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Copper oxide, methods of its preparation and its biophysical applications

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

﴿وَقُل رَّبِّ زِدْنِي عِلْمًا﴾

صَدَقَ اللَّهُ العَلِيُّ العَظِيم

(طه: 114)

DEDICATION

To God, the source of all goodness, the night is not good except by thanking You, and the day is not good except by obeying You.. And the moments are not good except by thanking You. With your remembrance.. and the Hereafter is not pleasant except with your forgiveness.. and Paradise is not pleasant except with your vision

In honor of the Prophet Muhammad, the Messenger of Mercy and the Light of the Worlds, who fulfilled the trust and guided the nation.

To my beloved father, an exemplar of dedication and sincerity, teaching the value of giving without expectation.

To my dear mother, who sacrificed her happiness for mine.

To my teachers, who tirelessly imparted knowledge.

To all relatives, friends, and those offering advice and support.

I present a summary of my scientific efforts to the University of Babylon, a young and formidable institution

THANKS AND APPRECIATION

I extend my thanks and gratitude to everyone who lent me a book, gave me advice, or provided me with information, and I especially mention my supervising professor, **Prof. Dr. Hikmat Adnan Jawad Kazem** for the effort, time, and patience he spent in order to reach our goal in completing this work. May God grant us success.

Abstract

Copper oxide (CuO) has emerged as a versatile material with wide-ranging applications across various fields. This paper provides a comprehensive overview of copper oxide, covering synthesis methods, physical and biological applications, characterization techniques, and future directions. Meticulous synthesis techniques enable precise control over the morphology and properties of copper oxide, facilitating its use in enhancing solar cell efficiency, improving gas sensing technology, combating bacterial infections, and potentially treating cancer. Interdisciplinary collaboration and continued research efforts are essential to further explore copper oxide's potential and optimize its properties for practical applications. Characterization techniques such as X-ray diffraction, scanning electron microscopy, and Fourier-transform infrared spectroscopy play a crucial role in elucidating the structural and functional properties of copper oxide. Looking ahead, continued innovation, investment, and education efforts are key to unlocking the full potential of copper oxide and addressing global challenges across industries.

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Chapter One

Introduction

1.1 background

Copper oxide (CuO) has captured widespread attention in both academic and industrial circles owing to its intriguing properties and versatile applications. A binary compound composed of copper and oxygen atoms, CuO manifests in various forms, each with distinct characteristics such as high electrical conductivity and catalytic activity [1].

The synthesis of copper oxide employs a range of techniques including chemical precipitation, thermal decomposition, and solvothermal synthesis, among others [2]. These methods afford precise control over the size, morphology, and crystallinity of CuO nanoparticles, facilitating tailoring for specific biophysical applications.

In biological realms, copper ions serve as essential micronutrients, but their excessive accumulation can induce toxicity through the generation of reactive oxygen species (ROS) [3]. Understanding the interactions between copper oxide nanoparticles and biological systems is thus imperative to assess their biocompatibility and mitigate potential adverse effects.

Biophysically, copper oxide holds promise across a spectrum of applications. It finds utility in biomedical imaging, drug delivery systems, biosensing technologies, cancer therapy, antimicrobial agents, and environmental remediation [4]. Leveraging its versatile properties, researchers aim to address pressing challenges in healthcare, diagnostics, and environmental sustainability.

Ongoing research endeavors continue to unravel the intricacies of copper oxide, striving to optimize synthesis techniques and explore novel applications, thereby driving progress in biophysics and related disciplines.

1.2 Copper oxide structure

Copper oxide (CuO) exhibits a monoclinic crystal structure with space group C12/c1, where each unit cell contains one copper ion (Cu^{2+}) and one oxygen ion (O^{-2}) [5]. In this crystal lattice, the copper ions are coordinated by four oxygen ions in a distorted square planar arrangement, resulting in a coordination number of four for copper. Conversely, each oxygen ion is coordinated by two copper ions, forming a linear coordination geometry.

The Cu-O bonds in copper oxide are predominantly covalent in nature, with significant ionic character due to the electronegativity difference between copper and oxygen. The sharing of electron pairs between copper and oxygen atoms leads to the formation of strong bonds, contributing to the stability of the crystal structure [6].

The crystallographic arrangement of atoms in copper oxide influences its physical and chemical properties. For instance, the presence of Cu-O bonds facilitates the conductivity of copper oxide, making it useful in applications such as semiconductors and catalysis. Additionally, the distorted coordination geometry around copper ions gives rise to magnetic interactions, leading to the material's magnetism [7].

It's worth noting that variations in the synthesis method and conditions can result in modifications to the crystal structure of copper oxide. However, the monoclinic structure described here is commonly observed in bulk copper oxide materials.

Other names – Dicopper oxide, Red copper oxide, Cuprous oxide

Cu_2O	**Copper(I) Oxide**
Density	**6 g/cm^3**

Molecular Weight/ Molar Mass	**143.09 g/mol**
Boiling Point	**1,800 °C**
Melting Point	**1,232 °C**
Chemical Formula	**Cu_2O**

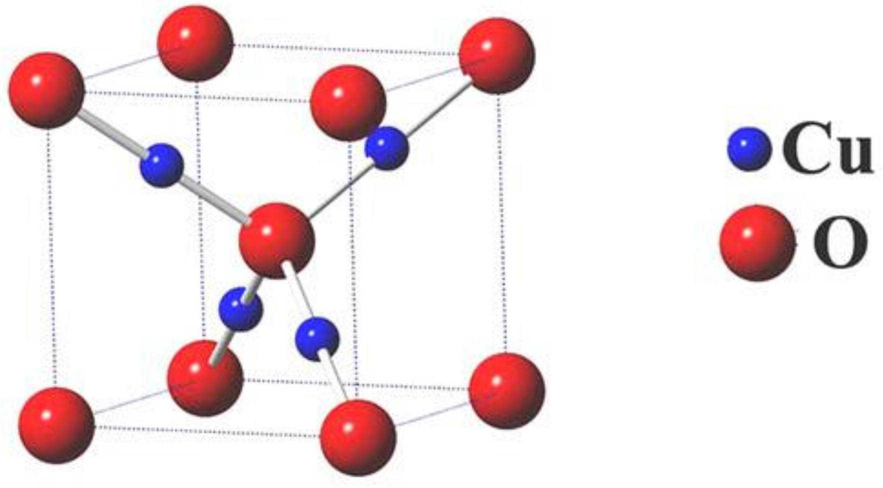

Fig (1): Copper(I) Oxide Structure – Cu_2O[8]

References:

1.3 Electrical Properties:

Copper(I) oxide (Cu2O) possesses fascinating electrical properties, rooted in its semiconductor nature and crystal structure. As a semiconductor, Cu2O exhibits a bandgap of approximately 2.1 eV [9], making it suitable for various electronic applications.

In its pristine form, Cu2O demonstrates p-type semiconductor behavior due to the presence of excess "holes" within its crystal lattice [10]. These holes, or positive charge carriers, result from the presence of copper vacancies and interstitial cations.

The electrical conductivity of Cu2O can be modified through doping, where intentional introduction of impurities alters its charge carrier concentration. Doping with elements such as lithium (Li) or sodium (Na) can enhance the conductivity of Cu2O, expanding its utility in solar cells and other photovoltaic devices [11].

Furthermore, Cu2O exhibits remarkable photoconductivity, where its electrical conductivity increases upon exposure to light. This phenomenon is attributed to the generation of electron-hole pairs in the material's bandgap, enabling its application in photodetectors and solar cells for efficient light-to-electricity conversion [12].

The manipulation of Cu2O's electrical properties is critical for optimizing its performance in electronic and optoelectronic devices. Research efforts continue to explore novel doping strategies, crystal growth techniques, and device architectures to unlock the full potential of Cu2O in next-generation semiconductor technologies.

The electrical properties of copper(I) oxide (Cu2O) presented in point form:

1. Bandgap: Cu2O exhibits a bandgap of approximately 2.1 eV, indicating its semiconductor nature [13]. This bandgap value makes Cu2O suitable for various electronic applications, as it allows the material to act as a semiconductor with distinct conducting and insulating properties.
2. Semiconductor Behavior: In its pristine form, Cu2O demonstrates p-type semiconductor behavior. This means that it contains an excess of positively charged "holes" within its crystal lattice [14]. These holes, or mobile charge carriers, contribute to the material's electrical conductivity.

3. Doping Effects: The electrical conductivity of Cu2O can be modified through intentional doping with impurities. Doping introduces additional charge carriers into the crystal lattice, altering its conductivity characteristics. For example, doping with elements like lithium (Li) or sodium (Na) can enhance the conductivity of Cu2O, expanding its applicability in electronic devices [15].
4. Photoconductivity: Cu2O exhibits photoconductivity, where its electrical conductivity increases upon exposure to light. This phenomenon occurs due to the generation of electron-hole pairs in the material's bandgap when illuminated. Photoconductivity enables Cu2O to be utilized in photodetectors and solar cells for efficient light detection and energy conversion [16].
5. Research and Development: Ongoing research efforts focus on exploring novel doping strategies, crystal growth techniques, and device architectures to optimize the electrical properties of Cu2O. These endeavors aim to unlock the full potential of Cu2O in next-generation semiconductor technologies, including solar cells, photodetectors, and other electronic devices.

1.4 Optical Properties:

Copper(I) oxide (Cu2O) exhibits intriguing optical properties, which are of great interest for various applications ranging from solar cells to optoelectronic devices. Here are some key points regarding its optical behavior:

1. Bandgap and Absorption: Cu2O has a direct bandgap of approximately 2.1 eV, making it transparent to visible light but absorbing in the near-infrared region [17]. This characteristic absorption spectrum is essential for

its application in photovoltaic devices, where Cu2O can efficiently absorb sunlight to generate electricity.

2. Color: Cu2O appears red in color due to its absorption properties. The absorption of longer wavelengths of light in the visible spectrum results in the transmission of shorter wavelengths, giving Cu2O its distinctive red hue. This coloration is exploited in various applications, including pigments, paints, and ceramic glazes.

3. Optical Transmittance: While Cu2O is transparent to visible light, its optical transmittance decreases as the wavelength of light increases into the near-infrared region. This behavior is attributed to the material's bandgap and absorption properties, which dictate its optical transmission characteristics.

4. Optical Reflectance and Refractive Index: Cu2O exhibits specific optical reflectance and refractive index values, which depend on factors such as crystal structure, surface morphology, and film thickness. These optical parameters play a crucial role in the design and optimization of Cu2O-based optical devices, such as mirrors, lenses, and optical coatings.

5. Photoluminescence: Cu2O displays photoluminescence behavior, where it emits light upon excitation with photons. This phenomenon arises from defects, impurities, or excitonic recombination processes within the material. Understanding the photoluminescence properties of Cu2O is essential for its applications in light-emitting devices and optoelectronic sensors.

Overall, the optical properties of copper(I) oxide (Cu2O) play a significant role in determining its suitability for various applications, including solar energy conversion, optical coatings, and photonic devices.

1.5 Morphological Properties:

The morphological properties of copper(I) oxide (Cu2O) refer to its physical structure, surface characteristics, and particle morphology. Understanding these properties is crucial for various applications, including catalysis, sensors, and energy storage devices. Here are some key points regarding the morphological properties of Cu2O[18]:

1. Particle Size and Shape: Cu2O can exist in various morphologies, including nanoparticles, nanowires, nanocubes, and nanospheres. The size and shape of Cu2O particles significantly influence its properties and performance in different applications. Control over particle morphology is achieved through various synthesis methods, such as solution-phase synthesis, chemical vapor deposition, and template-assisted growth.
2. Surface Area: The surface area of Cu2O nanoparticles or nanocrystals is an important morphological parameter that affects its reactivity and catalytic activity. High surface area facilitates increased contact with reactants, leading to enhanced catalytic performance in applications such as heterogeneous catalysis and gas sensing.
3. Surface Roughness: The surface of Cu2O particles can exhibit varying degrees of roughness, depending on the synthesis method and conditions. Surface roughness influences phenomena such as adsorption, desorption, and electron transfer processes, making it a crucial factor in determining the material's performance in electrochemical and sensing applications.
4. Porosity: Porosity refers to the presence of void spaces or pores within the Cu2O structure. Porous Cu2O materials offer increased surface area and accessibility, making them suitable for applications such as gas sensing, energy storage, and photocatalysis. Control over porosity is

achieved through appropriate synthesis strategies, such as templating or sacrificial template methods.

5. Agglomeration: Cu_2O nanoparticles or nanocrystals may exhibit tendencies to agglomerate or form clusters due to van der Waals forces or electrostatic interactions. Agglomeration affects the dispersibility and stability of Cu_2O in solution or within composite materials, influencing its performance in various applications, including coatings, composites, and biomedical devices.

Overall, the morphological properties of copper(I) oxide (Cu_2O) play a crucial role in determining its behavior and performance in diverse applications, highlighting the importance of precise control and characterization of its morphology.

1.6 Research Problem:

The research problem addressed in this study concerns the investigation of the morphological properties of copper(I) oxide (Cu_2O) and their implications for various applications. Understanding the morphology of Cu_2O is crucial for optimizing its performance in catalysis, sensors, and energy storage devices .

1.7 Research Objectives

1. Investigate various methods of preparing copper oxide, focusing on synthesis techniques and process optimization.
2. Explore the biophysical applications of copper oxide, including its use in biomedical imaging, drug delivery, and tissue engineering.
3. Evaluate the effectiveness and potential challenges associated with the utilization of copper oxide in biophysical applications, considering factors such as biocompatibility, toxicity, and targeted delivery mechanisms.

Chapter Two

Synthesis of Copper oxide

2.1 Introduction

Chapter 2 of this study focuses on two key aspects: the synthesis methods employed for copper oxide and its diverse biophysical applications. Synthesis methods play a crucial role in tailoring the properties of copper oxide nanoparticles, while biophysical applications explore the material's potential in various fields such as drug delivery, imaging, and sensing. By examining these two facets, this chapter aims to provide a comprehensive understanding of the preparation techniques and potential uses of copper oxide in biomedicine and beyond.

2.2 Literature' Review

Previous studies have extensively explored the synthesis methods and biophysical applications of copper oxide nanoparticles. These investigations provide valuable insights into the preparation techniques and potential biomedical uses of copper oxide materials.

- **"Preparation and Characterization of Copper Oxide Nanoparticles for Biomedical Applications"[19]**

This study focuses on the preparation and characterization of copper oxide nanoparticles specifically for biomedical applications. It explores various synthesis methods and assesses the physicochemical properties of the nanoparticles. The study investigates the potential of these nanoparticles in biomedical fields such as drug delivery, imaging, and therapy, providing insights into their applications in biomedicine.

- **"Synthesis Methods and Biophysical Applications of Copper Oxide Nanostructures: A Review"[20]**

This review article provides an overview of various synthesis methods used for copper oxide nanostructures and discusses their biophysical applications. It comprehensively examines the synthesis techniques, including their advantages, limitations, and applications. Additionally, the study reviews the biophysical properties of copper oxide nanostructures and their potential applications in areas such as biosensing, imaging, and cancer therapy.

- **"Biomedical Applications of Copper Oxide Nanoparticles: A Comprehensive Review"[21]**

This comprehensive review provides an in-depth analysis of the biomedical applications of copper oxide nanoparticles. It discusses the synthesis methods, physicochemical properties, and biocompatibility of these nanoparticles. Furthermore, the study reviews their applications in various biomedical fields such as drug delivery, antimicrobial agents, biosensors, and tissue engineering. It also addresses the challenges and future prospects of utilizing copper oxide nanoparticles in biomedical applications.

2.3 Synthesis Methods

Synthesis methods play a crucial role in shaping the properties of copper oxide nanoparticles, dictating their suitability for various applications. This section provides a detailed exploration of three prominent synthesis techniques employed in fabricating copper oxide nanoparticles, shedding light on their mechanisms and significance in nanoparticle engineering.

1. Chemical Precipitation: Chemical precipitation is a versatile and widely adopted method for synthesizing copper oxide nanoparticles. This approach involves the controlled reaction between copper salts and precipitating agents under specific conditions, leading to the formation of nanoparticles. The simplicity, scalability, and cost-effectiveness of

chemical precipitation render it an attractive choice for large-scale nanoparticle production[22].

2. Hydrothermal Synthesis: Hydrothermal methods represent a sophisticated approach to nanoparticle synthesis, leveraging high-pressure, high-temperature aqueous solutions to drive the nucleation and growth of copper oxide nanoparticles. Through precise control of reaction parameters, such as temperature and pressure, hydrothermal synthesis enables the generation of nanoparticles with tailored size, morphology, and crystallinity. This method is particularly advantageous for producing well-defined nanoparticles with enhanced properties suitable for a myriad of applications[23].
3. Sol-Gel Synthesis: Sol-gel synthesis presents a versatile and customizable route for the fabrication of copper oxide nanoparticles. The process involves the hydrolysis and condensation of metal alkoxides in a liquid medium to form a colloidal suspension, or sol, which subsequently undergoes gelation and thermal treatment to yield nanoparticles. Sol-gel synthesis offers exceptional control over nanoparticle size, shape, and composition, making it ideal for producing nanoparticles with tailored properties for specific applications. Moreover, the compatibility of sol-gel synthesis with various substrates and additives further enhances its versatility and applicability[24].

2.4 Characterization Techniques

Characterization techniques play a crucial role in understanding the properties and behavior of copper oxide nanoparticles. This section explores several common techniques used to characterize these nanoparticles, providing insights into their structural, morphological, and chemical properties.

1. X-ray Diffraction (XRD): XRD is a widely used technique for determining the crystal structure and phase composition of materials, including copper oxide nanoparticles. By analyzing the diffraction pattern produced when X-rays interact with the nanoparticles, XRD provides information about their crystallographic orientation, lattice parameters, and phase purity[25].
2. Scanning Electron Microscopy (SEM): SEM is a powerful imaging technique used to examine the surface morphology and structure of materials at high magnification. By scanning a focused beam of electrons across the surface of copper oxide nanoparticles, SEM generates detailed images revealing their size, shape, and surface features[26].
3. Transmission Electron Microscopy (TEM): TEM is another imaging technique that provides high-resolution images of materials at the nanoscale. By transmitting a beam of electrons through thin sections of copper oxide nanoparticles, TEM offers insights into their internal structure, crystallinity, and defects with atomic-level resolution[27].
4. Fourier Transform Infrared Spectroscopy (FTIR): FTIR is a spectroscopic technique used to analyze the chemical composition and bonding properties of materials. By measuring the absorption and transmission of infrared light, FTIR can identify functional groups and chemical bonds present in copper oxide nanoparticles, providing information about their surface chemistry and stability[27].
5. Thermogravimetric Analysis (TGA): TGA is a thermal analysis technique used to study the thermal stability and decomposition behavior of materials. By measuring changes in mass as a function of temperature, TGA can determine the thermal stability, decomposition temperature, and presence of impurities in copper oxide nanoparticles.

These characterization techniques, among others, play a critical role in elucidating the properties and behavior of copper oxide nanoparticles, facilitating their optimization for various applications[28].

2.5 Optimization of Synthesis Parameters

Achieving precise control over synthesis parameters is essential for tailoring the size, morphology, and properties of copper oxide nanoparticles. This section explores key parameters that can be optimized to fine-tune the characteristics of these nanoparticles, enhancing their suitability for various applications.

1. Precursor Concentration: The concentration of copper precursor in the synthesis solution plays a critical role in determining the size and yield of copper oxide nanoparticles [29].

2. Reaction Temperature: The temperature during synthesis significantly influences the kinetics of nanoparticle formation and the crystallinity of copper oxide nanoparticles [30].

3. Reaction Time: The duration of the synthesis reaction directly impacts the size distribution and morphology of copper oxide nanoparticles [31].

4. pH of the Reaction Solution: The pH level of the reaction solution affects precursor stability, nucleation rates, and nanoparticle growth [32].

5. Choice of Solvent: The selection of solvent can significantly influence precursor solubility, reaction kinetics, and intermediate stability, thereby impacting nanoparticle size and morphology [33].

By optimizing these synthesis parameters, researchers can effectively tailor the properties of copper oxide nanoparticles to meet specific application requirements, ranging from catalysis and sensing to biomedical applications.

2.6 Experimental Details

Copper(II) chloride dihydrate from Merck, India, and sodium hydroxide pellets from Lobha Chemie, India, were used without purification. Distilled and deionized water were employed for solution preparation and washing[34].

Synthesis: CuO-NPs were synthesized via a chemical precipitation method following a standard procedure. Copper(II) chloride dihydrate (9.0 g) and sodium hydroxide pellets (5.4 g) were dissolved separately in ethanol. Sodium hydroxide solution was added dropwise to the copper(II) chloride dihydrate solution with stirring, turning the solution from green to bluish-green, then black. The resulting black precipitate (copper hydroxide) was filtered, washed with ethanol and deionized water, then dried at 50°C and annealed at 200°C, 400°C, and 600°C to obtain crystalline CuO-NPs. The annealed sample was ground into powdered nanoparticles. The chemical reaction can be represented as: CuCl2 + 2NaOH → Cu(OH)2 + 2NaCl.

Characterization: X-ray diffraction (XRD) analysis was performed using a Bruker D8 Advance diffractometer, surface morphology was examined via scanning electron microscopy (SEM) using a JEOL JSM-7600F instrument, and energy dispersive X-ray (EDX) analysis was conducted for composition analysis. Fourier-transform infrared (FTIR) spectroscopy was carried out using a Thermo-Nicolet Avatar 370 model FTIR to understand the chemical and structural nature of the CuO-NPs.

2.7 Results and Discussion

- **XRD Patterns**

Figure 2 shows the XRD patterns of Cu(OH)2 complex obtained after drying the precipitate at 50˚C and also the XRD patterns of CuO-NPs annealed at temperatures at 200˚C, 400˚C and 600˚C. The peaks in the XRD patterns of CuO-NPs were compared with the standard [35] .

Figure 3 represents the XRD patterns of CuO-NPs annealed at temperature 600˚C along with the standard tenorite (CuO). This XRD pattern is similar to the monoclinic phase of CuO (tenorite) nanoparticles. The intensities and positions of peaks were in good agreement with that of reported values. The experimental results also found similar to the reported diffraction patterns of CuO-NPs [36] . Similarly, it was found that the intensities and positions of peaks in case of CuO-NPs annealed at 200˚C and 400˚C were in good agreement with the standard CuO (tenorite).

From Table 1, it was found that the peak intensity for CuO-NPs annealed at 600˚C was highest and for CuO-NPs annealed at 200˚C the value was the lowest. It was also observed that with increasing the annealing temperature, the intensity of the diffraction peaks became sharper and the degree of crystallinity of CuO-NPs were also increased. At the annealing temperature 200˚C, the cryatallization of CuO was incomplete. Further increase in annealing temperature to 600˚C leads towards the completeness of crystallization of CuO. Therefore, the degree of crystallinity of CuO-NPs annealed at 600˚C was the highest.

From Table 2, it was observed that with increasing annealing temperature the value of full width at half the maximum intensity, β increases. The values of lattice parameters (a, b, c) and full width at half the maximum intensity, β for CuO-NPs annealed at 600˚C almost matches with that of standard tenorite (CuO). Therefore, the lattice structure of CuO-NPs annealed at 600˚C is almost base-centered monoclinic [35] .

From the values (Table 3), it was noticed that with increasing annealing temperature the average crystallite size of CuO-NPs was increased. With increasing annealing temperature, the atoms in CuO-NPs diffuse across the boundaries of the particles, fusing the particles together and creating one larger particle. Therefore, the crystallite size of the samples increases with increasing the annealing temperature. Higher annealing temperature led to larger crystallite size of CuO-NPs, because higher annealing temperature means higher energy given which results in more oxidation [37] .

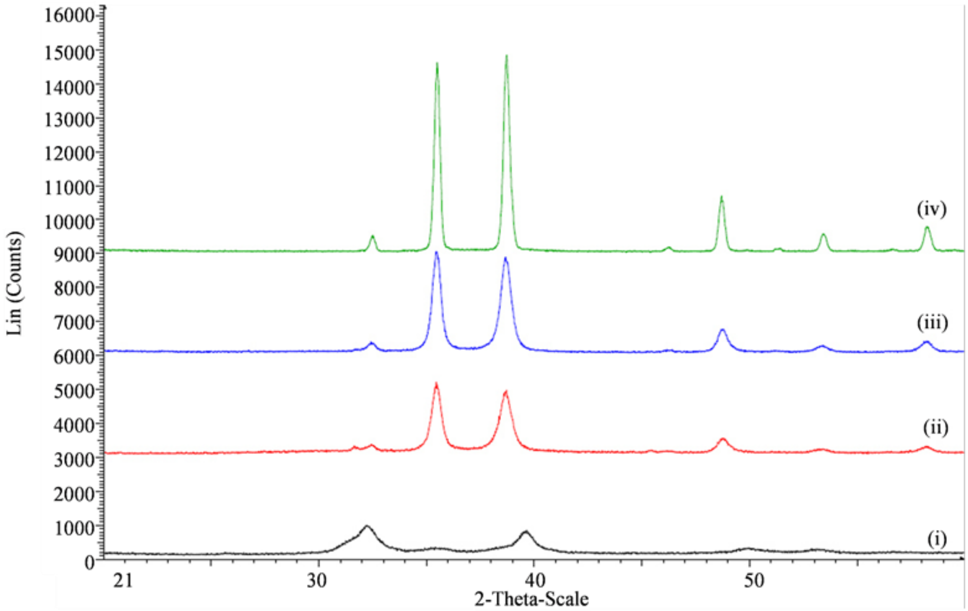

Figure 2. XRD patterns of (i) $Cu(OH)_2$ complex and CuO-NPs annealed at (ii) 200˚C, (iii) 400˚C and (iv) 600˚C.

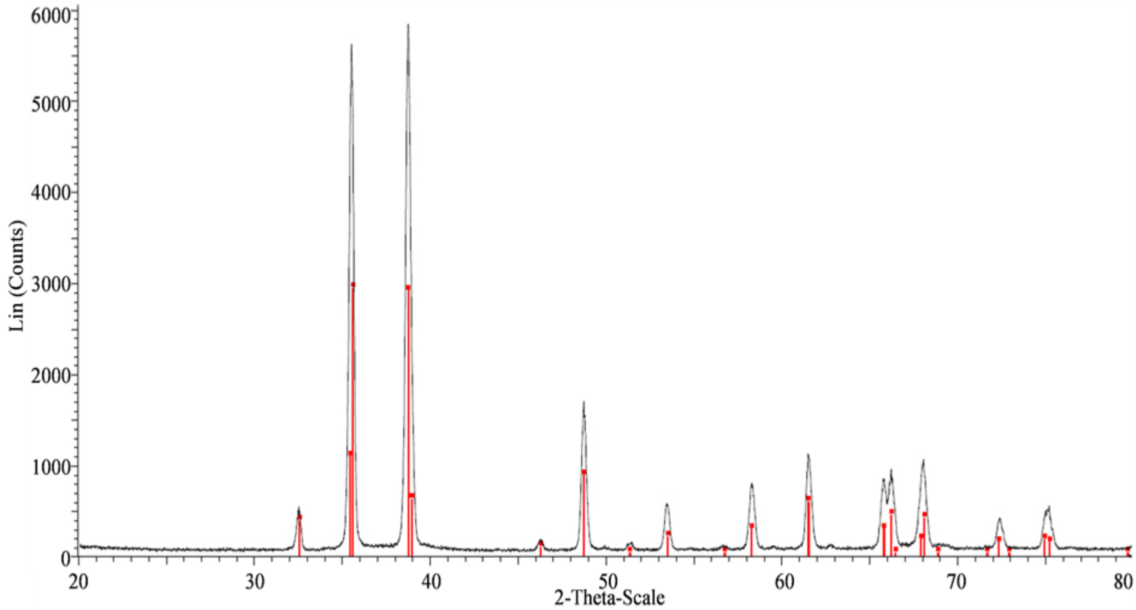

Figure 3. XRD patterns of CuO-NPs annealed at temperature 600˚C. The vertical lines (|) indicate the position and relative intensity of 05-0661 JCPDS card file diffraction peaks for the monoclinic phase.

Samples	Peak intensity (counts)	Relative peak intensity (%)
CuO-NPs annealed at 200˚C	1973	33.4
CuO-NPs annealed at 400˚C	2912	49.3
CuO-NPs annealed at 600˚C	5901	100

Table 1. Peak intensities and relative peak intensities of the most prominent peaks in the XRD patterns of CuO-NPs annealed at temperature 200˚C, 400˚C and 600˚C.

Samples	a (nm)	b (nm)	c (nm)	β (˚)
CuO-NPs annealed at 200˚C	0.466789	0.342411	0.511844	99.3485
CuO-NPs annealed at 400˚C	0.467401	0.342340	0.512304	99.3890
CuO-NPs annealed at 600˚C	0. 468323	0.342244	0.512795	99.5005
Standard tenorite (CuO)	0.468830	0.342290	0.513190	99.5100

Table 2. Lattice parameters (a, b, c) and full width at half the maximum intensity, β for CuO-NPs annealed at 200˚C, 400˚C and 600˚C, and standard tenorite (CuO).

Samples	Average crystallite size (nm)
CuO-NPs annealed at 200˚C	15.22
CuO-NPs annealed at 400˚C	16.44
CuO-NPs annealed at 600˚C	32.50

Table 3. Average crystallite size of CuO-NPs annealed at temperature 200˚C, 400˚C and 600˚C.

Chapter Three

Applications, Conclusions and Recommendations

3.1 Introduction

The applications of copper oxide have been a subject of extensive research and exploration due to its versatile properties and wide-ranging potential across various fields. From renewable energy to healthcare and electronics, copper oxide's unique characteristics make it a valuable material for addressing diverse challenges and driving innovation. In this introduction, we will explore the broad spectrum of applications of copper oxide, highlighting its significance and impact in advancing technology and addressing societal needs.

3.2 Physical Applications

Copper oxide has emerged as a versatile material with applications spanning across various fields due to its unique properties. In recent years, researchers have explored its potential in enhancing the efficiency of solar cells, improving gas sensing technology, and contributing to the development of transparent conductive coatings. In this section, we delve deeper into these physical applications of copper oxide, highlighting their significance and potential impact in advancing technology and addressing societal needs.

1. Solar Cells: The quest for efficient and sustainable energy sources has led to the exploration of novel materials for enhancing solar cell performance. Copper oxide nanoparticles have garnered attention for their ability to improve light absorption and charge carrier generation within solar cells [38]. By incorporating copper oxide into the photoactive layers of solar panels, researchers aim to maximize light-harvesting efficiency and minimize recombination losses, thereby increasing the overall power conversion efficiency of solar cells.

2. Gas Sensors: Monitoring air quality and detecting hazardous gases are essential tasks in various industrial, environmental, and healthcare settings. Copper oxide nanoparticles have shown remarkable sensitivity and selectivity in gas sensing applications [39]. Gas sensors employing copper oxide nanoparticles detect changes in electrical conductivity or optical properties upon gas adsorption, enabling the detection of a wide range of gases, including toxic pollutants and volatile organic compounds.
3. Transparent Conductive Coatings: Transparent conductive coatings play a crucial role in electronic devices such as touchscreens, displays, and solar panels. Copper oxide nanoparticles offer a promising solution for creating transparent conductive coatings that provide both electrical conductivity and optical transparency [40]. These coatings enable the transmission of electrical signals while maintaining visibility, contributing to the functionality and efficiency of electronic devices.

In conclusion, the physical applications of copper oxide demonstrate its versatility and potential to address challenges in renewable energy, environmental monitoring, and electronics. As research in this field continues to advance, we can expect further innovations that harness the unique properties of copper oxide to drive technological progress and meet the evolving needs of society.

3.3 Biological Applications

Copper oxide nanoparticles have garnered significant interest in biomedical research due to their potential applications in various therapeutic and diagnostic fields. In this section, we explore the diverse biological applications of copper oxide nanoparticles, highlighting their antibacterial activity, anticancer properties, and potential as pain killers.

1. Antibacterial Activity:

Copper oxide nanoparticles exhibit potent antibacterial activity against a wide range of pathogenic microorganisms [41]. Their ability to induce oxidative stress and disrupt bacterial cell membranes makes them effective agents for combating bacterial infections. Copper oxide nanoparticles have been investigated for use in wound dressings, medical implants, and surface coatings to prevent bacterial colonization and biofilm formation, thus reducing the risk of nosocomial infections and improving patient outcomes.

2. Anticancer Properties:

Research has shown that copper oxide nanoparticles possess anticancer properties, making them promising candidates for cancer therapy [42]. These nanoparticles can selectively target cancer cells while sparing healthy cells, leading to minimal off-target effects. Copper oxide nanoparticles exert their anticancer effects through various mechanisms, including induction of oxidative stress, inhibition of cell proliferation, and promotion of apoptosis. Furthermore, copper oxide nanoparticles can be functionalized with targeting ligands to enhance their specificity towards cancer cells, thereby improving treatment efficacy and reducing systemic toxicity.

3. Pain Killer:

Copper oxide nanoparticles have emerged as potential candidates for pain management due to their anti-inflammatory properties [43]. By modulating inflammatory responses and inhibiting pain signaling pathways, copper oxide nanoparticles can alleviate pain associated with various conditions, including arthritis, neuropathy, and inflammatory diseases. Additionally, copper oxide nanoparticles can be incorporated into topical formulations or drug delivery systems for targeted pain relief, offering a promising approach for improving the quality of life for individuals suffering from chronic pain.

In summary, the biological applications of copper oxide nanoparticles hold great promise in addressing healthcare challenges, ranging from combating bacterial infections to treating cancer and managing pain. Continued research efforts aimed at elucidating their mechanisms of action and optimizing their therapeutic properties will further advance their clinical translation and contribute to the development of novel biomedical interventions.

3.4 Conclusion

1. Copper oxide research spans various fields beyond nanotechnology, showcasing its versatility and significance in addressing diverse challenges.
2. Through meticulous research, precise control over copper oxide properties has been achieved, enabling its effective utilization in numerous applications.
3. Applications of copper oxide extend to areas such as renewable energy, healthcare, environmental science, and electronics.
4. Collaboration across disciplines is essential for further exploration of copper oxide's potential and optimization of its properties.
5. Continued innovation and investment in copper oxide research hold promise for driving progress and addressing global challenges across industries.

3.5 Recommendations:

1. Foster collaboration among researchers from diverse fields to explore the full range of applications for copper oxide and optimize their performance in various fields.
2. Prioritize studies assessing the safety profile and environmental impact of copper oxide to ensure their responsible use and mitigate potential risks.
3. Establish standardized synthesis protocols for copper oxide to ensure reproducibility, reliability, and scalability of production processes.
4. Facilitate the translation of research findings into practical applications by fostering partnerships between academia, industry, and regulatory agencies to facilitate the development and commercialization of copper oxide-based products.
5. Promote education and awareness initiatives to inform stakeholders about the potential benefits, challenges, and ethical considerations associated with the use of copper oxide nanoparticles.

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الملخص

لقد جذبت جسيمات أكسيد النحاس (CuO) اهتمامًا كبيرًا بفضل خصائصها الفريدة وتطبيقاتها الواسعة عبر مجموعة متنوعة من المجالات. يقدم هذا البحث نظرة شاملة على جسيمات أكسيد النحاس، مشمولًا طرق التركيب، والتطبيقات الفيزيائية والبيولوجية، وتقنيات التوصيف، والتوجهات المستقبلية. تُمكن تقنيات التركيب التحكم الدقيق في الشكل والخصائص لجسيمات أكسيد النحاس، مما يُيسّر استخدامها في تحسين كفاءة الخلايا الشمسية، وتحسين تقنية الاستشعار للغازات، ومحاربة العدوى البكتيرية، وربما علاج السرطان. بالإضافة إلى ذلك، فإن التعاون بين التخصصات المتعددة والجهود المستمرة في البحث ضروري لاستكشاف إمكانيات جسيمات أكسيد النحاس بشكل أعمق وتحسين خصائصها للتطبيقات العملية. تقنيات التوصيف مثل تفاضل الأشعة السينية، والمجهر الإلكتروني الماسح، والطيف الفوق البنفسجي بالتحويل المتقدم تلعب دورًا حاسمًا في إلقاء الضوء على الخصائص الهيكلية والوظيفية لجسيمات أكسيد النحاس. في المستقبل، فإن الابتكار المستمر والاستثمار والجهود التعليمية هي مفاتيح فتح الإمكانات الكاملة لجسيمات أكسيد النحاس ومواجهة التحديات العالمية عبر مختلف الصناعات.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية العلوم
قسم علوم الفيزياء

أوكسيد النحاس طريقة تحظيره وتطبيقاته الفيزياوية والجيلوجيه

بحث مُقَدَّم إلى مجلس كلية العلوم - جامعة بابل
ويشكل جزءًا من متطلبات الحصول على درجة البكالوريوس في الفيزياء

مقدم من قبل الطالبة
آية كاظم حنون

بإشراف
أ.د حكمت عدنان جواد كاظم

1445هـ 2024م