanol, NaOH, and at 180 °C for 20 hours (figure 9). [20]

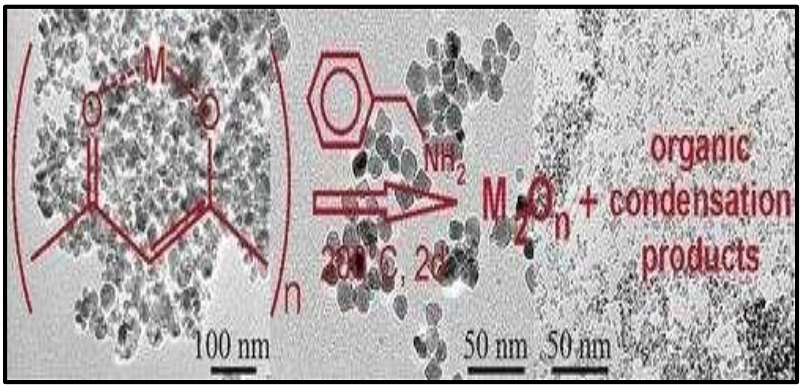


Fig. 7: Solvothermal reaction to obtain the nanorods with an average diameter below 50nm.

$CoFe_2O_4$ and γ-Fe_2O_3 nanoparticles with diameters of 7 and 10 nm, respectively, are produced by hydrothermal heating of a reaction mix containing n-octylamine, $Fe(cupf)_3$–$Co(cupf)_2$, and toluene for 1 hour at 220 °C. (21). Besides that, CdSe monodisperse nanoparticles (3nm) are prepared solvothermal using dodecanethiol, tetralin, $Cd(sterate)_2$, Se, and toluene in a stainless-steel autoclave at 250 °C for 5 hrs. [22]

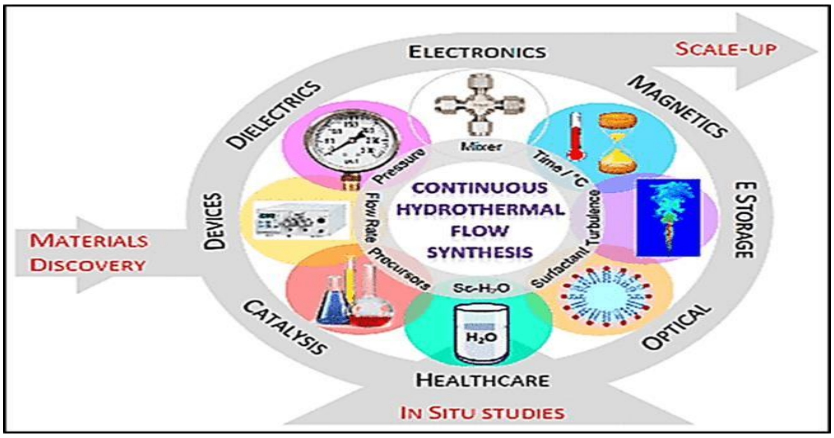


Fig.8: Continual hydrothermal synthesis of inorganic NPs. (18)

3.4. Sol–gel process:

This approach includes the hydrolysis and followed by condensation of metal precursor, which is then submitted to additional polymerization and condensation to produce a three-dimensional metal oxide lattice, making it in a gel. The sol–gel route can arise in both aqueous and non-aqueous media. The chemical methods of nanoparticles (NPs) by the sol–gel pathway are an active way for resulting high-class metal oxide nanoparticles compared to other chemical and physical ways. (23) A standard non-aqueous sol-gel method has also been advanced to prepare metal oxides such as ZnO, γ\gammaγ-Ga_2O_3, and cubic In_2O_3 by reacting metal acetones with benzylamine. [24] In the aqueous sol–gel pathway, and for the nano oxide formation, water molecules turn as the oxygen source. Reciprocally, in the non-aqueous pathway, the oxygen is given by solvents such as alcohols, ethers, aldehydes, or ketones, or by organic components of the precursor, such as acetylacetonates or alkoxides. **(Figure 10)** [18, 25]

The aqueous sol–gel process can be summarized as follows:

i. Hydrolysis:

$$M(OR)_X + mH_2O \longrightarrow M(OR)_{x-m}(OH) + mROH \qquad (OH)$$

$$When\ x = m, the\ reaction\ obtain\ the\ total\ hydrolysis.$$

ii. Condensation:

$$2M(OR)_{x-m}(OH)_m \longrightarrow (OH)_{m-1}(OR)_{x-m}\text{-}M\text{-}O\text{-}M(OR)_{x-m}(OH)_{m-1} + H_2O$$

Alternatively:

$$2M(OR)_{x-m}(OH)_m \longrightarrow (OH)_m\text{-}1\ (OR)_{x-m}\text{-}M\text{-}O\text{-}M(OR)_{x-m-1} + ROH$$

Overall process:

$$M(OR)_x + x/2H_2O \longrightarrow MO_{x/2} + xHOR$$

The examples consist of:

- titanium dioxide nanoparticles (TiO_2-NPs) were produced at nano crystallite size (11 nm) by using the sol-gel process and assisted by ultrasound with operating conditions of about (40 kHz, 350 W). [26]
- γ\gammaγ-Fe_2O_3 nanoparticles (6–15 nm) were obtained at 400 °C by direct heat treatment of gels.

- Cerium NPs were also obtained via the use of cerium isopropoxide in cyclohexane through a reverse micelle sol–gel approach. [27]

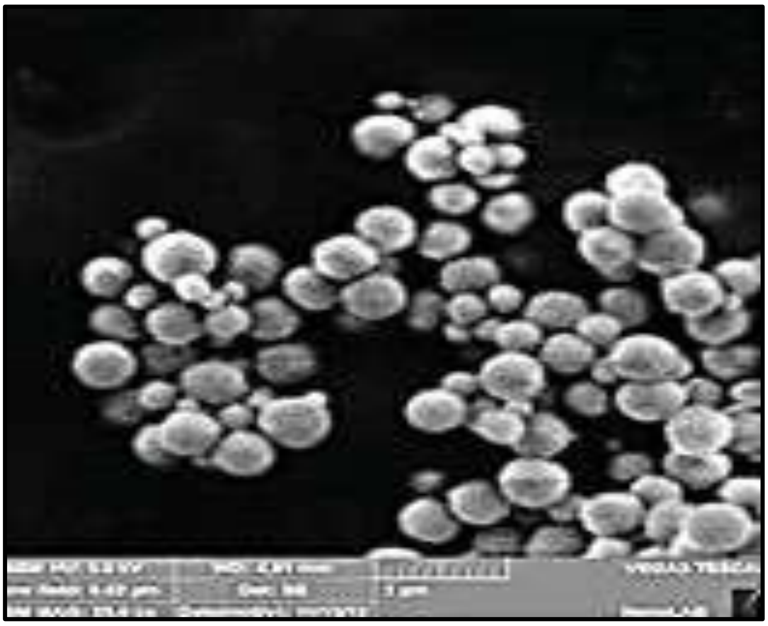


Figure 9: appear the SEM image of ZnO NPs. (25).

Several types of nano metal oxides, such as ZrO_2, ZnO, CeO_2, and iron oxide, have been produced using non-hydrolytic sol–gel route. [28]

3.5. Phase-transfer method

Many nanoparticles (NPs) can be prepared through phase transition synthesis, a method widely used. This method involves the transfer of reactants from a polar medium to a nonpolar medium, where more processing is carried out. Conversely, nanoparticles synthesized in a nonpolar medium can also undergo phase transition to a polar medium. (29) Here, a study on the production of a nanostructure of CdS nanocrystals via the phase transfer process of organic-capped cadmium sulfide by heptamine beta-cyclodextrin ($(NH_2)_7\beta CD$), CdS cover with an organic ligand and double molecules of heptamine beta-cyclodextrin ($(NH_2)_7\beta CD$) in aqueous solution is reported. The transformation method of the formerly prepared by hydrophobic cadmium sulfide crystals by $(NH_2)_7\beta CD$ was extensively explored using several structural and spectroscopic techniques. The formation of the complex depends on the direct coordination of amine groups of (NH2)7βCD on the NC surface, which was shown and found to be accountable for the phase transfer process of NC from cadmium sulfide.

The amine functional group in $(NH_2)_7\beta CD$ and the appropriate combination of pristine capping agent coordinating the NC surface and the appropriate solvent were found to be crucial for the success of the CdS NC phase transfer process. The hydrophobization of aqueous gold NPs enables their transfer into non-polar organic solvents. Yang et al. described a general protocol for transferring various metal ions from water to organic solvents using dodecylamine and ethanol as the solvent. This method allowed the synthesis of noble metal NPs, semiconductor–noble–metal composite NPs, and the heterogeneous deposition of noble metals on semiconductor NPs, as well as the homogeneous growth of semiconductors on noble metal NPs **(Figure 11).** [15,19,30]

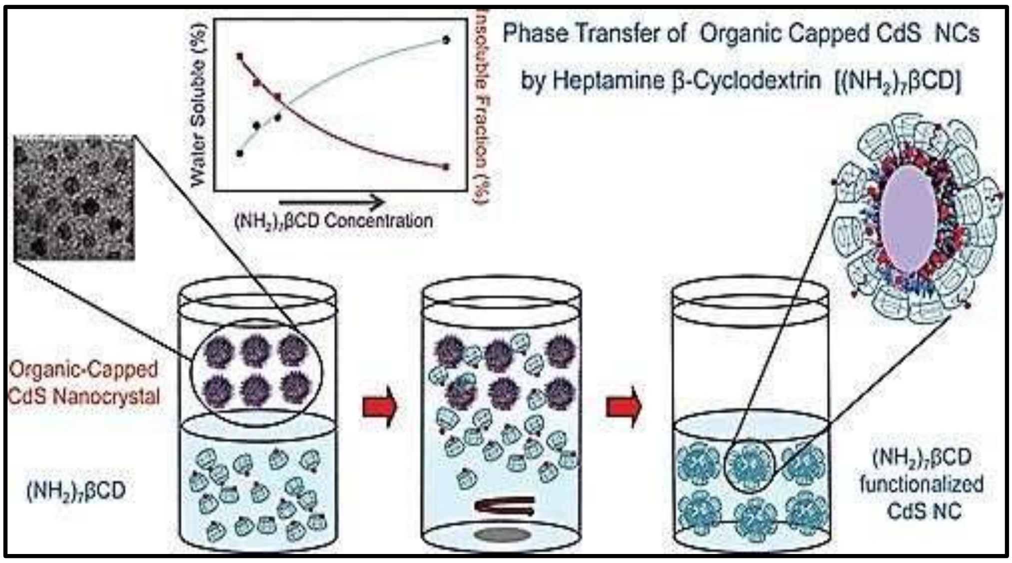


Figure 10: Phase transfer of CdS NCs by heptamine beta-cyclodextrin $((NH_2)7\beta CD)$.

3.6. Microwave process:

In this pathway, microwaves are typically produced by a magnetron, and the energy for the microwave is absorbed via the reactants, converting it into heat. This heat speeds up the decomposition of the starting materials and results in highly saturated solutions, where nucleation and growth of nano-crystalline products (NCs) occur. This method is widely used to create inorganic nanoparticles (NPs) energy-efficient. [31]

In the classical Turkevich process, the product of larger Au NPs (digested by using a Bergh of Speed wave XPERT microwave) of Au NPs synthesized from various concentrations of HAuCl4, a size-controlled way of citrate-stabilized Au NPs, followed by their growth through a half-continuous seed-mediated path. The result, Au NPs of up to 53 nm, were prepared by controlled addition of chloroauric acid ($HAuCl_4$) to pre-prepared citrate-stabilized Au NP seeds. (figure 12) [32]

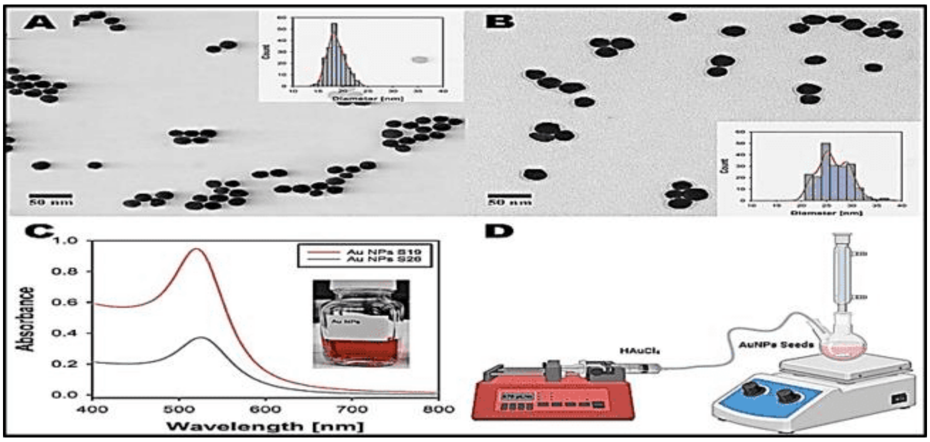


Figure 11: The Turkevich Au NPs at various chloroauric acid concentrations

By microwave-induced plasma in liquid process (MWPLP), Au/Pd alloy NPs were successfully prepared using H2PdCl4, HAuCl4, and α-thioglycerol as predecessor and a stabilizer, respectively, . After only several minutes of microwave irradiation, metallic AU-Pd NPs were obtained in an aqueous medium without use of any reducing agent. The reduction mechanism of metal ions was assured by UV–Vis spectral changes. The conclusion from HAADF-STEM and EDS indicated that produced NPs were bimetallic Au/Pd. overtime, XRD patterns of the prepared NPs rated that the structure of bimetallic NPs could be controlled by the change of initial ratio for metal precursors. [33]

A novel method has been developed to synthesize highly crystalline oleylamine-coated colloidal Pt nanocubes by microwave (MW) heating. The use of microwave heating helps to reduce reaction times, eliminates the need for hazardous reagents, and gives an efficient yield of approximately 8 nm monodisperse platinum nanocubes [MW nanoparticles (NPs)]. The absorption spectra of the MW nanoparticles NPs show an excellent localized surface plasmon resonance band at 213nm. This observation is important for the development of plasmonic photocatalytic processes and the use of advanced catalytic materials. [34]

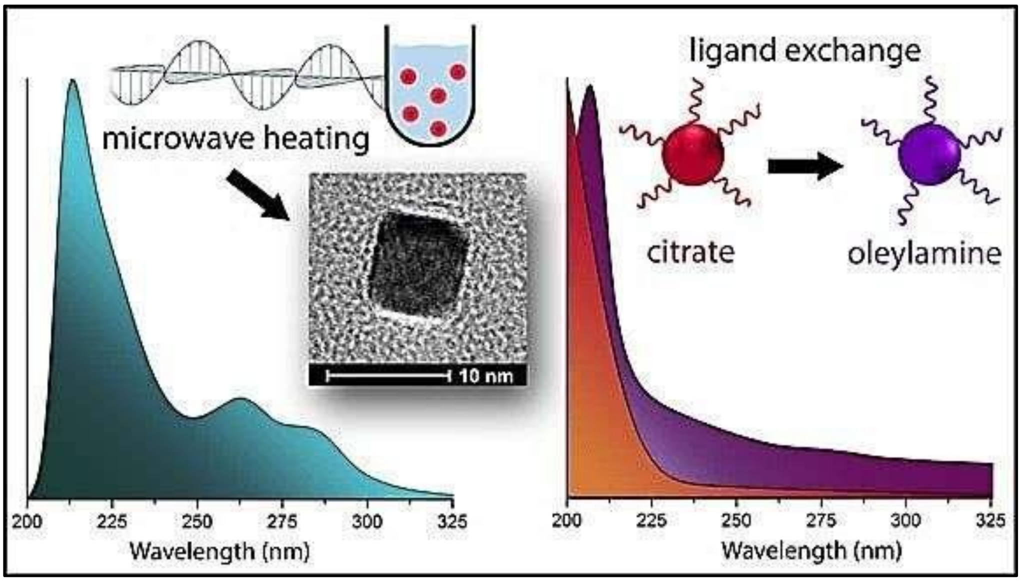


Figure 12: Absorption spectra of the MW of Pt nanoparticles NPs

3.7. The use of the liquid–liquid interface system method:

This method has been employed to produce NPs of metals such as: Ag, Au, and Pd, metal chalcogenides such as CdS and NiS, as well as extended ultrathin single-crystalline films of ZnO, CuO, PbS (32), CuS, and ZnS. Liquid–liquid interface is typically used to create clusters or thin films of inorganic (NPs). It is a heterogeneous region, usually only an any nanometers thick, due to the low interface energy, the nanoparticles be a highly moving and speedily form an equilibrium cluster. Many factors influence the aggregation process at the interface between two liquids, including: the interface nature, modification of the surface for the NPs, and finally the active radius of the nanoparticles NPs. Smaller nanoparticles typically bind weakly to the interface contrast to the lagers. [35]

In the synthesis process of inorganic NPs, the organic forerunner of the pertinent metal well place in the organic layer, and a suitable reagent is exit in the aqueous layer. The product that formed at the interface be composed of ultra-thin nanocrystalline films of the inorganic NPs. For example, in the synthesis method of Au–Cu–Ag nanocrystalline films, a solution of $Ag_2(PPh_3)_4Cl_2$ or $Au(PPh_3)Cl$–$Cu(PPh_3)Cl$ in toluene is place in touch with an aqueous alkali sol. at 300 K. When the two liquid layers stabilize, injected with tetrakishydroxymethylphosphonium chloride (THPC) into the aqueous layer with ensure to lower it is effect on the toluene layer. Nanocrystalline films of double Au–Cu and Au–Ag alloys, as well as triple Au–Ag–Cu alloys, are produced by mixing the corresponding metal predecessor in the organic layer. (36-41) Polycrystalline thin films of CdSe–CuSe can be produced at the organic–aqueous interface by reacting $Cd(cupf)_2$–$Cu(cupf)_2$ in the toluene layer with dimethylsilene urea in the aqueous layer. In addition, single-crystal CuO–CuS films are formed by reacting $Cu(cupf)_2$ in the organic layer with an aqueous solution of NaOH–Na_2S. Figure 14 shows electron microscope images of Au, CdS, Ag, and CuS nanoparticles formed in the liquid–liquid system. (42)

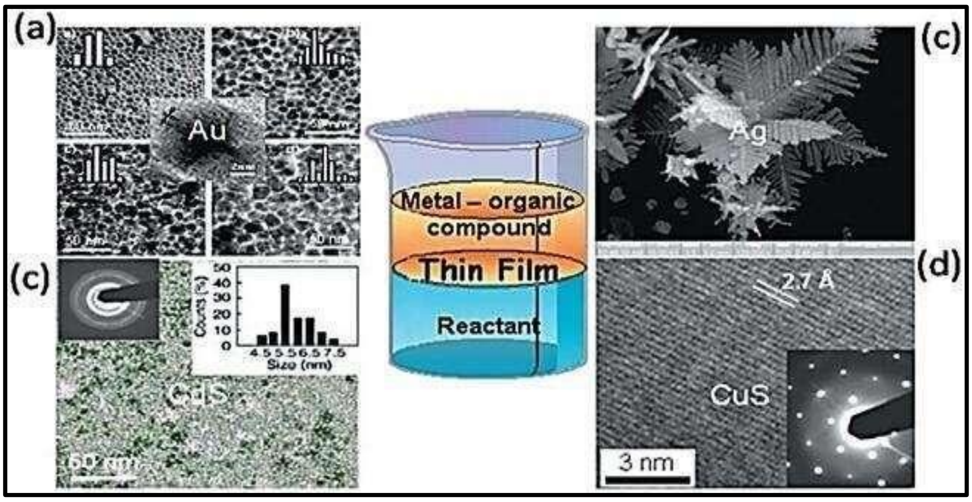


Figure 13:(a, b, c, d) TEM images for Au, Ag, CdS, CuS NPs respectively formed at the liquid–liquid interface system.

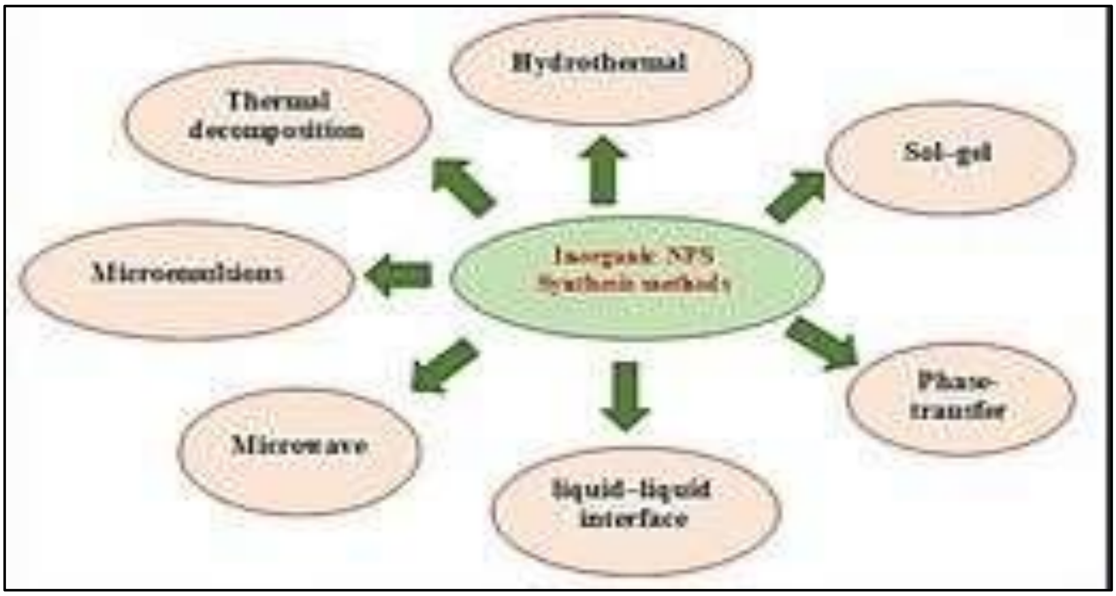


Figure 14: Summary of the most important methods for preparing inorganic nanoparticles covered in the review.

4. Characterization of nanoparticles NPs:

The potential applications of nanoparticles are determined by their properties. Therefore, various routes and modes are used to analyze and characterize their various physical and chemical properties. The detailed diagram (Diag.1), shows the most important methods used in diagnosing nanoparticles and their types, which most researchers have relied on in the processes of diagnosing and analyzing the nanoparticles that they have prepared. [43-49]

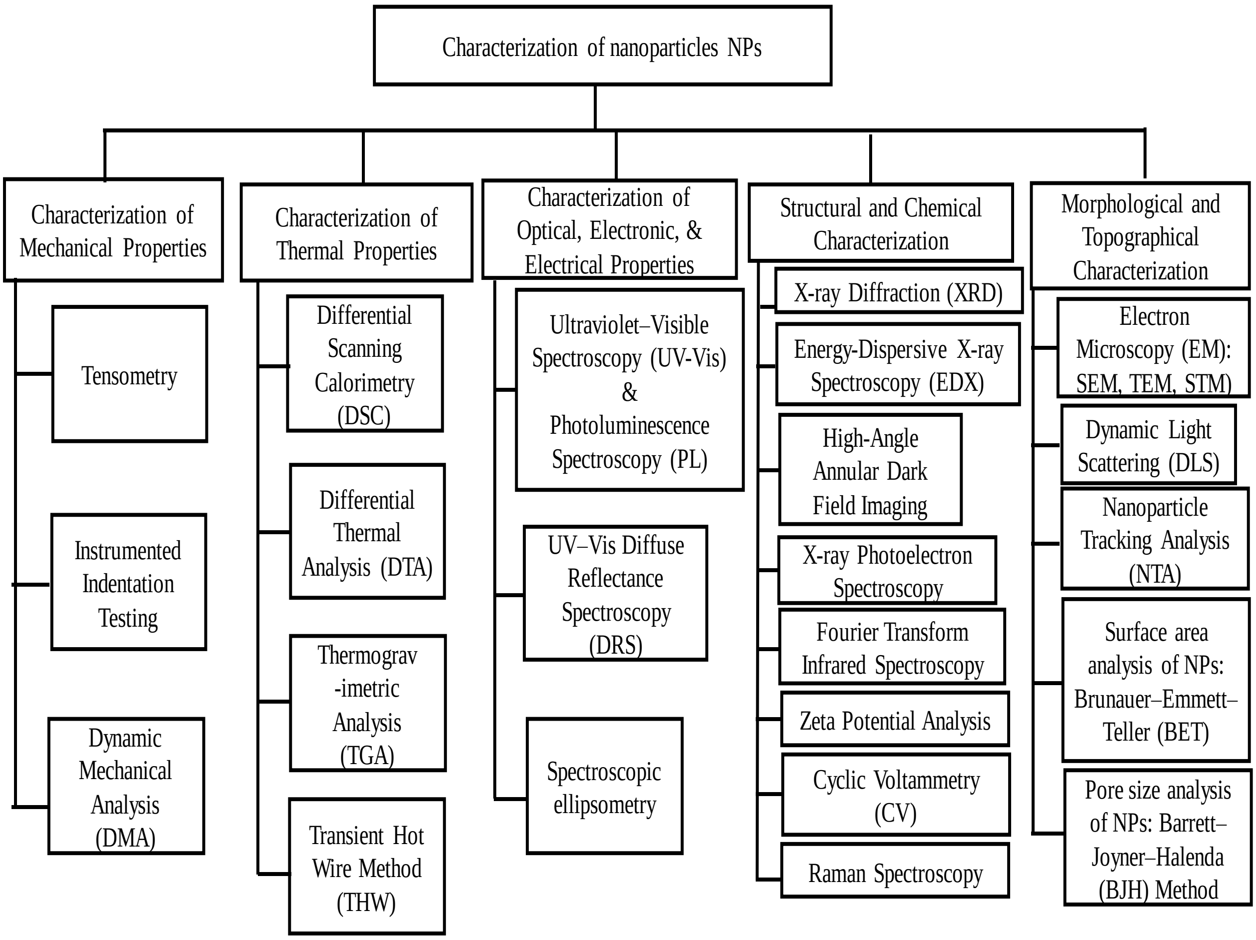


Diagram.1: Schematic overview on the most important methods used in diagnosing nanoparticles and their types.Applications of Inorganic Nanoparticles (INPs)

4.1. Medicine and Pharmaceuticals:

Metallic and semiconductor NPs hold promising potential in the diagnosis and treatment of cancer, thanks to their promoted light diffusion and absorption properties, resulting from the influence of LSPR (localized surface plasmon resonance). For example, gold nanoparticles (Au NPs) are active at absorbing light and turn it into localized heat, making them helpful in eclectic photothermal treatment, which includes using heat to prompt cancer cell death in tumor tissue. In addition, the individual optical properties of gold nanoparticles make them an ideal nominee for photodynamic treatment, where a drug will be activated by light to kill cancer cells. [49]

NPs have been successfully utilized in several medical areas, including biosensors for the disclosure of DNA, proteins, carbohydrates, and heavy metallic ions, also in cellular imaging, and for determining the blood glucose levels. They are also applied in medical diagnostics to detect viruses and bacteria. For ex., Au NPs have been used in a fast test to discover the presence of antibodies to the novel coronavirus (SARS-CoV-2) in the blood samples within 10-15 min. Moreover, nanoparticles such as CuO, ZnO, TiO_2, and $BiVO_4$ are increasingly utilized in medical products, including catheters, due to their antimicrobial and antibacterial properties. [50-54] Gadolinium nanoparticles have also shown a prospect in preventing tumor progression, inhibiting metastasis, and enhancing contrast in tumor-specific magnetic resonance imaging (MRI). (55) Another way where INPs exhibit promise in targeted drug delivery, with iron oxide (Fe_3O_4) and zinc oxide (ZnO) NPs being utilized functionally for targeted delivery and selective devastation of cancer cells. fig. 16 **[**56]

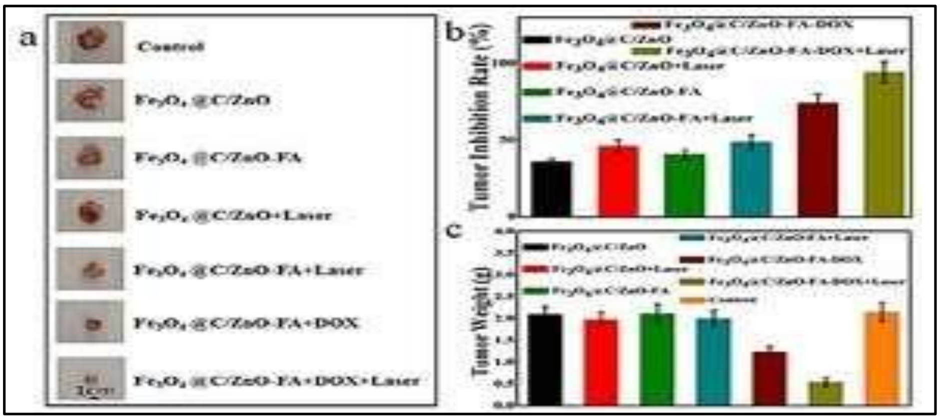


Figure 15: Antitumor effects of various samples. (a) Digital images of tumors rooted from tumor-bearing mice, (b) the rates of tumor inhibition, and (c) the weight of tumor.

4.2. Electronics applications:

A wide range of potential applications in electronics and imaging technologies offered by nanoparticles (NPs), with their special optical and electronic properties. For example, Gd-based NPs can improve the quality of photographs and minimize the dose of contrast agents applied in MRI (magnetic resonance imaging). $GdPO_4$ nanoparticles have been effectively applied to discover tumours in MRI utilizing one-10th the dose required for gadopentetic acid (Gd-DTPA) agent. Moreover, Gadolinium(III) trioxide (Gd_2O_3) nanoparticles have been exhibit to be more active as a contrast worker than gadoterate meglumine (Gd-DOTA), which is usually exercised at the selfsame concentration. [57]

Nanoparticles also have the capacity to track and image single molecules, which in turn provides useful insights into cellular processes, such as the arrangement and reactions of membrane proteins. For example, the application of Eu^{3+}oxidized NPs to track a single toxin receptor with noteworthy reliability. [58] In the battery range, separators play a critical function in preventing immediate contact between the anode and cathode, while also facilitating ion transport. The aerogel structure of some nanoparticles, such as zinc oxide nanoparticles, makes conventional battery partition materials (microporous polyolefin membranes), which suffer from limitations such as poor electrolyte absorption and low thermal stability, an excellent choice for partition plates, enabling batteries to store significantly more energy than conventional batteries.

[59] For lithium-air batteries, Bimetallic nanoparticles such as gold and platinum (Pt-Au NPs) significantly enhance oxygen reduction and modification reactions. [60] Moreover, Batteries made from nanoparticles of nickel and other metal hydrides have been found to last longer and need fewer charges. In addition to their applications in batteries, inorganic nanoparticles such as CdS and ZnSe are used in light-emitting diodes (LEDs) in modern display screens, improving their size and brightness. (61) CdTe NPs are applied in LEDs (liquid crystal displays). Mixing a layer of NPs in LCDs and LEDs

enables them to produce more light with the same amount of energy, while also promoting their lifespan. [61]

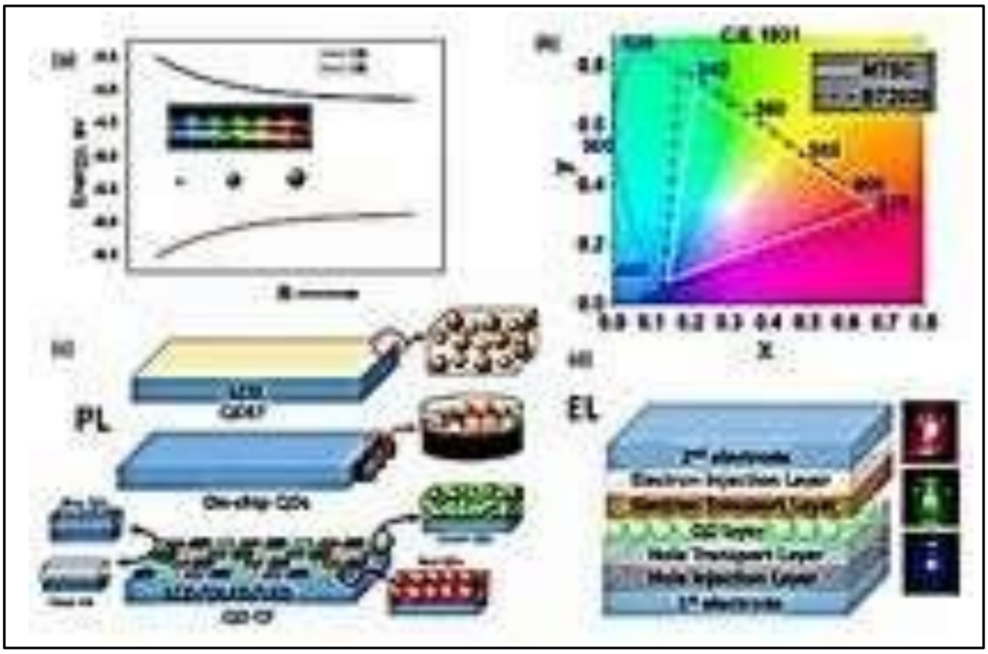


Figure 17. (a) A simple illustration of the dependence of the energy level of quantum points on particle size.
(b) The series of colors achieved by quantum dots (QDs) with a narrowing emission band. A nanoparticle provides very broad coverage of human vision. (c) Illustrates the three most common device structures used in nanoparticle optical displays. (d) Illustrates the simple structure of an electro luminescent device, and the inset shows photographs of many monochromatic LEDs

4.3. Applications in agriculture

Nanoparticles (NPs) have the potential to provide innovative solutions to current agricultural and environmental challenges. In agriculture, NPs are mostly applied in two shapes: nanopesticides and nanofertilizers. Several NPs display insecticidal, antimicrobial, and nematicidal properties, making them a good alternative to chemical pesticides and potentially a more effective choice than biopesticides. For ex., the photocatalytic action of TiO2 NPs gives them powerful antimicrobial properties versus Xanthomonas perforans, which gives rise to tomato spot disease. CuO NPs have insecticidal activity against the African cotton leafworm, Spodoptera littoralis. Meanwhile, Ag NPs exhibit nematicidal effect against root-knot nematodes, Meloidogyne spp.
Chemical fertilizers often have a limited capacity due to issues such as volatilization and leaching. As a result, farmers tend to use chemical fertilizers in excessive amounts, enhancing yield productivity but giving rise to environmental damage. In versus, nanofertilizers are used in minimal quantities than classical chemical fertilizers but are more active. Their afflicted efficiency stems from their ability to release nutrients precisely when and where plants need them, reducing the risk of excess fertilizer converting into gaseous forms or contaminating groundwater. Various NPs, including SiO_2, CuO, ZnO, Mg, and Fe NPs, have been applied to develop the fertilizers that enhance

nitrogen fixation, promote seed germination, alleviate drought stress, excess seed weight, and increase photosynthesis. The small size and large surface area of these NPs contribute to their superior activity compared to conventional fertilizers. [62-68]

4.4. In the food industry applications

Despite worries about their toxicity, nanoparticles (NPs) have unique applications in the food industry, usually in the food production, packaging, and preservation processes. Titanium dioxide (TiO_2) nanoparticles, which are known for their antimicrobial photocatalytic properties, hold promise in food packaging. They can also be used in sensors designed to detect volatile organic compounds. Silver (Ag) nanoparticles, due to their potent antimicrobial activity, are also important in food packaging. They help eliminate the risk of pathogens and extend the shelf life of food products. The effectiveness of mixing silver nanoparticles and zinc oxide (ZnO) into biodegradable and non-biodegradable packaging for bread, meat, fruits, and dairy products has been tested versus various types of bacteria, mold, and yeast. For ex., an Ag nanoparticle- impregnated polyvinyl chloride (PVC) package has been evaluated for saving minced meat at 4°C, a refrigerated temperature. The results showed that Ag NPs safely slowed bacterial growth, and elongated the shelf life of meat by (2-7) days. [68-71]

Conclusion:

Inorganic nanoparticles are of great importance today, as a large number of them have been prepared, and diagnostic technologies have demonstrated their unique and distinctive benefits in all aspects of life. This review presents a comprehensive overview of previous studies that have addressed this aspect, defining inorganic nanoparticles and their various preparation methods. The most important diagnostic techniques are also presented, essentialalong with some of their significant applications in the medical and pharmaceutical fields, such as treating tumors and killing cancer cells, as well as their importance in drug delivery. Many fundamental issues must be taken into consideration before applying these inorganic nanosystems clinically. The first issue is biocompatibility when choosing inorganic nanosystems. Compared to advanced organic nanoparticles, inorganic nanoparticles are of great importance in electronics, such as improving battery quality and their use in diodes. In addition, the importance of using inorganic nanoparticles in the food industry and agriculture is also highlighted.

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