TRANSITION METAL OXIDE NANO PARTICLE SYNTHESIS, CHARACTERIZATION, AND CATALYTIC APPLICATIONS: A REVIEW

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Abstract
Nanomaterials have the potential to enable tremendous technological advancement, which is why they are attracting the attention of leading researchers at the moment. Nanocomposites based on transition metal oxides show great promise across a variety of fields and devices, including solar cells, photocatalytic degradation, supercapacitors, sensors, and bactericidal applications. Nanocomposites have been synthesized using a wide variety of methods, from simple chemical procedures to more complex methods such as Co-precipitation, sol-gel techniques, hydrothermal procedures, microwave-assisted synthesis, and biosynthesis. Nanoscale transition-metal oxide particles have been successfully fabricated using several analytical techniques, XRD, SEM, TEM, EDX, BET, TGA, IR, Raman, and UV spectroscopy are all included. Testing the utility of synthetic nanomaterials in solar, electrical, magnetic, and storage applications is the key action plan. In an effort to develop cleaner, more sustainable processes, scientists are currently studying the catalytic activity of nanocomposites in organic transformations. Nanocomposites based on transition metal oxides are reviewed in this article, along with their numerous morphologies, several characterization methods for identifying surface and structural properties, and their catalytic potential.

Keywords: Catalytic, XRD, Nanopartical, Heterocycle.

Introduction

Nanotechnology is a field of applied science that focuses on materials less than 100 nm in size, including their environmental impacts, characterization, and use. Compared to other bulk materials, particles of sizes between 1 and 100 nm exhibit significant changes in their chemical and physical properties. This creates both opportunities and problems. Nanoscience and nanotechnology are branches that include chemistry, physics, materials science, biology, and other disciplines. Nanotechnology and nanoscience could change the way many problems in health, the environment, energy, and other areas are solved by being used in biomedical, sensing, energy generation, storage, water treatment, and other sectors [1-6]. sizes between 1 and 100 nm exhibit significant changes in their chemical and physical properties. These particles can serve as laboratory equivalents of combustion-generated nanoparticles to study how surface-condensed metal oxides manage surface-associated contaminants. The major environmental concern of the last decade has been the effects of combustion particles on the environment and human health. The health impacts of nanoparticles are most noticeable [7-9]. Understanding nanoparticle development and reactivity allows us to manage their emission and reduce their environmental impact. It is well known that the size and shape of metal nanoparticles affect their optical, electrical, magnetic, and catalytic properties [10]. Because of their diminutive size, nanoparticles have a high surface area, a property that is fundamental to their behavior. Thus, one approach to control the nanoparticles' catalytic activity is to alter their size and distribution.

There are more studies on traditional and advanced methods for producing nanocomposites, these include co-precipitation, sol-gel, hydrothermal processes, microwave-assisted synthesis, biosynthesis, and simple chemical methods. Analytical techniques, including XRD, SEM, TEM, EDX, BET, TGA, IR, Raman, and UV spectroscopy have successfully enabled the characterization of nanoscale metal oxide particles. Researchers are turning to multidisciplinary approaches to explore the catalytic efficiency of nanocomposites in organic transformations, developing greener methods. Pace change: Metal oxide nanocatalysts may replace standard materials. Smaller catalysts expose more surface area to the reactant, where the catalyst's activity is concentrated. Removing undesired items would establish selectivity, and only a small amount would produce a result. Stable, affordable, and recyclable, the nanocatalyst enables multiple cycles of sustained activity. This paper summarizes well-defined and acceptable methods for the synthesis of transition-metal oxide nanoparticles, including co-precipitation, sol-gel, microwave-assisted, and Biosynthesis. HR-TEM, XPS, and UV/Vis spectroscopy were used to analyze the metal oxide nanomaterial after synthesis. Nanoparticle synthesis and characterization methods are covered in this review. The production of ZnO, CuO, and Fe3O4 nanocomposites and their catalytic applications are highlighted. Green produced transition-metal and metal oxide nanoparticles are presented to improve the literature and benefit future researchers.Several techniques for the synthesis of nanoparticles

Carbon-based, polymer-based, transition-metal-based, and TMONC nanocomposites are the most popular. Their unique properties make transition-metal-oxide-based nanocomposites the most fascinating. Because nanomaterials exhibit size-dependent properties, nanoscience primarily focuses on their synthesis. This method determines the morphologies, physical and chemical properties, and potential uses of the produced nanomaterials. New synthesis methods that are fast, cheap, and environmentally friendly are being developed, yielding highly useful and efficient results. Nanocomposite synthesis using transition metal oxides is covered in this article. Discussed are co-precipitation, chemical vapor deposition, sol-gel, and hydrothermal processes.

1.1. Co-precipitation technique

This step is crucial to the production of nanomaterials. Solution chemistry is recommended for nanomaterial fabrication due to its short diffusion paths, higher product purities, minimized agglomeration, simplicity, uniformity, adjustable particle size, and cost-effectiveness [7, 11-13]. Hadi Eslami et al. developed a procedure for aeration-co-precipitation of a mesoporous

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Iron-Manganese bimetallic oxide nanocomposite. Manganese sulfate and ferric chloride were prepared separately, then mixed at 70 °C with stirring at 50 rpm in a 2:1 molar ratio. To achieve a pH of 9, 10% NH_4OH was added at 50 rpm for 4 hours, precipitating the nanocomposites [14]. $NiFeO_4$ nanocomposite was chemically precipitated from $FeSO_4 \cdot 7H_2O$ and $NiSO_4 \cdot 7H_2O$ in a 1:1 molar ratio at pH = 12. This reducing agent was hydrazine hydrate [15]. The literature describes many valuable transition-metal oxide-based nanocomposites prepared via co-precipitation. Thongthai explained Cu/ZnO CO_2 hydrogenation to methanol [16], ZnO-CuO nanocomposite showed antibacterial properties [13], Shengyan Pu synthesized graphene oxide /Fe_3O_4 nanocomposite used for wasterwater treatment using in situ co-precipitation method [16], etc. Some other transition metal oxide combinations have also been discovered in recent years, including CeO_2.CuO.ZnO [17], ZnO/Ag [12], $CuWO_4$, $CuWO_4$ / NiO [11], NiO-ZnO [7], and many more. This demonstrates that one of the most important, practical, and efficient methods for creating transition metal-based nanocomposites is the co-precipitation approach, hypothesis can be accepted.

1.1. Sol-Gel method

There are both chemical (sol-gel, co-precipitation, and chemical vapor deposition) and physical (ball milling, laser ablation, and sputtering) methods for making nanocomposites based on transition metals and oxides. A fascinating wet chemical process is the sol-gel method. Sol-Gel forms a sol, then a gel, and ultimately dries the solvent. Nanomaterials' size, shape, dimensions, composition, and structure affect catalysis, sensing, antibacterial activity, and other uses. Sol-Gel synthesis is important for its simplicity, low-temperature reaction conditions, controllable particle size, and high product purity and homogeneity [18-21]. Ternary CuO/TiO2/ZnO nanocomposites produced by Ardiansyah Taufik et al. using the sol-gel technique degraded the MB organic dye [22]. The sol-gel process was used to dissolve and disperse copper oxide and zinc nitrate to make ZnO/CuO nanomaterial by Alexis Lavin et al. PVA was added to the solution. To make a homogeneous gel, swirl in a 353 K ultrasonic bath. The nanocomposite was made by drying the gel for eight hours at 773 K [23]. Sol-gel-synthesized TiO4-Ag nanocomposite inhibited E. coli [24]. The literature shows that sol-gel synthesis can produce numerous nanocomposites.

1.2.Hydrothermal technique

Transition-metal oxide nanocomposites were prepared using several methods. Hydrothermal nanocomposites made from transition metal oxides were widely used. Hydrothermal synthesis is simpler, faster, cheaper, and easier than other methods. From the solution, controlled-size, -shaped, and composition goods are made. Often, hydrothermal synthesis does not require calcinations or grinding. Hydrothermal synthesis uses pressures and temperatures above room temperature [25-29]. Some with Yupeng Gao. TiO_2/Ti_3C_2 hydrothermal nanocomposite. In deionized water, he dissolved titanium sulfate and added 500 mg of Ti_3C_2. Storage in a Teflon autoclave followed by agitation to create a homogeneous solution. 18 hours were spent in an autoclave oven at 180 °C. Next, TiO_2/Ti_3C_2 were separated, cleaned, and vacuum-dried at 80

°C for 10 hours. The photocatalytic TiO_2/Ti_3C_2 nanocomposite destroyed methyl orange (MO) [30]. Sonam Dawar compares traditional and microwave heating methods for fabricating zinc oxide nanoparticles. Effective microwave heating produces ZnO nanoparticles with particular structural properties [31]. Using a Teflon-lined autoclave, Zhang et al. synthesized $ZnFe_2O_4$ nanocomposites. Dissolved in deionized water were $ZnSO_4 \cdot 7H_2O$, $FeCl_3 \cdot 6H_2O$, and sodium dodecyl sulfate. It was then cooked in a Teflon-lined autoclave for 15 hours, and 10 milliliters of NaOH was added at a specified temperature. Clean and dry the transition metal oxide nanocomposite [32]. Researchers discuss the synthesis of hydrothermal transition-metal oxide nanocomposites. Aijian Wang et al. hydrothermally synthesized TiO_2-reduced graphene oxide nanocomposites [33]. The hydrothermal synthesis of $CoFe_2O_4$/graphene nanocomposites uses graphene oxide and aqueous precursor solutions of $Co(NO_3)_2.6H_2O$ and $Fe(NO_3)_3$—$9H_2O$ [34]. Several TMONCs, such as Carbon nanotube/Cubic Fe_3O_4, α-Fe_2O_3-ZnO, MnO_2-CNT, TiO_2/reduced graphene oxide, and CuO-ZnO, have been produced utilizing hydrothermal methods [35-39].

1.3. Biological Method

Traditional chemical methods for nanomaterial synthesis require toxic reagents, high temperatures, and chemical waste. Plants and microbes use capping agents to biologically synthesize nanomaterials. Thus, this nanomaterial manufacturing method is simple, safe, and environmentally friendly. The biological synthesis of transition oxide-based nanocomposites represents a compelling domain within contemporary nanoscience. Plants are the best source of transition-metal oxide-based nanocomposites, as they are readily available, manageability, and lack of specific requirements compared to organisms [40-42]. Plant roots, bark, leaves, fruits, and other plant materials can be used to produce transition-metal oxide-based nanocomposites biologically. A few instances follow. Using biological synthesis [43]. Qiujie Liu et al. made a Loquat leaf extract-Fe, Cu oxide nanocomposite. Ramin Mohammadi-Alouchech and others made a ZnO/CuO nanocomposite by mixing copper acetate and zinc nitrate with deionized water, adding Mentha longifolia leaf extract, and adjusting the pH to 10 with NaOH. Irradiating the solution in a microwave oven for 10 minutes produced the antibacterial ZnO/CuO nanocomposite [44]. Paul O. Ameh produced iron oxide nanoparticles from Acacia nilotica leaves, which are economically viable and may absorb some heavy metal ions from aqueous solutions [45]. Kingsley Z. Kolo synthesizes iron oxide nanoparticles with Funaria hygrometrica to study their antibacterial properties [46]. Elias E. Elemike et al. developed anticancer Cu_2O/CuOZnO nanocomposites using only Alchornea cordifolia leaf extract [47]. Yoki Yulizar also synthesized Au and TiO_2 nanoparticles from Pandanus amarylifolius leaves and Averrhoa bilimbi fruits. With HAuCl4 and Pandanus amaryllifolius leaves, he created Au/TiO_2 nanocomposite [48]. Literature reports many plant extract-mediated nanocomposites, including: AgZnO nanocomposite synthesized from Trigonella foenum-graecum leaf extract [49], Fe2O3-Ag TMONCs from Psidium guajava leaf extract [50], ZnO-NiO from Azadirachta indica (Neem) leaf extract [26], and ZnFe2O4 from Moringa Oleifera [43]. A ZnO/CuO nanocomposite made from cacao seed bark extract [40] and more. The general mechanisms of plant extract nanomaterial synthesis are shown in Figure 1. Figure 1 is a simplified block schematic of plant extract nanomaterial fabrication methods [40-47].

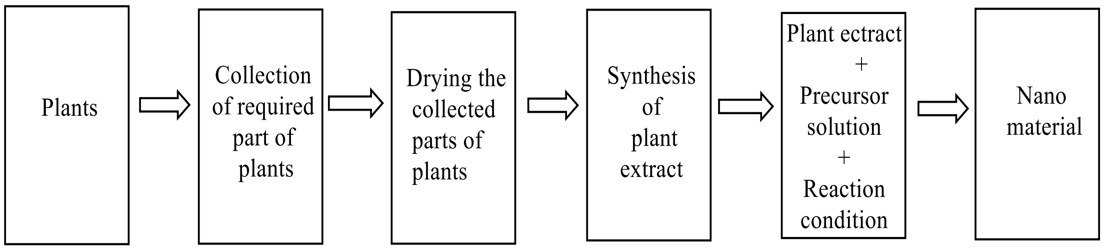

Fig.1. Plant extract nanomaterial synthesis processes are summarized into a block diagram.

2. The preparation methods of transition metal oxide nanoparticles

The prime aim of this article is to summarise synthesis routes for ZnO, CuO and Fe_3O_4 nanocomposite.

2.1.Synthesis of zinc oxide nanoparticles

The most popular nanoparticle was n-ZnO. High electrical conductivity, transparency, and 60 meV excitation binding energy at ambient temperature characterize wide-band-gap semiconductor ZnO [51]. Many methods have been utilized to make n-ZnO nanoparticles. Sol-gel, spray pyrolysis, microemulsion, thermal evaporation, laser ablation, chemical vapor deposition, mechanical milling, microwave, and hydrothermal methods are used to produce nanoparticles [52-60]. Dissolving ZnCl2 dry refined powder (Merck, 136.28 g/mol) in distilled water yielded 0.2 M n-ZnO. Dropwise ammonium hydroxide was introduced from the burette following $ZnCl_2$. At room temperature, a magnetic stirrer was used to stir the reaction mixture until precipitation. Rinse precipitate with distilled water after drying at 100 °C in a hot-air oven. We crushed and sieved the dried precipitate for homogeneity. A muffle furnace (Libratherm Instrument, PID 300 Naskar & Co.) was used to calcine sifted precipitate at 450 °C for 2 hours at 5 °C/min. The ZnO sample was characterized using SEM, FT-IR, X-ray diffraction, and transmission electron microscopy.

2.2.Synthesis of copper oxide nanoparticles

Copper oxide (CuO), a putative p-type semiconductor, is attracting attention for its optical, electrical, physical, and magnetic properties. CuO's 1.2 eV small band gap is used in field emission [61], gas sensors [62], solar energy conversion [63], and catalysis [7]. However, producing CuO nanostructures that outperform their bulk counterparts can enhance these distinctive properties. Nanowires, nanorods, nanoneedles, nano-flowers, and nanoparticles are made from CuO. CuO nanoparticles of various sizes and shapes have been generated by thermal oxidation [64], sonochemical [65], combustion [66], and rapid precipitation [67, 68]. One method is precipitation. Copper nitrate and copper chloride precipitated ($Cu(NO_3)_2 \cdot H_2O$) formed CuO nanostructures. Each precursor was dissolved in 100 mL of deionized water to make a 0.1 M solution. The 0.1 M NaOH solution was added gradually while vigorously stirring until the pH reached 14. Deionized water and 100% ethanol were used to wash the black precipitates until the pH reached 7 repeatedly. Dried the cleaned precipitates at 80 °C for

16 hours. In the end, the precursors were calcined at 500 °C for 4 hours and evaluated by X-ray diffraction. Morphology was observed with a scanning electron microscope. Chemical properties were examined using Fourier transform infrared spectroscopy.

2.3. Synthesis of iron oxide nanoparticles

In recent decades, the manufacture of iron oxide nanoparticles has been extensively studied. Numerous publications describe the successful production of shape-controlled, stable, biocompatible, monodispersed NPs. Excellent iron oxide nanoparticles can be produced by co-precipitation, thermal decomposition, hydrothermal synthesis, microemulsion synthesis, and sonochemical synthesis. Other methods for producing these NPs include electrochemical synthesis [69, 70], laser pyrolysis [71], bacterial or microbial production (particularly iron-reducing and magnetotactic bacteria) [73], etc. Co-precipitation was employed to create γ-Fe_2O_3 nanoparticles. 0.7954 g $FeCl_2.4H_2O$ and 1.2974 g $FeCl_3$ were dissolved in distilled water. The Experiment used a 1:2 mole ratio of iron(III) chloride to iron(II). The mixture was swirled for 30 minutes using a magnetic stirrer and a hot plate. Process temperatures, pH, and stirring speeds were controlled during mixing. After mixing, the solution was centrifuged for 15 minutes at 4000 rpm. The precipitate was oven-dried at 100 °C for 24 hours. A pestle and mortar ground the dried, dark-brown precipitate into powder. Using the chemically balanced equation 1-3, $FeCl_2{\cdot}4H_2O$ and $FeCl_3$ react, producing γ-Fe_2O_3 and water [74].

2.4.$Fe^{2+} + 2Fe^{3+} + 8OH^- \longrightarrow Fe_3O_4 + 4H_2O$ ……. (1)

$Fe_3O_4 + 0.25\ O_2 + 4.5\ H2O \longrightarrow 2(OH)_3$ ….…. (2)

$2(OH)_3\gamma\ Fe_2O_3 + 3H_2O$ ……………..…. (3)

The research above shows that TMONCs can be synthesized using many methods and have many applications. Table 1 shows that previous studies have described several methods for manufacturing synthetic transition-metal oxide-based nanocomposites.

Table 1. Different transition metal oxide nanocomposites production methods

Sr. No.	Transition metal oxide-based nano-composites	Precursor used	Synthesis Routes	Ref.
1	ZnO-CuO	$ZnCl_2$ and $CuCl_2$	Co-precipitation method	13
2	$NiFe_2O_4$	$FeSO_4.7H_2O$ and $NiSO_4.7H_2O$	Co-precipitation method	78
3	CeO_2 / ZnO / $ZnAl_2O_4$	Ce $(NO_3)_3.6H_2O$, Al $(NO_3)_2.9H_2O$ and Zn $(NO_3)_2.4H_2O$	Co-precipitation method	79
4	ZnO-SnO_2	$Zn(CH_3OO)_2.2H_2O$ and $SnCl_4.5H_2O$	Sol-Gel technique	26
5	CdO-ZnO	$Cd(NO_3)_2.4H_2O$ and $Zn(NO_3)_2.6H_2O$	Sol-Gel technique	36
6	TiO_2-Ag	Titanium tetra isopropoxide and silver nitrate	Sol-Gel technique	38
7	$CoFe_2O_4$ / graphene	Graphite powder, $Co(NO_3)_2.6H_2O$ and $Fe(NO_3)_3.9H_2O$	Hydrothermal technique	80
8	α-Fe_2O_4-ZnO-Au	$FeCl_3.6H_2O$, $ZnSO_4.7H_2O$ and $HAuCl_4.4H_2O$	Hydrothermal technique	51
9	MnO_2-CNT	Multi-wall carbon nanotubes (CNTs) and $MnSO_4.H_2O$	Hydrothermal technique	81
10	ZnO / CuO $ZnFe_2$	$Zn(NO_3)_2.6H_2O$ and $Cu(NO_3)_2.3H_2O$	Biological method	53
11	$ZnFe_2O_4$	$Fe(NO_3)_3.9H_2O$ and $Zn(NO_3)_2.6H_2O$	Biological method	82
12	Fe_2O_3-Ag	$AgNO_3$ and $Fe(NO_3)_3$	Biological method	15

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3. Experimental

Create mesoporosity, increase surface area, increase active sites, reduce electron-hole recombination, and accelerate charge transfer. The literature has examined these distinct properties for various uses [15, 82, 83, 84]. XRD, EDX, SEM, TEM, and FTIR were used to characterize metal oxide-based nanocomposites for structural and morphological investigation. The morphologies and uses of transition-metal oxide nanocomposites are examined in this paper. Morphologies and surface characteristics determine the practical uses of transition metal oxide-based nanocomposites [85-88]. Characterization matters in TMONC research. Because they were synthesized using different methods, reaction conditions, and precursors, the TMONCs in this work exhibit distinct shapes, sizes, particle distributions, topologies, morphologies, elemental configurations, and practical applications. A good nanomaterial requires certain physical and chemical qualities. Understanding and employing nanomaterials requires characterizing their size, shape, morphology, chemical composition, and other features. Key TMONC characterization methods are covered here.

3.1.XRD (X-ray diffraction technique)

XRD often identifies nanocomposite phases and crystallite sizes. Most research has examined the crystalline quality and phase of transition-metal-oxide-based synthetic nanocomposites using XRD. A graphene oxide / Fe3O4 nanocomposite was effectively synthesized, according to Shengyan Pu et al. [18], as shown by XRD data. Hadi Eslami et al. confirmed iron-manganese metal oxide nanocomposite synthesis using XRD data. Nanocomposite size was calculated using Scherrer's equation.

$D = 0.89\, \lambda\, (\beta \cos \Theta)$ ………… ………………………….(1)

X-ray wavelength (λ), crystal size (D), full width at half-maximum (β), and diffraction angle (Θ) are defined [16]. Numerous researchers have synthesized and analyzed XRD data, including Tariq Jan et al.'s ZnO-CuO nanocomposite [15], K. Egizbek's $NiFe_2O_4$ nanocomposite [17], Thongthai Witoon et al.'s Cu/ZnO nanocomposite [89], and others. XRD is a fundamental method for nanomaterial characterization, as shown above.

3.2. SEM and TEM (Electron Microscopy)

Nanomaterials' properties and applications depend on their shape and particle size. Electron microscopes have been used to study their transition-metal oxides and other nanomaterials. Researchers often use TEM and SEM for this. Based on a TEM picture, Abdessalem Hamrouni et al. found the ZnO-SnO_2 nanocomposite to be 30-80 nm [78]. Ardiansyah Tanfik et al. found spherical and clew-like $CuO/TiO_2/ZnO$ nanocomposites in their FESEM image [24]. M. A. Ahmed produced NiO/TiO_2 with 1,2,5, and 10% NiO. He found that finer particles increased the percentage of nickel oxide in TEM images. Also, the nanocomposite has a size range of 4-32 nm [90]. A literature survey found that electron microscopy is essential for characterizing nanomaterials. Alexin Lavin et al. created the ZnO/CuO nanocomposite for SEM and TEM examination. The SEM showed irregularly shaped semispheroidal nanoparticles, and the TEM showed spheroidal (10 nm) and rod-shaped (50 nm) particles agglomerating [91]. TEM was used to examine the morphology and size of the TiO_2-Ag nanocomposite reported by Ansari et al. [85]. Bin Shahab GaO et al. produced CNT/TiO_2 nanocomposites and examined their morphology and size using TEM [93]. Morphology is crucial for the specific use of each nanomaterial, as seen in the example.

3.3.EDX (Energy dispersive X-ray)

EDX identifies elements in nanomaterials and transition metal oxide nanocomposites. Susanta Kumar Biswal et al. produced the Fe_2O_3-Ag nanocomposite, which was evaluated by EDX, which confirmed the presence of iron (25.63), silver (23.25), and oxygen (51.12) [93]. For the synthesized Ag-ZnO nanocomposite, Zahra Noohpisheh et al. used EDX to show that Ag weight was 5.60 and ZnO weight was 86.02 [52]. EDX was used to analyze an Au/TiO_2 nanocomposite made by Yoki Yulizar and coworkers. EDX examination of the Au/TiO_2 nanocomposite showed Au (9.53), Ti (32.66), and O (57.81) components [51]. A key characterization method is EDX. EDX elemental composition determination gives structural information for any nanomaterial when paired with FTIR, UV, and XRD.

3.4.Some other characterization techniques

DTA, BET, AFM, UV-visible spectroscopy, and TGA are also used to characterize nanomaterials and transition metal oxide-based nanocomposites. Abdur Rahman et al. reported the production of CdO-MgO-Fe_2O_3. He shared UV-visible spectra for the same substance. He found a large UV-visible absorption band between 340 and 500 nm. That nanocomposite redshifted compared to CdO, MgO, and Fe_2O_3 nanoparticles. The 1.76 eV band gap of the CdO-MgO-Fe_2O_3 nanocomposite was also calculated [94]. Since K. Kaviyarasu et al. created MgO: CuO nanocomposite and observed its pictures using atomic force microscopy, AFM was also being employed for nanocomposite imaging [95]. For more property investigation and surface area observations, the BET is helpful. ZnO/CuO nanocomposite BET experiments were published by Ramin Mohammadi Aloucheh et al. After looking at photos that showed mesopores, he determined that the specific surface areas of ZnO/CuO (5%) and ZnO/CuO (10%) were, respectively, 36.0 and 26.0 m2g-1. Additionally, he determined the pore volumes to be 0.0939 and 0.0984 cm^3g^{-1} for ZnO/CuO (5%) and ZnO/CuO (10%), respectively [41]. For studying a sample's thermal performance, researchers use TGA DTA. Fe_3O_4/CNC/Cu nanocomposite was manufactured by Mohammad A. Khalizadeh et al., who also examined the TGA/DTA data demonstrating the material's thermal stability [96]. The previously mentioned investigations make it abundantly evident that each characterization serves a specific purpose and collaborates with the others to fully investigate the structural and chemical characteristics of transition metal oxide-based nanocomposites. A concise overview of the characterization methods applied in transition metal oxide-based nanocomposites is provided in Figure 2 [15, 17, 25, 78, 41, 94, 51, 53, 96].

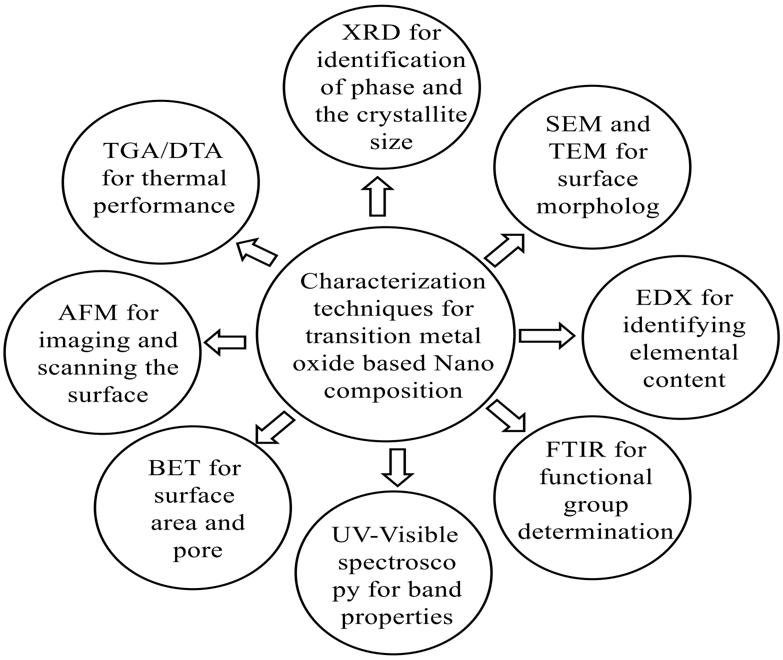


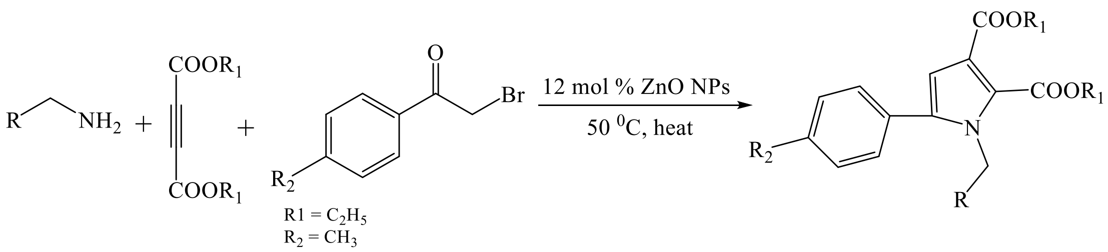
Fig. 2. General nanocomposites characterization methods in a simplified block diagram.

4. Catalytic Applications

Synthesized nanocomposites exhibit additional properties and applications. Researchers may use nanocomposites as Lewis acid catalysts because they are heterogeneous, non-toxic, and readily removable from organic solvents. In line with current catalysis trends, nanocatalysts for classical organic transformations are being developed. Such an Experiment shows that nanocatalysts are more efficient, reusable, and yield high organic conversions. We discussed, in this part, the catalytic production of physiologically active heterocyclic moieties using ZnO, CuO, and Fe_3O_4 nanocomposites.

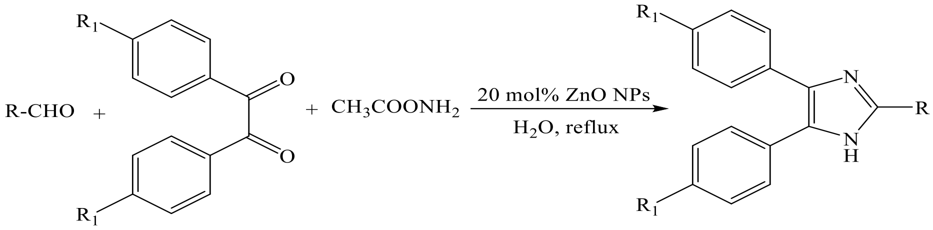
4.1.N-heterocycle synthesis catalyzed by nano-ZnO

Pyrroles are abundant in natural co-enzymes, alkaloids, and porphyrins with various pharmacological effects [41, 97-100]. Pyrrol skeleton is found in tallimustine and Lipitor [101, 103]. Sabbaghan et al. [103] A one-pot, three-component reaction involving primary amines, dialkyl acetylenedicarboxylates, and phenacyl bromide at 50 °C produced polysubstituted pyrroles. without solvent, using ZnO nanorods as a reusable catalyst. Repeated use kept the catalyst active. After testing, ZnO nanorods were more effective than store-bought ZnO, and even nanoparticles and sheets.



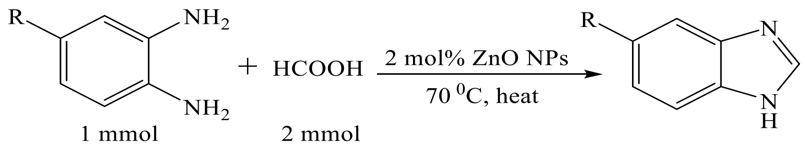
Project 1. Polysubstituted pyrroles synthesis with ZnO nanocatalyst

Imidazole and its derivatives exhibit anti-inflammatory, antitumor, and antifungal effects [75–77]. Nikoofar et al. synthesized imidazole using ZnO-nanorods [78]. After characterization using XRD, IR, and SEM, these ZnO nanorods were found to be an effective, mild, reusable catalyst to create 2,4,5-triaryl-1H-imidazolesin, a one-pot, three-component reaction using benzils, ammonium acetate, and different aldehydes in water when refluxed.



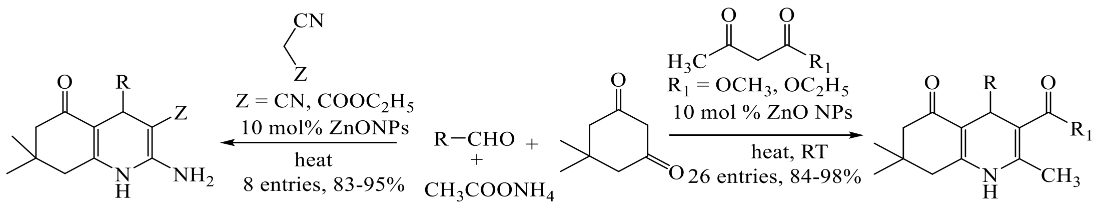
Project 2. ZnO-catalyzed imidazole synthesis

In 2012, Alinezhad et al. [79] synthesized benzimidazoles from o-phenylenediamines and formic acid with nano-ZnO as a catalyst at 70 °C in solvent-free circumstances. Paul et al. biogenerated zinc oxide nanoparticles from Parkia roxburghii seed extract [80]. ZnO nanoparticles catalyzed the reaction of o-phenylenediamine with various aldehydes in ethanol at room temperature to produce 2-substituted benzimidazoles.



Project 3. ZnO-catalyzed benzimidazole synthesis

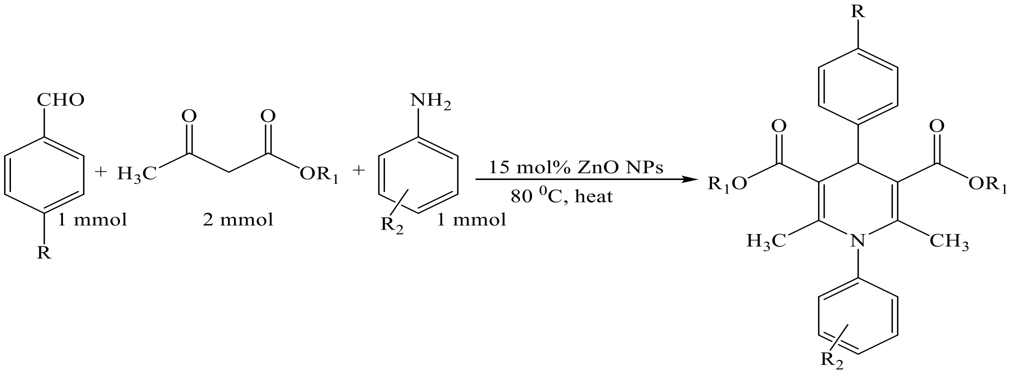
Kassaee et al. (Project 4) [81] synthesized 2-methyl-hexahydroquinoline derivatives without solvents at room temperature using ZnO nanoparticles as a catalyst in a one-pot, four-component condensation of aldehydes, dimedone, alkyl acetoacetate, and ammonium acetate. Under the same optimized conditions, they produced 2-aminohexahydroquinolines by replacing alkyl acetoacetate with malononitrile in the four-component synthesis. After each of the four processes, Reusing the catalyst did not degrade its catalytic activity.



R = C_6H_5, 4-$OCH_3C_6H_4$, 4-Cl-C_6H_4, 3-Cl-C_6H_4, 2-Cl-C_6H_4, 4-$CH_3C_6H_4$, 2,4-diClC_6H_3, 3,4-diClC_6H_3, 4-Br-C_6H_4, 4-F-C_6H_4 4-NO_2-C_6H_4, 3-NO_2-C_6H_4, 2-NO_2-C_6H_4, 4-OH-C_6H_4, 4-OH-3-OCH_3-C_6H_3

Project 4. Polyhydroquinoline synthesis using ZnO nanocomposite.

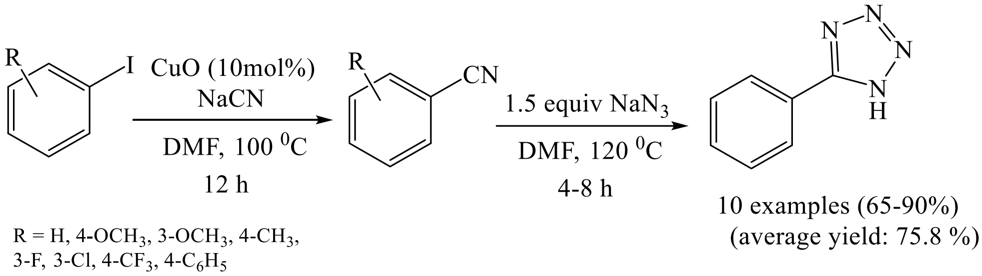
ZnO-nanoparticles were an effective, reusable catalyst for 1,4-diaryl dihydropyridine synthesis from aldehydes, alkyl acetoacetate, and substituted anilines [82].



Project 5. ZnO nano-composite-catalyzed 1,4-diaryl dihydropyridine derivative synthesis.

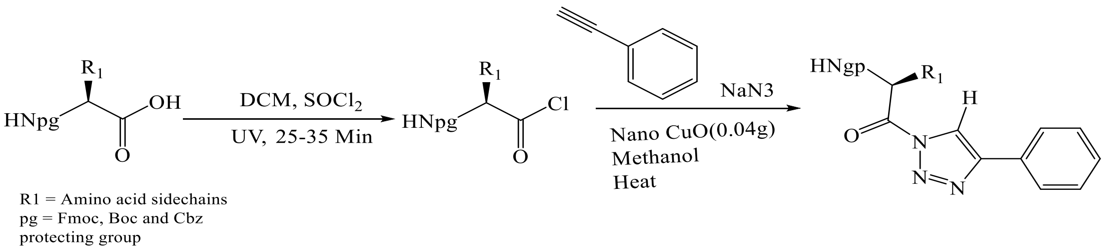
4.2. N-heterocycle synthesis catalyzed by nano-CuO

Yapuri et al. synthesized aryl nitriles by cyanating aryl iodides using sodium cyanide and copper (II) oxide nanoparticles. Copper-catalyzed one-pot [2+3] cycloaddition with sodium azide produced 5-substituted 1H-tetrazoles from aryl nitriles (Project 6) [83].



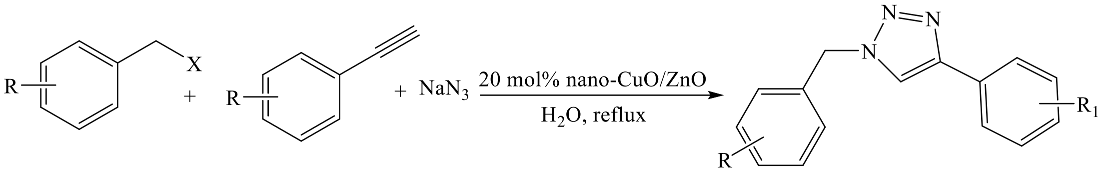
Project 6. CuO nan-composite-catalyzed 5-substituted 1H-tetrazole synthesis.

Raghavendra et al. prepared Na-protected amino keto-1,2,3-triazoles Project 7 mixes phenylacetylene, sodium azide, protected amino acid/dipeptide acid derivatives, and amino acyl chloride with a nano-CuO catalyst. Many methods for 1,2,3-triazole formation in the literature use expensive chemicals, operate under harsh conditions, are lengthy, yield poorly, and generate several in situ intermediates that require special attention for the final products. This safe, well-organized method for producing named heterocyclic compounds does not require separation of the acyl azide intermediate [84].



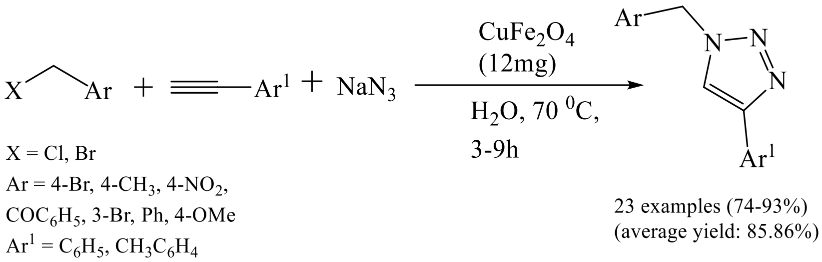
Project 7. CuO nan-composite synthesis of Na-protected amino keto-1,2,3-triazoles

Albadi et al. [85] produced 1,2,3-triazoles by employing a co-precipitation technique and an innovative, very efficient catalytic device to carry out refluxed one-pot three-component reactions involving sodium azide, phenylacetylenes, and different benzyl halides in water (Project 8). The combination nano (CuO-ZnO) demonstrated greater catalytic efficacy than nano-ZnO or nano-CuO during optimization. After the reaction, the catalyst was easily recovered and reused without loss of catalytic activity.



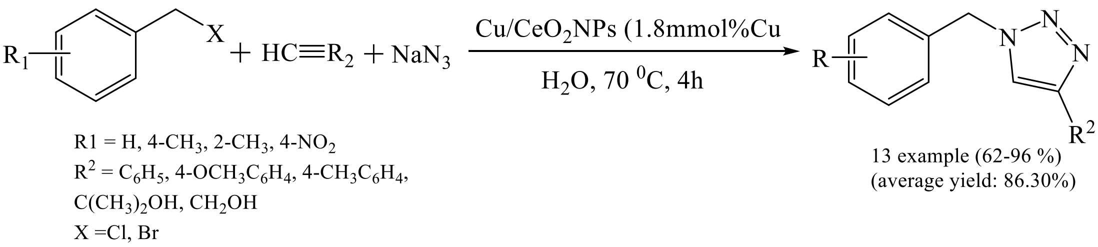
Project 8. Synthesis of 1,2,3-triazoles with CuO nan-composite

Kumar et al. [86] discussed the high-yielding one-pot synthesis of 1,2,3-triazoles. The synthesis of 1,2,3-triazoles began with benzyl azides being produced in situ by substituting benzyl halides with sodium azide. Copper ferrite catalyzed cycloaddition reaction with alkynes was then performed in water at 70 °C Electron-donating methyl and methoxy, and electron-withdrawing bromo and nitro groups at the para position of benzyl bromide all contributed to azide nucleophilic substitution and 1,3-dipolar cycloaddition. The procedure described here is simple and suitable for many substrates, with excellent functional-group tolerance (Project 9).



Project 9: $CuFe_2O_4$ nan-composite organic azide synthesis.

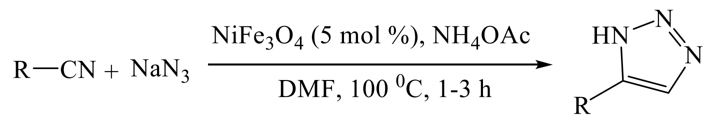
According to Amini et al. [87], a sustainable method for producing 1,2,3-triazoles by use of $CuNPs/CeO_2$. This process begins with terminal alkynes undergoing a 1,3-dipolar cycloaddition to organic azides prepared on the spot using sodium azide and other halides in water at 70°C. The present method (Project 10) is characterized by a short reaction time, mild reaction conditions, easy operation, reusable catalyst, readily available preparation materials and reagents, and a wide substrate applicability.



Project 10. Cu/CeO_2 nan-composite 1,4-disubstituted-1,2,3-triazoles.

4.3. N-heterocycle synthesis catalyzed by Iron Oxide nanoparticles.

Abrishami et al. [88] synthesized 5-substituted 1H tetrazoles using magnetically recoverable nickel ferrite nanoparticles as a catalyst in a one-pot [2+3] cycloaddition of sodium azide to various nitriles in DMF at 100 °C for 13 h. Despite prolonged testing, this model reaction fails without the nickel ferrite nanocatalyst. Project 11 shows no significant decrease in catalytic activity even after runs.

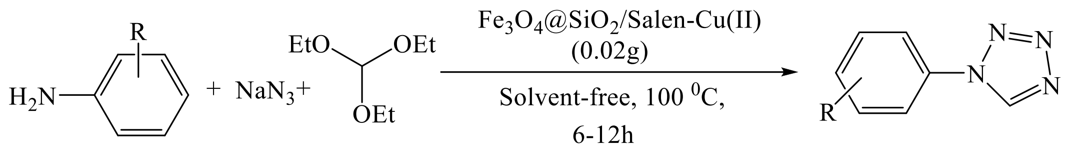


R = C_6H_5, 4-ClC_6H_4, 3-Pyridinyl, 4-Pyridinyl, 4-FC_6H_4, 4-$CH_3C_6H_4$, 2-$NH_2C_6H_4$, 4-CNC_6H_4, $CNCH_2$, $C_6H_5CH_2$,CH_3, 4-$NO_2C_6H_4$

12 examples (80-98%)
(average yield: 94 %)

Project 11. Synthesis of tetrazole derivatives in DMF catalyzed by $NiFe_3O_4$ nan-composite.

Dehghani et al. A green technique was devised to yield 1- and 5-substituted 1H-tetrazoles from amines and nitriles in a solvent-free environment at 100 °C with the help of a catalyst consisting of magnetite nanoparticles immobilized on salen-Cu (II). Project 12's catalytic efficacy did not diminish after 7 rounds of nanocatalyst use [89].

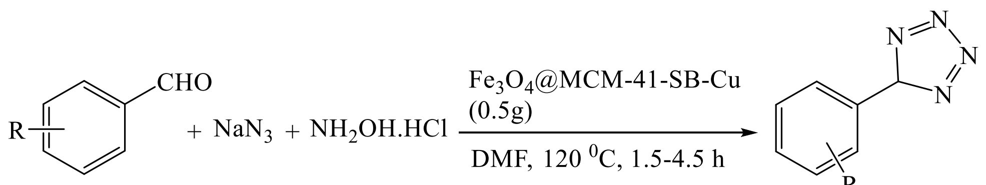


R = H, 4-NO_2, 4-Cl, 4-Br, 4-MeO, 4-Me, 4-OCH_3, 3-Me

11 examples (75-96%)
(average yield: 83.63%)

Project 12. Synthesis of tetrazole analogues catalyzed by Fe_3O_4@SiO_2 nan-composite.

Ahmadi et al. devised a one-pot MCR synthesis of 5-substituted-1H-tetrazole derivatives using Fe_3O_4@MCM-41-SB-Cu nanocatalyst and aldehydes, hydroxylamine hydrochloride, and sodium azide (Project 13). The magnetic nanocatalyst Fe_3O_4@MCM-41-SB-Cu can be isolated and reused without loss of catalytic efficiency [90].

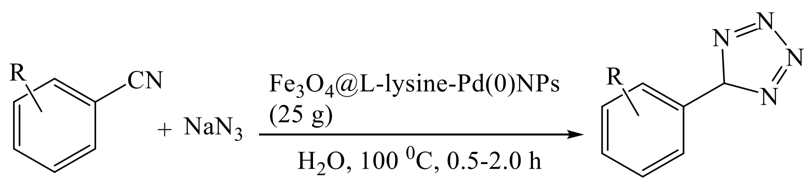


R = H, 4-Br, 4-Cl, 4-OCH_3, 4-CH_3, 2-OH, 2-Cl, 3-NO_2

11 examples (69-95%)
(average yield: 81.36 %)

Project 13. Fe_3O_4@MCM-41 nanocomposite synthesizes 5-substituted 1H-tetrazoles.

Muhammad et al. developed a green and effective method for the production of 5-substituted 1H-tetrazole derivatives using L-lysine-palladium nanoparticle (NPs) modified Fe3O4 nanoparticles in an aqueous medium via aryl nitriles and NaN3. This procedure used [2+3] cycloaddition (Project 14). The current approach offers simple recovery, Pd NP reusability, shorter reaction times, green solvent, high yield, easy to use, economy of atoms and steps, and separation of heterogeneous catalysts [91].

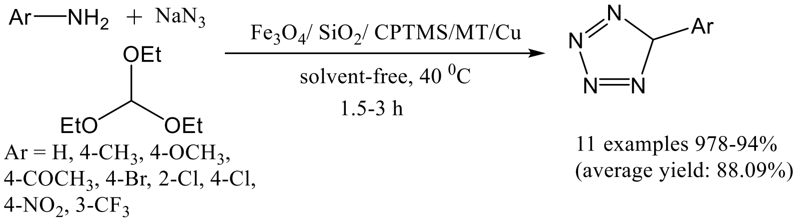


R = H, 4-OCH_3, 4-CH_3, 3-CH_3, 2-NO_2, 3-NO_2, 4-NO_2, 4-F, 3-Cl, 4-Cl, 4-Br, 4-CHO, 4-$COCH_3$, 2-OH, 2-CN, 2-Cl, 4-OH, 4-CN

24 examples (70-100%)
(average yield: 90.5 %)

Project 14. Fe_3O_4@L-lysine-Pd(0)NPs nanocomposite synthesizes 5-substituted 1H-tetrazoles.

In Project 15, Khorramabadi et al. I used the magnetic nanocatalyst Fe_3O_4/SiO_2/CPTMS/MT/Cu to create 1-substituted tetrazole derivatives in a solvent-free reaction involving aromatic amines, sodium azide, and triethyl orthoformate at 40 °C. In about 2 hours with a 94% yield, our method achieved the desired result [92].



Project 15. Fe_3O_4/ SiO_2/CPTMS/Cu nanocomposite-catalyzed 1-substituted tetrazole derivative synthesis.

5. Conclusion and future perspective

Transition metal oxide nanocomposites have been useful in both materials science and chemical science within the realm of nanotechnology. The ZnO, CuO, and Fe3O4 nanoparticles have garnered significant attention from researchers and were manufactured using conventional procedures, with structural confirmation achieved by standard analytical techniques. The commendable research has been documented in the literature on transition metal oxides and has established effective protocols for the production of biologically active organic compounds. This article provides novices with an overview of synthesis methods, general characterization techniques, and catalytic applications of ZnO, CuO, and Fe_3O_4.

Further research is required to synthesize innovative TMONCs with enhanced surface area, controlled morphology, size, porosity, and uniform dispersion of all components in nanocomposites. Scientists and researchers must exert considerable effort to develop cost-effective, eco-friendly approaches to produce nanocomposites based on transition metal oxides with high yields at ambient temperature and under mild reaction conditions. A lot of nanocomposites based on transition metal oxides are only useful in the lab right now, so scientists should concentrate on finding ways to mass-produce and use them in industry.

References

[1] S. Yadav, N. Rani, and K. Saini, "A review on transition metal oxides based nanocomposites, their synthesis techniques, different morphologies and potential applications," in *IOP Conference Series: Materials Science and Engineering*, 2022, vol. 1225, no. 1: IOP Publishing, p. 012004.

[2] M. Magro and F. Vianello, "Bare iron oxide nanoparticles: Surface tunability for biomedical, sensing and environmental applications," *Nanomaterials,* vol. 9, no. 11, p. 1608, 2019.

[3] M. Tyagi and D. Tyagi, "Polymer nanocomposites and their applications in electronics industry," *International Journal of Electronic and Electrical Engineering,* vol. 7, no. 6, pp. 603-608, 2014.

[4] S. Shyamala and R. Muthuchudarkodi, "Polyindole based zinc oxide nanocomposite-synthesis and characterization," *Int. J. Sci. Eng. Manag,* vol. 3, pp. 588-595, 2018.

[5] S. Khorrami, Z. Abdollahi, G. Eshaghi, A. Khosravi, E. Bidram, and A. Zarrabi, "An improved method for fabrication of Ag-GO nanocomposite with controlled anti-cancer and anti-bacterial behavior; a comparative study," *Scientific reports,* vol. 9, no. 1, p. 9167, 2019.

[6] S. Krasno and K. Swathi, "A review on types of nanocomposites and their applications," *Int J Adv Res Ideas Innov Technol,* vol. 4, no. 6, pp. 235-236, 2018.

[7] P. V. Patale, S. R. Mathapati, and J. L. Somawanshi, "A Review on Progression in Synthesis Techniques, Characterization and Catalytic Applications of Transition Metal Oxide Nano Particles," *Journal of Chemistry Letters,* vol. 5, no. 4, pp. 206-220, 2024.

[8] F. Zeng and S. C. Zimmerman, "Dendrimers in supramolecular chemistry: from molecular recognition to self-assembly," *Chemical reviews,* vol. 97, no. 5, pp. 1681-1712, 1997.

[9] d. A. Bosman, H. Janssen, and E. Meijer, "About dendrimers: structure, physical properties, and applications," *Chemical reviews,* vol. 99, no. 7, pp. 1665-1688, 1999.

[10] R. M. Crooks, M. Zhao, L. Sun, V. Chechik, and L. K. Yeung, "Dendrimer-encapsulated metal nanoparticles: synthesis, characterization, and applications to catalysis," *Accounts of chemical research,* vol. 34, no. 3, pp. 181-190, 2001.

[11] F. Sedighi, M. Esmaeili-Zare, A. Sobhani-Nasab, and M. Behpour, "Synthesis and characterization of CuWO4 nanoparticle and CuWO4/NiO nanocomposite using co-precipitation method; application in photodegradation of organic dye in water," *Journal of Materials Science: Materials in Electronics,* vol. 29, no. 16, pp. 13737-13745, 2018.

[12] F. S. Jazi, N. Parvin, M. Rabiei, M. Tahriri, Z. M. Shabestari, and A. R. Azadmehr, "Effect of the synthesis route on the grain size and morphology of ZnO/Ag nanocomposite," *Journal of Ceramic Processing Research,* vol. 13, no. 5, pp. 523-526, 2012.

[13] T. Jan *et al.*, "Superior antibacterial activity of ZnO-CuO nanocomposite synthesized by a chemical Co-precipitation approach," *Microbial pathogenesis,* vol. 134, p. 103579, 2019.

[14] H. Eslami *et al.*, "Synthesis of mesoporous Fe-Mn bimetal oxide nanocomposite by aeration co-precipitation method: physicochemical, structural, and optical properties," *Materials Chemistry and Physics,* vol. 224, pp. 65-72, 2019.

[15] K. Egizbek *et al.*, "Stability and cytotoxicity study of NiFe2O4 nanocomposites synthesized by co-precipitation and subsequent thermal annealing," *Ceramics International,* vol. 46, no. 10, pp. 16548-16555, 2020.

[16] S. Pu, S. Xue, Z. Yang, Y. Hou, R. Zhu, and W. Chu, "In situ co-precipitation preparation of a superparamagnetic graphene oxide/Fe3O4 nanocomposite as an

Web of Scientists and Scholars: Journal of Multidisciplinary Research

adsorbent for wastewater purification: synthesis, characterization, kinetics, and isotherm studies," *Environmental Science and Pollution Research,* vol. 25, no. 18, pp. 17310-17320, 2018.

[17] M. A. Subhan, N. Uddin, P. Sarker, A. K. Azad, and K. Begum, "Photoluminescence, photocatalytic and antibacterial activities of CeO2· CuO· ZnO nanocomposite fabricated by co-precipitation method," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* vol. 149, pp. 839-850, 2015.

[18] M. Parashar, V. K. Shukla, and R. Singh, "Metal oxides nanoparticles via sol–gel method: a review on synthesis, characterization and applications," *Journal of Materials Science: Materials in Electronics,* vol. 31, no. 5, pp. 3729-3749, 2020.

[19] R. Cheng, J. Xia, J. Wen, P. Xu, and X. Zheng, "Nano metal-containing photocatalysts for the removal of volatile organic compounds: doping, performance, and mechanisms," *Nanomaterials,* vol. 12, no. 8, p. 1335, 2022.

[20] D. A. Ward and E. I. Ko, "Preparing catalytic materials by the sol-gel method," *Industrial & engineering chemistry research,* vol. 34, no. 2, pp. 421-433, 1995.

[21] M. M. Collinson, "Sol-gel strategies for the preparation of selective materials for chemical analysis," *Critical Reviews in Analytical Chemistry,* vol. 29, no. 4, pp. 289-311, 1999.

[22] A. Taufik, A. Albert, and R. Saleh, "Sol-gel synthesis of ternary CuO/TiO2/ZnO nanocomposites for enhanced photocatalytic performance under UV and visible light irradiation," *Journal of Photochemistry and Photobiology A: Chemistry,* vol. 344, pp. 149-162, 2017.

[23] A. Lavin, R. Sivasamy, E. Mosquera, and M. J. Morel, "High proportion ZnO/CuO nanocomposites: Synthesis, structural and optical properties, and their photocatalytic behavior," *surfaces and Interfaces,* vol. 17, p. 100367, 2019.

[24] S. A. Amin, M. Pazouki, and A. Hosseinnia, "Synthesis of TiO2–Ag nanocomposite with sol–gel method and investigation of its antibacterial activity against E. coli," *Powder Technology,* vol. 196, no. 3, pp. 241-245, 2009.

[25] S. Yuvaraj, A. C. Fernandez, M. Sundararajan, C. S. Dash, and P. Sakthivel, "Hydrothermal synthesis of ZnO–CdS nanocomposites: structural, optical and electrical behavior," *Ceramics International,* vol. 46, no. 1, pp. 391-402, 2020.

[26] M. Hessien, E. Da'na, and A. Taha, "Phytoextract assisted hydrothermal synthesis of ZnO–NiO nanocomposites using neem leaves extract," *Ceramics International,* vol. 47, no. 1, pp. 811-816, 2021.

[27] S. Feng and R. Xu, "New materials in hydrothermal synthesis," *Accounts of chemical research,* vol. 34, no. 3, pp. 239-247, 2001.

[28] G. W. Morey, "Hydrothermal synthesis," *Journal of the American Ceramic Society,* vol. 36, no. 9, pp. 279-285, 1953.

[29] S. Sōmiya and R. Roy, "Hydrothermal synthesis of fine oxide powders," *Bulletin of Materials Science,* vol. 23, no. 6, pp. 453-460, 2000.

[30] Y. Gao *et al.*, "Hydrothermal synthesis of TiO2/Ti3C2 nanocomposites with enhanced photocatalytic activity," *Materials Letters,* vol. 150, pp. 62-64, 2015.

[31] S. Dawar, D. Mehta, and B. Mehta, "Phyto assisted synthesis and comparative studies of zinc oxide nanoparticles with Ficus benghalensis from Conventional Heating and Microwave Heating Method," *Journal of Chemistry Letters,* vol. 4, no. 4, pp. 190-199, 2024.

[32] G.-Y. Zhang, Y.-Q. Sun, D.-Z. Gao, and Y.-Y. Xu, "Quasi-cube ZnFe2O4 nanocrystals: hydrothermal synthesis and photocatalytic activity with TiO2 (Degussa P25) as nanocomposite," *Materials Research Bulletin,* vol. 45, no. 7, pp. 755-760, 2010.

[33] W. I. Park, C. H. Lee, J. H. Chae, D. H. Lee, and G. C. Yi, "Ultrafine ZnO nanowire electronic device arrays fabricated by selective metal-organic chemical vapor deposition," *Small,* vol. 5, no. 2, pp. 181-184, 2009.

[34] L. Gan, S. Shang, C. W. M. Yuen, S.-x. Jiang, and E. Hu, "Hydrothermal synthesis of magnetic CoFe2O4/graphene nanocomposites with improved photocatalytic activity," *Applied surface science,* vol. 351, pp. 140-147, 2015.

[35] D. Guan *et al.*, "Hydrothermal synthesis of carbon nanotube/cubic Fe3O4 nanocomposite for enhanced performance supercapacitor electrode material," *Materials Science and Engineering: B,* vol. 178, no. 10, pp. 736-743, 2013.

[36] Y. V. Kaneti *et al.*, "Hydrothermal synthesis of ternary α-Fe2O3–ZnO–Au nanocomposites with high gas-sensing performance," *Sensors and Actuators B: Chemical,* vol. 209, pp. 889-897, 2015.

[37] F. Teng, S. Santhanagopalan, Y. Wang, and D. D. Meng, "In-situ hydrothermal synthesis of three-dimensional MnO2–CNT nanocomposites and their electrochemical properties," *Journal of Alloys and Compounds,* vol. 499, no. 2, pp. 259-264, 2010.

[38] D. Liang *et al.*, "One-step hydrothermal synthesis of anatase TiO2/reduced graphene oxide nanocomposites with enhanced photocatalytic activity," *Journal of Alloys and Compounds,* vol. 582, pp. 236-240, 2014.

[39] M. Mansournia and L. Ghaderi, "CuO@ ZnO core-shell nanocomposites: novel hydrothermal synthesis and enhancement in photocatalytic property," *Journal of Alloys and Compounds,* vol. 691, pp. 171-177, 2017.

[40] Y. Yulizar, R. Bakri, D. O. B. Apriandanu, and T. Hidayat, "ZnO/CuO nanocomposite prepared in one-pot green synthesis using seed bark extract of Theobroma cacao," *Nano-Structures & Nano-Objects,* vol. 16, pp. 300-305, 2018.

[41] D. Bharathi, R. Ranjithkumar, B. Chandarshekar, and V. Bhuvaneshwari, "Bio-inspired synthesis of chitosan/copper oxide nanocomposite using rutin and their anti-proliferative activity in human lung cancer cells," *International Journal of Biological Macromolecules,* vol. 141, pp. 476-483, 2019.

[42] N. Matinise *et al.*, "Green synthesis of novel zinc iron oxide (ZnFe2O4) nanocomposite via Moringa Oleifera natural extract for electrochemical applications," *Applied Surface Science,* vol. 446, pp. 66-73, 2018.

[43] Q. Liu *et al.*, "Green synthesis of stable Fe, Cu oxide nanocomposites from loquat leaf extracts for removal of Norfloxacin and Ciprofloxacin," *Water Science and Technology,* vol. 81, no. 4, pp. 694-708, 2020.

[44] R. Mohammadi-Aloucheh, A. Habibi-Yangjeh, A. Bayrami, S. Latifi-Navid, and A. Asadi, "Green synthesis of ZnO and ZnO/CuO nanocomposites in Mentha longifolia leaf extract: characterization and their application as anti-bacterial agents," *Journal of Materials Science: Materials in Electronics,* vol. 29, no. 16, pp. 13596-13605, 2018.

[45] P. AMEH, "Synthesized iron oxide nanoparticles from Acacia nilotica leaves for the sequestration of some heavy metal ions in aqueous solutions," *Journal of Chemistry Letters,* vol. 4, no. 1, pp. 38-51, 2023.

[46] K. Z. Kolo, N. C. Nwokem, and S. E. Abechi, "Green Synthesis of Iron Oxide Nanoparticle using Funaria hygrometrica Extract, and the study of its antimicrobial activities," *Journal of Chemistry Letters,* vol. 4, no. 4, pp. 222-231, 2024.

[47] E. E. Elemike, D. C. Onwudiwe, and M. Singh, "Eco-friendly synthesis of copper oxide, zinc oxide and copper oxide–zinc oxide nanocomposites, and their anticancer applications," *Journal of Inorganic and Organometallic Polymers and Materials,* vol. 30, no. 2, pp. 400-409, 2020.

[48] Y. Yulizar, D. O. B. Apriandanu, and A. P. Wibowo, "Plant extract mediated synthesis of Au/TiO2 nanocomposite and its photocatalytic activity under sodium light irradiation," *Composites Communications,* vol. 16, pp. 50-56, 2019.

[49] Z. Noohpisheh, H. Amiri, S. Farhadi, and A. Mohammadi-Gholami, "Green synthesis of Ag-ZnO nanocomposites using Trigonella foenum-graecum leaf extract and their antibacterial, antifungal, antioxidant and photocatalytic properties," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* vol. 240, p. 118595, 2020.

[50] S. K. Biswal, G. K. Panigrahi, and S. K. Sahoo, "Green synthesis of Fe2O3-Ag nanocomposite using Psidium guajava leaf extract: An eco-friendly and recyclable adsorbent for remediation of Cr (VI) from aqueous media," *Biophysical Chemistry,* vol. 263, p. 106392, 2020.

[51] K. Nakahara *et al.*, "Interactions between gallium and nitrogen dopants in ZnO films grown by radical-source molecular-beam epitaxy," *Applied physics letters,* vol. 79, no. 25, pp. 4139-4141, 2001.

[52] M. Tokumoto, V. Briois, C. V. Santilli, and S. H. Pulcinelli, "Preparation of ZnO nanoparticles: structural study of the molecular precursor," *Journal of Sol-Gel Science and Technology,* vol. 26, no. 1, pp. 547-551, 2003.

[53] H. Oh, J. Krantz, I. Litzov, T. Stubhan, L. Pinna, and C. J. Brabec, "Comparison of various sol–gel derived metal oxide layers for inverted organic solar cells," *Solar Energy Materials and Solar Cells,* vol. 95, no. 8, pp. 2194-2199, 2011.

[54] T. Tani, L. Mädler, and S. E. Pratsinis, "Homogeneous ZnO nanoparticles by flame spray pyrolysis," *Journal of Nanoparticle Research,* vol. 4, no. 4, pp. 337-343, 2002.

[55] X. Li, G. He, G. Xiao, H. Liu, and M. Wang, "Synthesis and morphology control of ZnO nanostructures in microemulsions," *Journal of Colloid and Interface Science,* vol. 333, no. 2, pp. 465-473, 2009.

[56] Z. R. Dai, Z. W. Pan, and Z. L. Wang, "Novel nanostructures of functional oxides synthesized by thermal evaporation," *Advanced Functional Materials,* vol. 13, no. 1, pp. 9-24, 2003.

[57] I. Amarilio-Burshtein, S. Tamir, and Y. Lifshitz, "Growth modes of ZnO nanostructures from laser ablation," *Applied Physics Letters,* vol. 96, no. 10, 2010.

[58] L. Damonte, L. M. Zélis, B. M. Soucase, and M. H. Fenollosa, "Nanoparticles of ZnO obtained by mechanical milling," *Powder Technology,* vol. 148, no. 1, pp. 15-19, 2004.

[59] S. Komarneni, M. Bruno, and E. Mariani, "Synthesis of ZnO with and without microwaves," *Materials research bulletin,* vol. 35, no. 11, pp. 1843-1847, 2000.

[60] M. Bitenc *et al.*, "Correlation between morphology and defect luminescence in precipitated ZnO nanorod powders," *Crystal Growth and Design,* vol. 9, no. 2, pp. 997-1001, 2009.

[61] B.-R. Huang, C.-S. Yeh, D.-C. Wang, J. Tan, and J. Sung, "Field emission studies of amorphous carbon deposited on copper nanowires grown by cathodic arc plasma deposition," *New carbon materials,* vol. 24, no. 2, pp. 97-101, 2009.

[62] Y. Zhang, X. He, J. Li, H. Zhang, and X. Gao, "Gas-sensing properties of hollow and hierarchical copper oxide microspheres," *Sensors and Actuators B: Chemical,* vol. 128, no. 1, pp. 293-298, 2007.

[63] J. Kaneshiro, N. Gaillard, R. Rocheleau, and E. Miller, "Advances in copper-chalcopyrite thin films for solar energy conversion," *Solar Energy Materials and Solar Cells,* vol. 94, no. 1, pp. 12-16, 2010.

[64] M. Kaur *et al.*, "Growth and branching of CuO nanowires by thermal oxidation of copper," *Journal of Crystal Growth,* vol. 289, no. 2, pp. 670-675, 2006.

[65] N. Wongpisutpaisan, P. Charoonsuk, N. Vittayakorn, and W. Pecharapa, "Sonochemical synthesis and characterization of copper oxide nanoparticles," *Energy Procedia,* vol. 9, pp. 404-409, 2011.

[66] M. Yamukyan, K. V. Manukyan, and S. Kharatyan, "Copper oxide reduction by combined reducers under the combustion mode," *Chemical Engineering Journal,* vol. 137, no. 3, pp. 636-642, 2008.

[67] J. Zhu, D. Li, H. Chen, X. Yang, L. Lu, and X. Wang, "Highly dispersed CuO nanoparticles prepared by a novel quick-precipitation method," *Materials Letters,* vol. 58, no. 26, pp. 3324-3327, 2004.

[68] R. Wu, Z. Ma, Z. Gu, and Y. Yang, "Preparation and characterization of CuO nanoparticles with different morphology through a simple quick-precipitation method in DMAC–water mixed solvent," *Journal of Alloys and Compounds,* vol. 504, no. 1, pp. 45-49, 2010.

[69] S. M. Taimoory, J. F. Trant, A. Rahdar, M. Aliahmad, F. Sadeghfar, and M. Hashemzaei, "Importance of the inter-electrode distance for the electrochemical

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synthesis of magnetite nanoparticles: synthesis, characterization, computational modelling, and cytotoxicity," *e-Journal of Surface Science and Nanotechnology,* vol. 15, pp. 31-39, 2017.

[70] C. Pascal, J. Pascal, F. Favier, M. Elidrissi Moubtassim, and C. Payen, "Electrochemical synthesis for the control of γ-Fe2O3 nanoparticle size. Morphology, microstructure, and magnetic behavior," *Chemistry of materials,* vol. 11, no. 1, pp. 141-147, 1999.

[71] O. Bomatí-Miguel, L. Mazeina, A. Navrotsky, and S. Veintemillas-Verdaguer, "Calorimetric study of maghemite nanoparticles synthesized by laser-induced pyrolysis," *Chemistry of Materials,* vol. 20, no. 2, pp. 591-598, 2008.

[72] A. A. Bharde *et al.*, "Bacteria-mediated precursor-dependent biosynthesis of superparamagnetic iron oxide and iron sulfide nanoparticles," *Langmuir,* vol. 24, no. 11, pp. 5787-5794, 2008.

[73] Y. Roh, H. Vali, T. Phelps, and J.-W. Moon, "Extracellular synthesis of magnetite and metal-substituted magnetite nanoparticles," *Journal of nanoscience and nanotechnology,* vol. 6, no. 11, pp. 3517-3520, 2006.

[74] M. N. Salimi, R. H. Bridson, L. M. Grover, and G. A. Leeke, "Effect of processing conditions on the formation of hydroxyapatite nanoparticles," *Powder Technology,* vol. 218, pp. 109-118, 2012.

[75] J. G. Lombardino and E. H. Wiseman, "Preparation and antiinflammatory activity of some nonacidic trisubstituted imidazoles," *Journal of Medicinal Chemistry,* vol. 17, no. 11, pp. 1182-1188, 1974.

[76] L. Wang *et al.*, "Potent, orally active heterocycle-based combretastatin A-4 analogues: synthesis, structure− activity relationship, pharmacokinetics, and in vivo antitumor activity evaluation," *Journal of medicinal chemistry,* vol. 45, no. 8, pp. 1697-1711, 2002.

[77] P. Lindberg, P. Nordberg, T. Alminger, A. Braendstroem, and B. Wallmark, "The mechanism of action of the antisecretory agent omeprazole," *Journal of medicinal chemistry,* vol. 29, no. 8, pp. 1327-1329, 1986.

[78] K. Nikoofar, M. Haghighi, M. Lashanizadegan, and Z. Ahmadvand, "ZnO nanorods: efficient and reusable catalysts for the synthesis of substituted imidazoles in water," *Journal of Taibah University for Science,* vol. 9, no. 4, pp. 570-578, 2015.

[79] H. Alinezhad, F. Salehian, and P. Biparva, "Synthesis of benzimidazole derivatives using heterogeneous ZnO nanoparticles," *Synthetic Communications,* vol. 42, no. 1, pp. 102-108, 2012.

[80] B. Paul, S. Vadivel, S. S. Dhar, S. Debbarma, and M. Kumaravel, "One-pot green synthesis of zinc oxide nano rice and its application as sonocatalyst for degradation of organic dye and synthesis of 2-benzimidazole derivatives," *Journal of Physics and Chemistry of Solids,* vol. 104, pp. 152-159, 2017.

[81] M. Kassaee, H. Masrouri, and F. Movahedi, "ZnO-nanoparticle-promoted synthesis of polyhydroquinoline derivatives via multicomponent Hantzsch reaction," *Monatshefte für Chemie-Chemical Monthly,* vol. 141, no. 3, pp. 317-322, 2010.

[82] G. K. Reen, M. Ahuja, A. Kumar, R. Patidar, and P. Sharma, "ZnO Nanoparticle-catalyzed multicomponent reaction for the synthesis of 1, 4-diaryl dihydropyridines," *Organic Preparations and Procedures International,* vol. 49, no. 3, pp. 273-286, 2017.

[83] G. C. Pariyar, "Explorative studies on carbon hetero bond transformation reaction and carbon-hetero bond formation reaction," University of North Bengal, 2018.

[84] M. Raghavendra, K. Yatish, H. Lalithamba, and B. Omkaresh, "Effective utilization of green synthesized CuO nanoparticles for the preparation of keto-1, 2, 3-triazole analogues of protected amino acids/dipeptide acids and recyclable catalyst for the optimization and kinetic study of biodiesel production," *The European Physical Journal Plus,* vol. 136, no. 11, p. 1156, 2021.

[85] J. Albadi, A. Alihosseinzadeh, and A. Mansournezhad, "Regioselective synthesis of 1, 2, 3-triazoles catalyzed over ZnO supported copper oxide nanocatalyst as a new and efficient recyclable catalyst in water," *Acta Chimica Slovenica,* vol. 62, no. 3, pp. 617-624, 2015.

[86] B. A. Kumar, K. H. V. Reddy, B. Madhav, K. Ramesh, and Y. Nageswar, "Magnetically separable CuFe2O4 nano particles catalyzed multicomponent synthesis of 1, 4-disubstituted 1, 2, 3-triazoles in tap water using 'click chemistry'," *Tetrahedron Letters,* vol. 53, no. 34, pp. 4595-4599, 2012.

[87] M. Amini, R. Hassandoost, M. Bagherzadeh, S. Gautam, and K. H. Chae, "Copper nanoparticles supported on CeO2 as an efficient catalyst for click reactions of azides with alkynes," *Catalysis Communications,* vol. 85, pp. 13-16, 2016.

[88] F. Abrishami, M. Ebrahimikia, and F. Rafiee, "Synthesis of 5-substituted 1H-tetrazoles using a recyclable heterogeneous nanonickel ferrite catalyst," *Applied Organometallic Chemistry,* vol. 29, no. 11, pp. 730-735, 2015.

[89] R. Tarasi *et al.*, "Synthesis of Magnetic Fe 3 O 4@ polyethyleneimine. Mn (II) from Fe 3 O 4,[3-(2, 3-Epoxypropoxy) propyl] trimethoxysilane, Polyethyleneimine and Mn (II) Acetate as a Novel Silicon-Containing Polymeric Organic-Inorganic Hybrid Nanomaterial and Its Catalytic Investigation Towards the Oxidation of Cyclohexene, Ethyl Benzene and Toluene in the Presence of H 2 O 2 as an Oxidant," *Silicon,* vol. 10, no. 2, pp. 257-265, 2018.

[90] A. Ahmadi, T. Sedaghat, H. Motamedi, and R. Azadi, "Anchoring of Cu (II)-Schiff base complex on magnetic mesoporous silica nanoparticles: catalytic efficacy in one-pot synthesis of 5-substituted-1H-tetrazoles, antibacterial activity evaluation and immobilization of α-amylase," *Applied Organometallic Chemistry,* vol. 34, no. 5, p. e5572, 2020.

[91] M. A. Ashraf, Z. Liu, C. Li, and D. Zhang, "Fe3O4@ L-lysine-Pd (0) organic–inorganic hybrid: As a novel heterogeneous magnetic nanocatalyst for chemo and homoselective

[2+ 3] cycloaddition synthesis of 5-substituted 1H-tetrazoles," *Applied Organometallic Chemistry,* vol. 35, no. 3, p. e6133, 2021.

[92] M.-S. Mashhoori and R. Sandaroos, "New ecofriendly heterogeneous nano-catalyst for the synthesis of 1-substituted and 5-substituted 1 H-tetrazole derivatives," *Scientific Reports,* vol. 12, no. 1, p. 15364, 2022.