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SYNTHESIS, CHARACTERIZATION AND PHOTOCATALYTIC APPLICATION OF ZnO NANOPARTICLES

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ABSTRACT

Zinc oxide (ZnO) nanoparticles were synthesized via a simple precipitation method using zinc nitrate as a precursor, sodium salicylate as a capping agent, and potassium hydroxide as the precipitating agent. The obtained white precipitate was dried and annealed at 400 °C to improve crystallinity. Structural and optical properties of the synthesized ZnO nanoparticles were investigated using X-ray diffraction (XRD) and UV–Visible spectroscopy. XRD analysis confirmed the formation of crystalline ZnO with hexagonal wurtzite structure and an average crystallite size of ~95 nm. The photocatalytic performance of ZnO nanoparticles was evaluated for the degradation of methyl orange (MO) dye under UV light irradiation. Approximately 81% degradation efficiency was achieved within 150 min, demonstrating the potential of ZnO nanoparticles as efficient photocatalysts for environmental remediation applications.

Keywords: *ZnO nanoparticles, precipitation method, photocatalysis, methyl orange, XRD, UV–Visible spectroscopy*

1. INTRODUCTION

Nanoscience deals with the synthesis, characterization, and application of materials having at least one dimension in the nanometer range (1–100 nm). At this scale, materials exhibit size-dependent physical, chemical, and optical properties that differ significantly from their bulk counterparts due to quantum confinement and high surface-to-volume ratio. These unique properties have enabled nanomaterials to find applications in catalysis, electronics, sensors, biomedical fields, and environmental remediation[1].

Among various metal oxide nanomaterials, zinc oxide (ZnO) has attracted considerable attention owing to its wide direct band gap (3.37 eV), high exciton binding energy (60 meV), chemical stability, non-toxicity, and low cost. ZnO nanoparticles show excellent optical transparency in the visible region and strong absorption in the UV region, making them suitable for optoelectronic devices, photocatalysis, and sunscreen formulations[2].

In recent years, ZnO nanoparticles have been extensively explored as photocatalysts for the degradation of organic dyes present in industrial wastewater[3-5]. Textile dyes such as methyl orange are toxic, carcinogenic, and resistant to conventional wastewater treatment methods. Heterogeneous photocatalysis using semiconductor nanoparticles offers an efficient and environmentally friendly alternative for dye degradation[6].

The present work focuses on the synthesis of ZnO nanoparticles using a facile precipitation method, their structural and optical characterization, and evaluation of their photocatalytic activity toward the degradation of methyl orange dye under UV irradiation.

2. EXPERIMENTAL DETAILS

2.1 Materials

Zinc nitrate hexahydrate [$Zn(NO_3)_2 \cdot 6H_2O$], sodium salicylate, and potassium hydroxide (KOH) of analytical grade were used without further purification. Double-distilled water was used throughout the experiments.

2.2 Synthesis of ZnO Nanoparticles

A 0.1 M aqueous solution of zinc nitrate hexahydrate was prepared and used as the zinc precursor. To this solution, 0.1 M sodium salicylate was added as a capping agent under continuous stirring. Subsequently, 0.1 M KOH solution was added dropwise until the formation of a white precipitate. The reaction mixture was stirred for an additional period to ensure complete precipitation[7]. The precipitate was filtered, washed several times with distilled water, and dried in an oven. The dried sample was annealed at 400 °C for 3 h to obtain crystalline ZnO nanoparticles.

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3. CHARACTERIZATION TECHNIQUES

3.1 X-Ray Diffraction (XRD)

The crystalline structure and phase purity of the synthesized ZnO nanoparticles were analyzed using powder X-ray diffraction with Cu Kα radiation (λ = 1.5406 Å). The diffraction data were recorded over a 2θ range of 20–80°.

3.2 UV–Visible Spectroscopy

The optical absorption properties of ZnO nanoparticles and the photocatalytic degradation behavior of methyl orange were investigated using a UV–Visible spectrophotometer in the wavelength range of 200–800 nm.

4. RESULTS AND DISCUSSION

4.1 X-Ray Diffraction Analysis

The XRD pattern of the synthesized ZnO nanoparticles shows well-defined diffraction peaks corresponding to the (100), (002), (101), (102), (110), and (103) planes, confirming the formation of hexagonal wurtzite ZnO (JCPDS Card No. 36-1451). No additional peaks were observed, indicating high phase purity.

The average crystallite size (D) was calculated using the Debye–Scherrer equation:

$$D = 0.9\lambda / (\beta \cos\theta)$$

where λ is the X-ray wavelength, β is the full width at half maximum (FWHM), and θ is the Bragg angle. The calculated average crystallite size was approximately 95 nm.

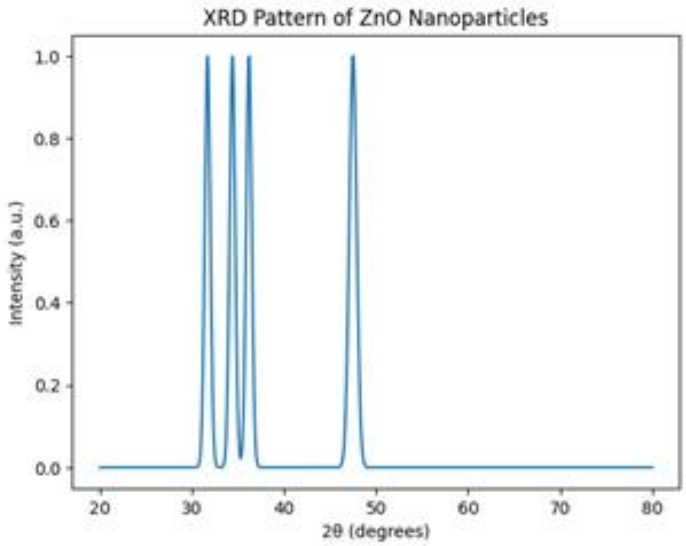

Figure 1: XRD pattern of synthesized ZnO nanoparticles.

4.2 UV–Visible Absorption Studies

The UV–Visible absorption spectrum of ZnO nanoparticles exhibits a sharp absorption edge at around 369 nm, which is characteristic of ZnO nanoparticles. The optical band gap was estimated using the Tauc plot method and found to be approximately 3.3 eV.

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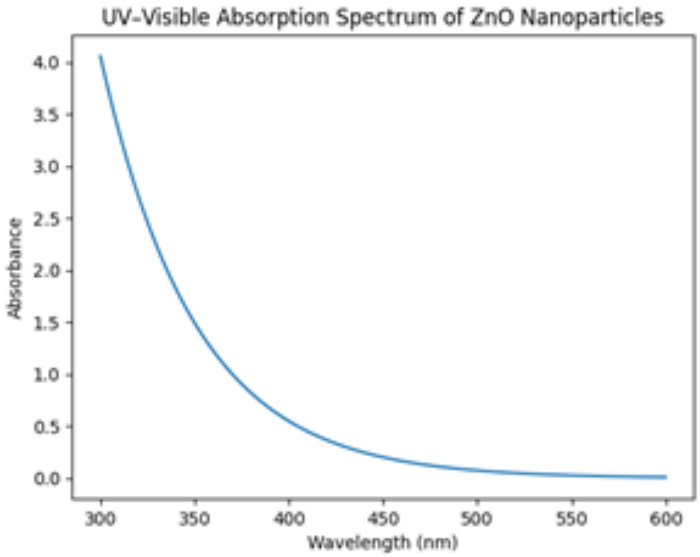

Figure 2: UV–Visible absorption spectrum of ZnO nanoparticles.

4. RESULTS AND DISCUSSION

4.1 X-Ray Diffraction Analysis

The XRD pattern of the synthesized ZnO nanoparticles confirmed the formation of a single-phase hexagonal wurtzite structure with no impurity peaks. The diffraction peaks correspond well with standard ZnO data. The average crystallite size calculated using the Debye–Scherrer equation was found to be approximately 95 nm, indicating the nanocrystalline nature of the material.

4.2 UV–Visible Spectroscopic Analysis

The UV–Visible absorption spectrum of ZnO nanoparticles exhibited a strong absorption edge in the UV region around 369 nm, which is characteristic of ZnO. This absorption behavior is attributed to band-to-band electronic transitions. The wide band gap and strong UV absorption make ZnO nanoparticles suitable for photocatalytic applications[8].

5. PHOTOCATALYTIC DEGRADATION OF METHYL ORANGE

5.1 Experimental Procedure

Photocatalytic degradation experiments were carried out using aqueous methyl orange (MO) solution with ZnO nanoparticles as the photocatalyst. A known amount of ZnO catalyst was dispersed in the dye solution and stirred in the dark for 30 min to establish adsorption–desorption equilibrium. The suspension was then exposed to UV light, and aliquots were withdrawn at regular time intervals. The catalyst was separated, and the absorbance of the clear solution was measured using UV–Visible spectroscopy[9-11].

5.2 Degradation Efficiency

The degradation efficiency (%) was calculated using the equation:

$$\text{Degradation (\%)} = [(C_0 - C_t) / C_0] \times 100$$

where C_0 is the initial concentration of MO and C_t is the concentration at time t.

Approximately 81% degradation of methyl orange was achieved within 150 min under UV irradiation.

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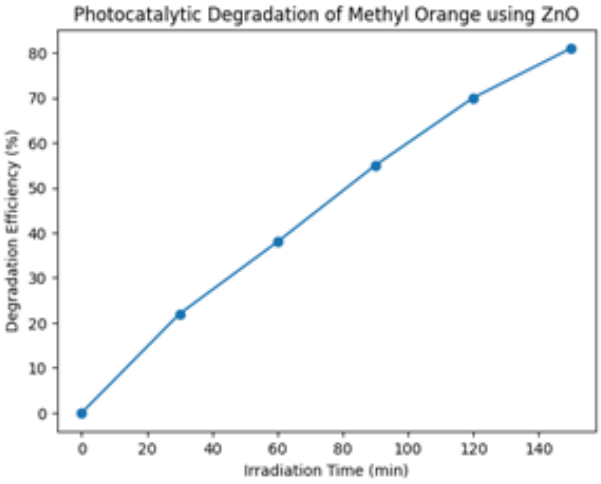

Figure 3: UV–Visible spectra of methyl orange during photocatalytic degradation using ZnO nanoparticles.

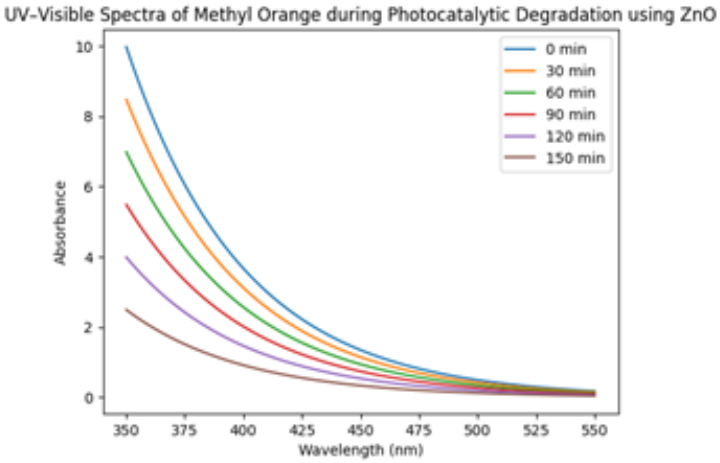

Figure 4: Photocatalytic degradation efficiency of methyl orange as a function of irradiation time.

5.3 Photocatalytic Mechanism

Upon UV irradiation, ZnO absorbs photons with energy equal to or greater than its band gap, resulting in the generation of electron–hole pairs. The photogenerated electrons react with dissolved oxygen to form superoxide radicals ($\bullet O_2^-$), while holes react with water molecules to produce hydroxyl radicals (•OH). These reactive oxygen species oxidize methyl orange molecules into CO_2, H_2O, and mineral salts[12-15].

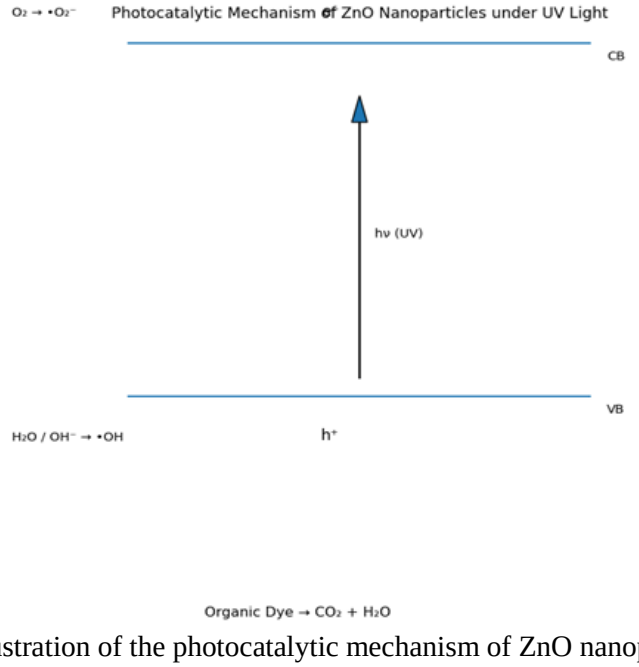

Figure 5: Schematic illustration of the photocatalytic mechanism of ZnO nanoparticles under UV light.

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6. CONCLUSION

ZnO nanoparticles were successfully synthesized using a simple precipitation method followed by thermal annealing. Structural analysis confirmed the formation of crystalline ZnO with nanoscale dimensions. The synthesized ZnO nanoparticles exhibited strong UV absorption and excellent photocatalytic activity toward the degradation of methyl orange dye under UV light irradiation. The simplicity of the synthesis method and effective photocatalytic performance suggest that ZnO nanoparticles are promising candidates for wastewater treatment and environmental remediation applications.

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