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OPTIMIZED CHEMICAL SYNTHESIS OF STABLE SILVER NANOPARTICLES USING VARIOUS REDUCING AND STABILIZING AGENTS

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Abstract: This article discusses the influence of stabilizing agents on the stability and particle size of silver nanoparticles (AgNPs) during synthesis. AgNPs were synthesized via chemical reduction of silver nitrate ($AgNO_3$) using different reducing agents (sodium citrate, hydrazine, glucose) and stabilizers (gelatin, dextrin, and PVP). Syntheses were conducted under various temperature conditions (0°C, 20°C, 40°C), and the particle size of the resulting nanoparticles was measured using the MasterSizer-3000 laser diffraction method. The most stable AgNPs were obtained using sodium citrate as a reducing agent and 1% gelatin as a stabilizer at 20°C. Under these conditions, the synthesized particles exhibited small and uniform size and remained stable for up to 6 months without sedimentation. Increasing the temperature led to the formation of larger particles. Sodium citrate and gelatin represent an optimal combination for the controlled and stable synthesis of AgNPs. This approach offers promising applications in medicine, biotechnology, and environmental sciences.

Keywords: silver nanoparticles, chemical reduction, sodium citrate, gelatin, stability, dispersion, nanoscale.

Introduction. Nanomaterials differ significantly in their properties compared to their bulk counterparts due to differences in physicochemical characteristics and the surface-to-volume ratio. With the development of nanotechnology, a wide range of novel nanomaterials with unique properties has emerged. Among them, silver nanoparticles (AgNPs) have attracted growing interest due to their exceptional properties. However, the synthesis of stable and broadly applicable AgNPs remains a major challenge for researchers.

AgNPs exhibit excellent antibacterial properties and are commonly synthesized from silver nitrate ($AgNO_3$). There are two main categories of synthesis methods: physical and chemical processes. Physical methods are often expensive and complex, whereas chemical methods offer a more cost-effective approach for AgNP synthesis.

The production of metallic nanoparticles (NPs) in solution involves several key components: a metal source (typically a salt or complex), a reducing agent, and often a stabilizer [1,2]. In photochemical processes, metal ions (M^+) are reduced to their zero-valent state (M^0) under light irradiation, forming metal nuclei, which subsequently grow and aggregate into metallic NPs [3–5].

The formation and stability of NPs depend on factors such as solution pH, reagent composition and concentration, reaction time, and temperature. These parameters influence particle size, morphology, and the aging behavior of the system.

Stabilizing and capping agents play a crucial role in maintaining colloidal properties and preventing agglomeration. These agents allow control over the size and shape of metal NPs and enhance colloidal stability by preventing self-coagulation and aggregation [6–11].

Different substances uniquely affect the properties of AgNPs and AuNPs. For example, the effects of polyvinylpyrrolidone (PVP) [12–14], polymethacrylate (PMA) [15], polysaccharides and proteins (chitosan, glucose, dextrose, gelatin) [13,16], sodium dodecyl sulfate (DDS-Na) [16], and natural rubber [17] have been studied in the literature.

Investigations have shown that favorable results in AgNP synthesis can be achieved through the proper selection and concentration of stabilizing agents.

Methods. This study focused on synthesizing AgNPs using different reducing agents and stabilizers, with silver nitrate as the primary precursor. The chemicals used included analytical-grade silver nitrate, sodium citrate, glucose, and hydrazine as reducing agents, and gelatin, dextrin, and PVP as stabilizers.

First, stabilizer solutions were prepared at 20°C. A 500 mg/mL solution of silver nitrate was then prepared. 0.1 M solutions of the reducing agents—sodium citrate, hydrazine, and glucose—were also prepared. AgNPs were synthesized via a chemical reduction method involving the reduction of silver nitrate.

Result and discussion. From the experimental analysis, the most stable AgNP samples—those that did not produce any sediment for up to 6 months—were identified. Their particle sizes were measured using the MasterSizer-3000 laser diffraction method (Table 1).

Table 1. Particle size of highly stable AgNPs synthesized from $AgNO_3$ under different conditions

Sample ID	Reducing Agent	Stabilizer	Temperature (°C)	Picture	Particle Size (nm)
16	Sodium citrate	1 % Gelatin	20		19,6-158
116	Sodium citrate	1 % Dextrin	0		20,2-192

120	Natriy sitrat	1 % Dextrin	0		20,4-220
69	Sodium citrate	2 % Gelatin	40		20,1-269
128	Sodium citrate	1 % Gelatin	0		20,4-24,5
72	Sodium citrate	5 % Dextrin	40		20,4-197
164	Hydrazine	5 % Gelatin	20		19,8-178
26		5 %li PVS	20		38,8-135

72	Sodium citrate	5 % Dextrin	40		20,4-197
146	Glucose	3 % li PVP	20		19,8-198
53	Sodium citrate	1 %li Dextrin (potato)	20°C		20.4-22.4

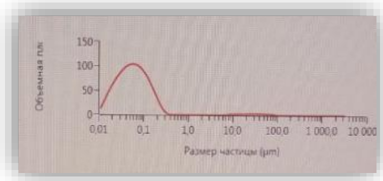
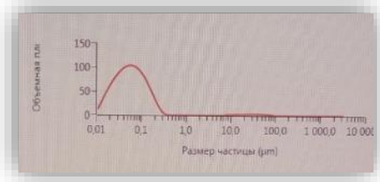
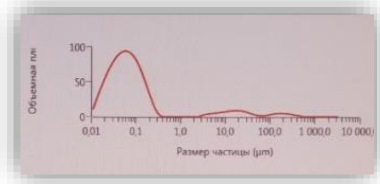
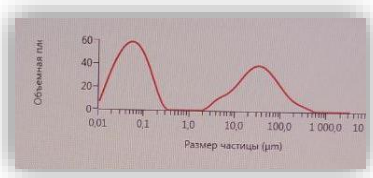
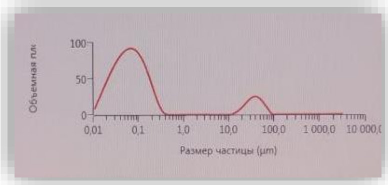
The table shows how reducing and stabilizing agents, as well as temperature, influence AgNP particle sizes. Sodium citrate was widely used as a reducing agent and proved effective across several samples. Using 1% gelatin or 1% dextrin as stabilizers resulted in particle sizes ranging from 20.4 to 269 nm. These findings suggest that sodium citrate is highly efficient in synthesizing AgNPs.

Particles synthesized with glucose as a reducing agent were of intermediate size (19.8–198 nm) compared to those synthesized with sodium citrate and hydrazine. Using gelatin solutions of 1% and 2% resulted in particles ranging from 20.1 to 269 nm, demonstrating gelatin's effectiveness in stabilizing and controlling particle size.

There was a noticeable difference in particle size between those synthesized at 20°C and 40°C. For instance, with 2% gelatin at 40°C, particles reached sizes up to 269 nm. This indicates that elevated temperatures accelerate the chemical reaction, leading to the formation of larger nanoparticles.

AgNP size and stability depend on many factors, particularly the type of reducing and stabilizing agents used, and the synthesis temperature. The most stable particles were obtained using sodium citrate and gelatin at 20°C.

Table 2. Average particle size of AgNPs synthesized using sodium citrate as the reducing agent.

Sample ID	Avg. Size (nm)	Stabilizer	Temperature (°C)	**Mastersizer graph**
16	80	1 % Gelatin	20	
69	75	2 % Gelatin	40	
128	80	1 % Gelatin	0	
163	80	5 % Gelatin	20	
53	85	1 % dextrin	20	

Based on these results, the most optimal synthesis conditions for AgNPs include using sodium citrate as a reducing agent and gelatin as a stabilizer at room temperature (20°C).

Conclusions. In this study, silver nanoparticles (AgNPs) were synthesized via chemical reduction using different reducing agents (sodium citrate, glucose, hydrazine) and stabilizers (gelatin, dextrin, PVP). The results demonstrated that the size and stability of AgNPs are highly dependent on the synthesis conditions, particularly the type of reducing and stabilizing agents used and the reaction temperature.

The most stable colloidal systems were obtained using sodium citrate and gelatin at 20°C, producing small, uniform particles that remained stable for over six months. This proves that the combination of sodium citrate and gelatin is optimal for the controlled and stable synthesis of AgNPs. This approach holds great potential for applications in medicine, biotechnology, and environmental science.

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