# Synthesis and optical properties of copper-containing nanoparticles for antibacterial coatings

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**Abstract.** The paper presents a simple and cost-effective method for copper nanoparticles synthesis by the reduction of copper sulfate with tert-butylamine borane in the presence of polyvinylpyrrolidone as a stabilizer. The optical properties and stability of the obtained colloidal systems were investigated using electron spectroscopy. It was found that the synthesized nanoparticles exhibit a polydisperse size distribution with two dominant fractions: small spherical particles (less than 10 nm) showing an absorption peak at 360 nm, and larger particles (20–50 nm) with a plasmon resonance at 575 nm. The system demonstrated good stability for 45 minutes, after which partial aggregation and sedimentation of predominantly larger particles were observed. The potential applications of the synthesized copper nanoparticles as an antimicrobial component in functional coatings for transportation, agriculture, and the food industry are discussed. The potential synergistic effect of the polydisperse system is noted, where small particles provide rapid bactericidal action, and large particles provide a prolonged antimicrobial effect. For practical application, further investigation of the antibacterial activity and stability of the nanoparticles within the target materials is recommended.

## 1 Introduction

Global challenges in recent years, including the COVID-19 pandemic and the need to ensure biosafety in public spaces, have highlighted the importance of developing effective antimicrobial coatings for frequently touched surfaces. Solutions for transportation facilities—such as public transport cabins, airports, and railway stations—have become particularly significant, as these environments present the highest risk for the spread of pathogenic microorganisms.

However, to date, such coatings have found broader application in agriculture and the food industry. One of the most promising directions is the use of functional materials based on copper nanoparticles, which combine high bactericidal activity with accessibility. In the agro-industrial sector, they can be employed to create protective coatings for fruits and vegetables, extending their shelf life; as components of smart packaging materials; and for

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the treatment of seeds and plants to suppress bacterial infections. In the food industry, these nanomaterials hold promise for coating processing equipment and surfaces that come into contact with products, thereby reducing microbial load and enhancing food safety.

A key task is the control of nanoparticle size and morphology, which determine their properties. The simplest and most economically feasible approach is the chemical reduction method in aqueous solutions in the presence of stabilizers.

The aim of this study was the synthesis and investigation of the optical properties of copper nanoparticles obtained by the reduction of copper sulfate with tert-butylamine borane in the presence of polyvinylpyrrolidone. Optical spectroscopy was used to monitor nanoparticle formation and to analyze the stability of the resulting systems, which is of considerable interest for the subsequent development of antimicrobial coatings for transportation and the agro-industrial sector.

## 2 Materials and methods

A simple and cost-effective method of chemical reduction of metal ions in the presence of a polymer stabilizer and a strong reducing agent was used to obtain copper-containing nanoparticles [1].

Copper sulfate was used as the source of metal ions, polyvinylpyrrolidone (PVP) with a molecular weight of 360,000 served as the polymer stabilizer, and tert-butylamine borane (TBAB) was used as the reducing agent. Distilled water was used to prepare the aqueous solutions of the reagents.

Pre-prepared aqueous solutions of the initial reagents (CuSO4 and the polymer) were mixed in a test tube under normal conditions, then the reducing agent was added. The final concentrations were as follows: $CuSO_4$ – 0.01 mol/L, PVP – 0.02 base-mol/L, and TBAB – 0.03 mol/L.

Electronic spectra were recorded using PE-5400VI spectrophotometer (Ecroschem, Russia), which allows measurements in the range of 300 to 1000 nm. For analysis, the samples were placed in a glass cuvette with an optical path length of 10 mm.

The spectra were processed using SC5400 software (Ecroschem, Russia) and MS Excel (Microsoft, USA).

## 3 Results and discussion

### 3.1 Synthesis products and their optical properties

During the synthesis, a color change from transparent to yellow-brown was observed after 15 minutes from the start. 20-30 minutes after the start of synthesis, dark brown suspensions with a characteristic type of phase motion were observed. After 45 minutes, the sample acquired a dark brown hue with a purple tint. After 24 hours, partial sedimentation occurred, resulting in the formation of a black precipitate.

At the beginning of the synthesis process, the electronic spectra show a broad rise around 800 nm with a relatively low absorption value (Fig. 1a). These data indicate the presence of $Cu^{2+}$ ions in the studied solution, which is in good agreement with the literature. [2].

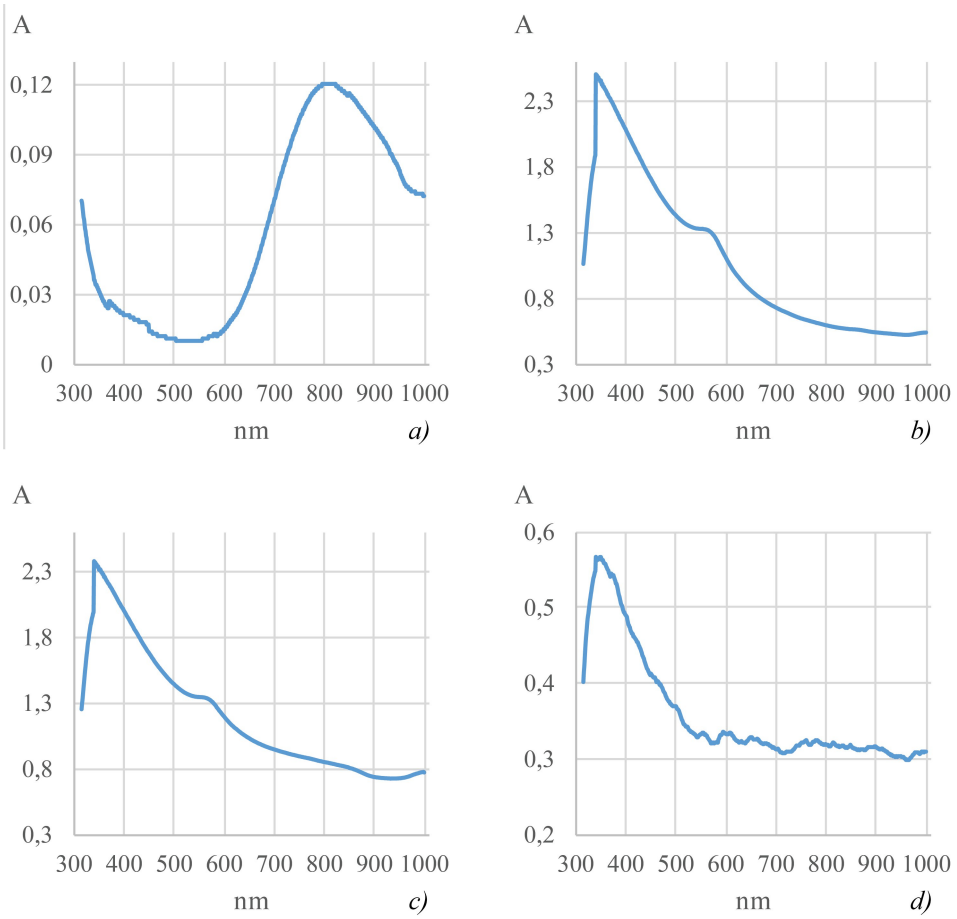


**Fig. 1.** Electronic spectra of the copper-containing nanoparticles obtained during synthesis: immediately after the addition of the reducing agent (a), after 25 minutes (b), after 45 minutes (c), and after 24 hours (d).

As early as 15 minutes after the start of the synthesis, the absorption values in the range between 300 and 750 nm in the undiluted sample exceed 3, reaching the measurement limits of the available equipment. At this stage, the formation and growth of copper-containing nanoparticles take place. The sample likely represents a polydisperse system in which particle growth, dissolution and reorganization of the smallest particles, as well as aggregate formation, occur.

The analysis performed 25 minutes after the start of the synthesis on samples diluted with water at a 1:9 ratio shows the formation of two peaks in the spectrum (Fig. 1b). The first peak, with a sharp shape, appears around 360 nm, while the second, step-like peak is observed around 575 nm. The formation of a stable system has already been completed. The first peak (360 nm) corresponds to the interband transition of copper, which overlaps with the plasmon resonance of small particles (less than 10 nm) [3]. This peak serves as a clear indicator of the presence of small spherical copper-containing nanoparticles. The second peak (575 nm) represents the classical localized surface plasmon resonance of spherical copper nanoparticles [4]. It indicates the presence of larger spherical nanoparticles in the solution (20–50 nm and above).

The analysis of the diluted sample performed 45 minutes after the start of the synthesis confirms the formation of a stable system. The positions of the peaks remained unchanged (Fig. 1c).

Twenty-four hours after the synthesis, the peak around 575 nm disappears, and the intensity of the peak around 360 nm decreases (Fig. 1d). This is explained by partial aggregation of the small particles and the sedimentation of larger particles and aggregates. The sample is dominated by a monodisperse phase of small particles with sizes below 10 nm, which are less prone to aggregation and sedimentation.

### 3.2 Antibacterial properties of copper-containing nanoparticles

Copper-containing nanoparticles have significant potential for use as components of antibacterial coatings. For example, they can be employed to create nanostructured coatings on frequently touched surfaces, preventing contamination of individuals in contact with them and limiting the spread of pathogenic microorganisms [5]. Nanoparticles have also found applications in food packaging, helping to extend shelf life and facilitate transportation [6]. Furthermore, they can potentially be used as functional components of films and coatings applied to the surfaces of fruits and vegetables to prolong their storage life [7].

Overall, the relationship between the optical properties of nanoparticles and their antibacterial activity is not direct. Both of these characteristics are determined by the fundamental properties of the nanoparticles: morphology, surface charge, and chemical reactivity.

The primary mechanism underlying the antibacterial properties of copper-containing nanoparticles is the release of $Cu^{2+}$ ions. During the slow oxidation of nanoparticles, copper ions are released at the cell surface, generating reactive oxygen species and disrupting the function of cellular enzymes and transport systems. In addition, nanoparticles can adsorb onto the cell surface through electrostatic interactions, compromising the integrity of the cell membrane [8].

Smaller copper nanoparticles (with an absorption peak around 360 nm in the electronic spectra) have a high specific surface area. As a result, more copper atoms are available for interaction with the environment and pathogenic cells. Due to their large specific surface area, these particles release $Cu^{2+}$ ions more rapidly [9]. In addition, small particles can more easily penetrate the cell wall.

Larger particles (with an absorption peak around 575 nm in the electronic spectra) act as a reservoir of antibacterial resources. These particles release ions more slowly, providing a prolonged antibacterial effect [10].

It is suggested that polydispersity leads to a synergistic effect, enhancing the antibacterial capabilities of the system. Smaller particles provide a rapid response to pathogens, while larger particles maintain prolonged disinfection of the environment.

## 4 Conclusion

The study demonstrates a simple and reproducible method for obtaining polydisperse copper nanoparticles stabilized by PVP. The optical properties of the synthesized nanoparticles (presence of two plasmon peaks) indicate the existence of two main fractions in the system—small and large particles.

The combination of these fractions can potentially provide a synergistic antibacterial effect: the small particles, due to their high specific surface area and rapid ion release, ensure fast bactericidal action, while the large particles act as a reservoir, providing a prolonged effect.

The synthesized nanoparticles are promising for use as a functional component in antibacterial coatings and materials for the agro-industrial and food sectors.

For further development of this work, it is advisable to conduct a direct study of the antibacterial activity of the obtained samples and their stability within the target materials (films, coatings).

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