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Gold Nanoparticles: Synthesis Techniques, Biomedical Applications, and Future Prospects

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Opinion Article

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DESCRIPTION

Gold Nanoparticles (AuNPs) have captivated researchers for their unique optical, electronic, and catalytic properties, making them indispensable in various fields ranging from biomedical imaging and therapeutics to sensing and environmental remediation. This commentary explores the significance of gold nanoparticle synthesis, recent advancements, applications, and future prospects.

Synthesizing gold nanoparticles involves reducing gold salts in solution to form stable colloidal dispersions of nanoscale gold particles. Numerous synthesis methods have been developed, each offering advantages in terms of control over nanoparticle size, shape, and surface chemistry. Common methods include chemical reduction, citrate reduction, seed-mediated growth, and green synthesis using biological agents.

Chemical reduction methods, such as the Turkevich method and Brust-Schiffrin method, involve the reduction of gold salts by chemical agents like sodium borohydride or citrate. These methods offer simplicity and scalability, producing monodisperse spherical nanoparticles with tunable sizes. However, achieving precise control over nanoparticle morphology and surface functionalization can be challenging.

Seed-mediated growth methods involve the controlled growth of gold nanoparticles from preformed seed particles. This approach enables the synthesis of nanoparticles with well-defined shapes, such as rods, triangles, and stars, by varying reaction conditions and seed morphology. Seed-mediated growth methods offer versatility in tailoring nanoparticle properties for specific applications but may require additional steps and optimization.

Green synthesis methods utilize natural sources such as plant extracts, bacteria, or fungi as reducing agents for gold nanoparticle synthesis.

Functionalization techniques have also been employed to impart specific functionalities to the nanoparticles, such as targeting ligands for drug delivery or catalytic sites for enhanced reactivity.
These methods offer eco-friendly alternatives to traditional chemical synthesis, reducing the need for harsh chemicals and energy-intensive processes. Green synthesis approaches yield biocompatible nanoparticles with potential applications in biomedicine and environmental science.

Gold nanoparticles find widespread applications in biomedical imaging, drug delivery, cancer therapy, and diagnostics due to their unique optical properties and biocompatibility. In imaging applications, AuNPs serve as contrast agents for enhancing the sensitivity and resolution of various imaging modalities, including Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Surface-Enhanced Raman Spectroscopy (SERS).

Furthermore, gold nanoparticles exhibit strong Surface Plasmon Resonance (SPR) absorption in the visible and near-infrared regions, making them ideal candidates for Photo Thermal Therapy (PTT) and Photo Dynamic Therapy (PDT) of cancer. By selectively targeting cancer cells and converting light energy into heat or reactive oxygen species, AuNPs offer precise and minimally invasive treatment modalities with reduced side effects.

In addition to biomedical applications, gold nanoparticles are used in catalysis, sensing, electronics, and environmental remediation. AuNPs serve as efficient catalysts for various chemical reactions, including oxidation, hydrogenation, and carbon-carbon coupling, due to their high surface area and unique electronic properties.

Looking ahead, research in gold nanoparticle synthesis continues to advance, driven by the quest for enhanced control over nanoparticle properties and the exploration of novel applications. Future efforts will focus on developing innovative synthesis methods, such as microfluidic-based approaches and bottom-up assembly techniques, for producing complex nanostructures with tailored functionalities.

Moreover, interdisciplinary collaborations between chemists, physicists, biologists, and engineers will drive innovation and accelerate the translation of gold nanoparticles from the laboratory to real-world applications. By controlling the unique properties of gold nanoparticles and pushing the boundaries of nanotechnology, researchers can unlock new possibilities for addressing societal challenges and improving human health and well-being.