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GOLD NANOPARTICLES FOR THE DETECTION OF ORGANOPHOSPHATE

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ABSTRACT

Organophosphates are toxic compounds commonly used in agriculture, industry and warfare, making their detection a critical issue for public health and safety. Gold nanoparticles have emerged as a promising tool for the detection of organophosphates due to their unique optical properties and surface chemistry. This review discusses the various methods for synthesizing gold nanoparticles and their functionalization for improved organophosphate detection. The sensitivity and selectivity of the detection method are also discussed, as well as its potential applications in environmental monitoring, food safety, clinical diagnosis and industrial applications. The use of gold nanoparticle-based detection methods for organophosphates has the potential to provide a rapid, sensitive and reliable tool for the detection and monitoring of these toxic compounds in various fields.

Keywords: Gold nanoparticles; Detection; Organophosphate; Toxic chemicals; Clinical diagnosis

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1. INTRODUCTION

1.1. History of Gold Nanoparticles

Humans have used gold for thousands of years with evidence of gold objects dating back to ancient Egypt, Mesopotamia and South America. Gold has been used for decoration, jewelry and even in medicine (Hauptmann et al. 2018). In the late 19th century, Michael Faraday observed the red color of gold nanoparticles in colloidal solutions, but their properties and applications were not fully understood at the time (Faraday 2020). In the researchers began to develop methods for synthesizing gold nanoparticles, such as the reduction of gold salts with reducing agents or the use of surfactants (Turkevich et al. 2020). The gold nanoparticles accelerated with advances in microscopy and spectroscopy techniques. Researchers began to explore the unique physical and chemical properties of gold nanoparticles, such as their surface plasmon resonance, which makes them useful for sensing and imaging applications (Daniel and Astruc 2004). Today, gold nanoparticles are widely used in biomedical imaging, drug delivery, and diagnostics, as well as in environmental monitoring and sensing applications. Gold nanoparticles are particles of gold with diameters ranging from a few nanometers to hundreds of nanometers. Due to their unique physical and chemical properties, gold nanoparticles have found numerous applications in a variety of fields, including biomedicine, catalysis, environmental sensing, and electronics (Daniel and Astruc 2004). One of the most well-known properties of gold nanoparticles is their surface plasmon resonance which is a collective oscillation of electrons on the nanoparticle surface in response to incident light. The SPR of gold nanoparticles results in their distinctive optical properties, such as their intense color and strong light scattering (Jain et al. 2006). In addition to their optical properties, gold nanoparticles also have a high surface area-to-volume ratio and a large number of surface atoms, which make them highly reactive and useful for catalysis and sensing applications. Gold nanoparticles can also be functionalized with a variety of molecules, such as antibodies or DNA strands, for targeted delivery or sensing (Daniel and Astruc 2004). Gold nanoparticles have been widely used in the development of sensors for the detection of a variety of targets, including metal ions, proteins, DNA, and small

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molecules. The use of gold nanoparticles in sensing is based on their unique optical and electronic properties, which allow for the development of sensitive and selective detection platforms (Kumar et al. 2023). One of the most commonly used sensing strategies with gold nanoparticles is based on the interaction between the target molecule and a specific probe molecule that is attached to the surface of the gold nanoparticle. When the target molecule binds to the probe molecule, it causes a change in the surface properties of the gold nanoparticle, such as its size or shape, which can be detected using various techniques, such as colorimetry, fluorescence, or electrochemistry (Anker et al. 2008). In addition to probe-based sensing, gold nanoparticles have also been used in label-free sensing, where the interaction between the target molecule and the gold nanoparticle surface is detected directly, without the need for a specific probe molecule. This can be achieved using techniques such as surface-enhanced Raman spectroscopy or localized surface plasmon resonance (Elahi et al. 2018). The use of gold nanoparticles in sensing offers many advantages, including their high sensitivity, selectivity, and versatility, as well as their ease of functionalization and stability. These properties have made gold nanoparticles a popular choice for the development of sensors for a wide range of applications, including environmental monitoring, food safety, and biomedical diagnostics (Qin et al. 2018).

2. CONCEPT OF ORGANOPHOSPHATE DETECTION

Organophosphates are a class of chemicals that are widely used as insecticides, herbicides, and fungicides in agriculture and other industries (Süntar 2020). The detection of organophosphates in environmental samples, such as water, soil, and food, is of great importance for ensuring public health and safety. There are several methods for the detection of organophosphates, including chromatography, mass spectrometry, and enzymatic assays. However, these methods are often time-consuming, require expensive equipment, and may not be suitable for field-based applications (Alex and Mukherjee 2021). Recently, there has been increasing interest in the use of biosensors and nanosensors for the rapid and sensitive detection of organophosphates. Biosensors are devices that use biological molecules, such as enzymes or antibodies, to detect a target molecule, while nanosensors use nanoparticles, such as gold nanoparticles or quantum dots, to detect the target molecule. These technologies have the potential to provide fast, portable, and highly sensitive detection of organophosphates in a variety of environmental samples (Rhouati et al. 2018). Organophosphates are a class of highly toxic chemicals that are widely used as pesticides, herbicides, and other industrial chemicals. These compounds pose a significant threat to human health and the environment, as they can cause a range of health effects, including neurological damage, respiratory failure, and even death (Qin et al. 2021). The detection of organophosphates in environmental samples, such as water, soil, and food, is of great importance for ensuring public health and safety. Exposure to organophosphates can occur through ingestion of contaminated food or water, inhalation of contaminated air, or direct contact with the skin. Therefore, the development of sensitive and reliable methods for detecting these chemicals is critical for protecting human health and the environment (Süntar 2020). In addition, the detection of organophosphates is important for environmental monitoring and control. Organophosphate contamination can lead to the degradation of soil and water quality, loss of biodiversity, and ecological imbalances. Therefore, it is essential to monitor the levels of these compounds in the environment to prevent or mitigate their harmful effects (Agrawal et al. 2021). Furthermore, the detection of organophosphates is also important for food safety and quality control. Organophosphate residues in food can pose a risk to human health, and their presence can lead to trade restrictions and loss of market access for food products. Therefore, the development of sensitive and reliable methods for detecting organophosphates in food is essential for ensuring food safety and quality (Huang and El-Sayed 2010). Fig. 1 shows the stabilizing agents of gold nanoparticles for the detection of organophosphates.

3. SYNTHESIS OF GOLD NANOPARTICLES

Gold nanoparticles can be synthesized using various methods, including physical, chemical, and biological methods. These methods vary in complexity, cost, and scalability, and each has its advantages and limitations (Hammami and Alabdallah 2021). In this method, gold ions are reduced to gold nanoparticles using a reducing agent, such as sodium borohydride or citrate. This method is simple, easy to control, and can produce monodisperse nanoparticles of different sizes and shapes (Lee et al. 2021). In this method, gold nanoparticles are synthesized using UV or visible light in the presence of a reducing agent, such as citrate or hydrazine. This method is fast, scalable, and can produce nanoparticles of different sizes and shapes (Zhang et al. 2011).In this method, gold nanoparticles are synthesized by reducing gold ions at the cathode of an electrochemical cell. This method is simple, cost-effective, and can produce nanoparticles of different sizes and shapes (Song et al. 2017). In this method, gold nanoparticles are synthesized using a microwave irradiation technique, which can produce nanoparticles of different sizes and shapes with high yield and purity (Hassanisaadi et al. 2021). In this method, gold nanoparticles are synthesized using biological agents, such as bacteria, fungi, plants, or their extracts. This

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method is eco-friendly, cost-effective, and can produce nanoparticles of different sizes and shapes with high biocompatibility (Zhang et al. 2020).

The various methods for synthesizing gold nanoparticles

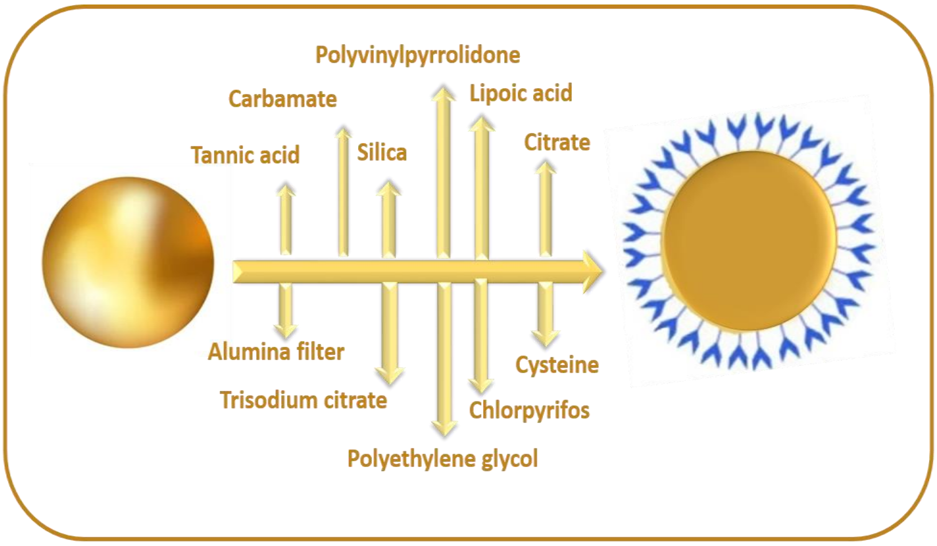

Fig. 1: Stabilizing agents of gold nanoparticles for the detection of organophosphates.

3.1. Gold Nanoparticles are Suitable for Organophosphate Detection

Gold nanoparticles (AuNPs) are suitable for organophosphate detection due to their unique optical and surface properties, which allow them to interact with organophosphate molecules in specific ways. Organophosphates are a class of highly toxic compounds that are widely used as pesticides, nerve agents, and chemical warfare agents. Detecting these compounds is crucial for ensuring public health and safety, as well as for environmental monitoring (Che Sulaiman et al. 2020). Gold nanoparticles exhibit a strong surface plasmon resonance (SPR) effect, which is a collective oscillation of electrons on the surface of the nanoparticles in response to incident light. This effect causes the nanoparticles to absorb and scatter light at specific wavelengths, depending on their size, shape, and surrounding environment (Do et al. 2020). By functionalizing the surface of gold nanoparticles with specific ligands or receptors, the nanoparticles can be made to selectively bind to organophosphate molecules, which alter their SPR effect and enable their detection (Aldewachi et al. 2018). Gold nanoparticles can amplify the detection signal by several orders of magnitude due to their large surface area and high extinction coefficients. This property makes them highly sensitive and enables the detection of low concentrations of organophosphate molecules in complex matrices, such as food, water, or soil (Zhou et al. 2020). Gold nanoparticles are biocompatible and non-toxic, which makes them suitable for use in biological and environmental applications. They can be easily functionalized with various biomolecules, such as enzymes, antibodies, or aptamers, which enables their selective detection of organophosphate molecules (Rónavári et al. 2021).

4. FUNCTIONALIZATION OF GOLD NANOPARTICLES

4.1. Process of Functionalizing Gold Nanoparticles

Functionalizing gold nanoparticles (AuNPs) involves attaching specific ligands or biomolecules to the surface of the nanoparticles to enable their selective detection of target analytes, such as organophosphate molecules. The process of functionalizing AuNPs typically involves several steps, including surface modification, ligand or receptor attachment, and characterization (Ielo et al. 2021). The surface of gold nanoparticles is usually modified with a layer of thiol or amine functional groups to create a stable, biocompatible surface for further functionalization. This can be achieved using thiolated or aminated ligands, such as mercaptoundecanoic acid or cysteamine, which form strong covalent bonds with the gold surface. Alternatively, the surface can be modified with a layer of polyethylene glycol or other polymers to improve stability and reduce nonspecific binding (Liu et al 2021). The surface of the modified gold nanoparticles can be functionalized with specific ligands or receptors that enable their selective detection of target analytes. Ligands can be small molecules, such as aptamers, peptides, or antibodies that bind to the target analyte with high affinity and selectivity (Byun 2021). Receptors can be biological molecules, such as enzymes or membrane proteins that recognize and catalyze the conversion of the target analyte into a detectable signal. The ligands or receptors can be attached to the surface of the modified gold

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nanoparticles through covalent or noncovalent interactions, such as electrostatic attraction or hydrogen bonding (Kozitsina et al. 2018).

4.2. Characterization

The functionalized gold nanoparticles should be characterized to ensure their stability, biocompatibility, and selectivity. Characterization methods may include UV-Vis spectroscopy, transmission electron microscopy, dynamic light scattering, zeta potential measurements, or surface plasmon resonance spectroscopy. These methods can provide information on the size, shape, surface charge, and binding affinity of the functionalized gold nanoparticles (Liu et al 2021). Functionalization of gold nanoparticles (AuNPs) can improve organophosphate detection in several ways. Functionalization can enable the selective detection of specific organophosphate molecules by attaching ligands or receptors that recognize and bind to the target analyte. For example, aptamers or antibodies can be attached to the surface of AuNPs to selectively bind to specific organophosphate molecules. This improves the specificity of the detection and reduces false positives (Hua et al. 2021). Functionalization can improve the sensitivity of the detection by amplifying the signal generated by the binding of the target analyze. For example, enzymes or catalytic nanoparticles can be attached to the surface of AuNPs to catalyze the conversion of the target analyze into a detectable signal. This amplifies the signal and improves the limit of detection (Chen et al. 2020). Functionalization can improve the stability of AuNPs in complex sample matrices, such as biological fluids or environmental samples, by reducing nonspecific binding and aggregation. For example, PEGylating of AuNPs can improve their stability and reduce nonspecific binding by creating a hydrophilic surface that repels biomolecules (Bressan et al. 2019). Fig. 2 shows the Mechanism of detection of organophosphate by Gold nanoparticles.

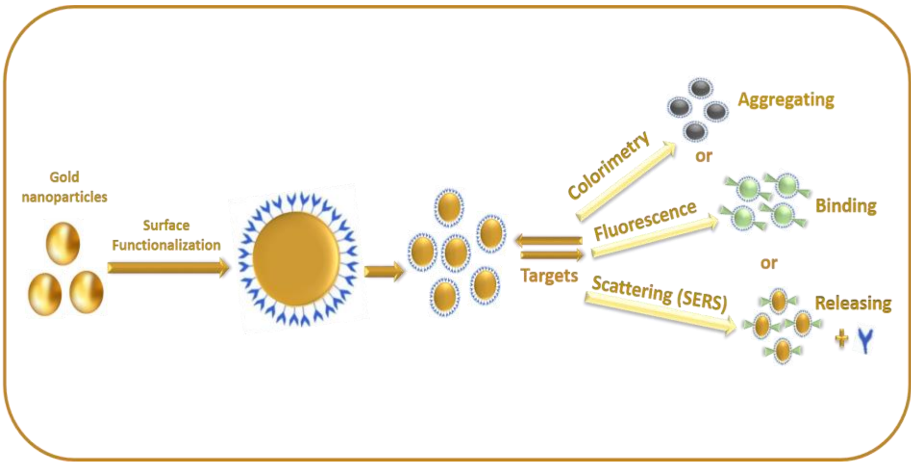

Fig. 2: Mechanism of detection of organophosphate by gold nanoparticles.

5. DETECTION OF ORGANOPHOSPHATES USING GOLD NANOPARTICLES

5.1. The Process of Organophosphate Detection using Gold Nanoparticles

The process of organophosphate detection using gold nanoparticles (AuNPs) typically involves the following steps.

AuNPs are synthesized using various methods, such as citrate reduction, seed-mediated growth, or microemulsion techniques. The size, shape, and surface properties of the AuNPs can be controlled during synthesis to optimize their properties for detection (Zahra et al. 2021). The AuNPs are functionalized with ligands, receptors, or enzymes that recognize and bind to the target organophosphate molecules. The functionalization can be achieved through various methods, such as covalent attachment, adsorption, or electrostatic interaction (Hua et al. 2021).The functionalized AuNPs are incubated with the sample containing the target organophosphate molecules. The binding of the target analyte to the functionalized AuNPs causes a change in the optical or electrical properties of the nanoparticles, which can be measured using various techniques, such as UV-vis spectroscopy, colorimetry, or electrochemical sensing (Kaur and Singh 2020). The measurement of the signal generated by the functionalized AuNPs is analyzed to determine the concentration of the target organophosphate molecules in the sample. This can be done using various data analysis methods, such as calibration curves, statistical analysis, or machine learning algorithms (Bajpai et al. 2018).

6. ADVANTAGES OF USING GOLD NANOPARTICLES FOR DETECTION

The use of gold nanoparticles (AuNPs) for the detection of organophosphates offers several advantages. AuNPs exhibit strong surface plasmon resonance (SPR) signals, which enable their detection at very low concentrations, in

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the range of picomolar to femtomolar. This high sensitivity is crucial for the detection of organophosphates, which are often present at trace levels in environmental or biological samples (Hua et al. 2021). AuNPs can be functionalized with specific ligands, receptors, or enzymes that recognize and bind to the target organophosphate molecules. This functionalization enhances the selectivity of the detection method, as the AuNPs only respond to the target analyte and not to other interfering compounds (Li et al. 2018). The detection of organophosphates using AuNPs can be achieved in a matter of minutes, making it a rapid and efficient method compared to other conventional analytical methods (Kaur and Singh 2020). The synthesis and functionalization of AuNPs are relatively simple and inexpensive compared to other detection methods, such as mass spectrometry or chromatography (Adamo et al. 2020). AuNP-based detection methods can be easily integrated into microfluidic devices, which enable miniaturization and automation of the detection process. This can lead to high-throughput analysis and reduced sample volumes (Zhao et al. 2023). Table 1. Show the Gold nanoparticles stabilization of organophosphate, their method, and results.

Table 1: Gold nanoparticles stabilization of organophosphate (OP), their method, and results

AuNPs Size (nm)	OP	Stabilizing Agent	Detection Limit (ppm)	Stabilization Method	Results	References
10	Hydrolase	Polyethylene glycol (PEG)	8.04	Ultrasonic homogenization	High colloidal stability and enhanced catalytic activity in organophosphate degradation	Tseng et al. (2020)
5	Sodium Arsenite	Lipoic Acid (LA)	0.50	Chemical reduction	Improved selectivity and sensitivity in detecting paraoxon, an organophosphate pesticide	Qin et al. (2018)
20	Malathion	Cysteine	0.05	Seed-mediated growth	Enhanced adsorption capacity and selective removal of organophosphate pesticides from water	Zhu et al. (2021)
15	Sumithion	Polyvinylpyrrolidone (PVP)	0.1	Microwave-assisted method	Improved thermal stability and catalytic activity in organophosphate degradation	Hu et al. (2020)
30	Sodium Citrate	Citrate	0.01	Turkevich method	High colloidal stability and efficient removal of methyl parathion, an organophosphate pesticide, from water	Arya et al. (2019)
3	Fenitrothion	Silica	0.45	Coating	Stable for 2 years	Yang et al. (2014)
5	Chlorpyrifos	Chlorpyrifos	0.01	Sodium citrate	Stability of AuNPs and retention of chlorpyrifos	Rovina et al. (2021)
30	Diazinon	Carbamate	0.32	Polyethylene glycol	Stability of AuNPs and retention of Diazinon	Mehta et al. (2022)
5	Malathion	Alumina Filter	1	Polyvinyl alcohol	Increase in absorbance intensity with increasing Malathion concentrations	Liang et al.(2021)
20	Dihydrate	Trisodium Citrate	1.0	Citrate Reduction	High organophosphate Binding	Lu et al. (2021)
50	Parathion	Tannic Acid	10	Tannic Acid Coating	High stability and selectivity	Tseng et al. (2020)
30	Serotonin	Lipoic Acid	0.5	Lipoic Acid Modification	Affinity detection of low concentration of organophosphate	Kudr et al. (2017)
15	Thiodicarb	Glutathione	0.005	Glutathione Functionalization	Improved sensitivity and stability	Oun and Rhim (2015)
3	Malathion	Diazinon	0.32	Chitosan	Decrease in malathion degradation rate	Meng et al. (2020)
5	Dichlorvos	Thiram	0.5	Polyvinylpyrrolidone	Increase in dichlorvos half life	Shanmugaraj et al. (2020)

6.1. The Sensitivity and Selectivity of the Detection Method

The sensitivity and selectivity of the detection method based on gold nanoparticles (AuNPs) for organophosphates are crucial for its effectiveness as a detection tool. Sensitivity refers to the ability of the method to detect low concentrations of the target analyte. AuNPs exhibit strong surface plasmon resonance signals, which enable their detection at very low concentrations, in the range of picomolar to femtomolar (Che Sulaiman et al. 2020). This high sensitivity is critical for the detection of organophosphates, which are often present at trace levels in environmental or biological samples. Selectivity, on the other hand, refers to the ability of the method to distinguish the target analyte from other interfering compounds. Functionalization of the AuNPs

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with specific ligands, receptors, or enzymes that recognize and bind to the target organophosphate molecules enhances the selectivity of the detection method (Hua et al. 2021). The functionalized AuNPs only respond to the target analyte and not to other interfering compounds. This selectivity is critical for the accuracy and reliability of the detection method, especially in complex matrices where there may be multiple compounds present (Hua et al. 2021).

7. CONCLUSION

The use of gold nanoparticles for the detection of organophosphates, and its importance in various applications such as environmental monitoring and food safety. The history and various methods of synthesizing gold nanoparticles were also briefly introduced. The advantages of using gold nanoparticles for organophosphate detection were highlighted, including their high sensitivity and selectivity. The process of functionalizing gold nanoparticles was explained, and how it can improve organophosphate detection. Finally, the process of organophosphate detection using gold nanoparticles was described, and how the sensitivity and selectivity of the detection method are critical for its effectiveness. The use of gold nanoparticle-based detection methods for organophosphates has a wide range of potential applications, including. Organophosphate pesticides are widely used in agriculture and can pose a significant risk to the environment. The use of gold nanoparticle-based detection methods can help in the detection and monitoring of these pesticides in soil, water, and air. Organophosphates are also used in the production of fruits and vegetables. The use of gold nanoparticle-based detection methods can help in the detection of these pesticides in food products, ensuring their safety for consumption. Organophosphates are also used as chemical warfare agents and can pose a significant threat to human health. The use of gold nanoparticle-based detection methods can help in the detection of these agents in biological fluids, such as blood and urine. Organophosphates are also used in various industrial applications, such as oil refining and plastics production. The use of gold nanoparticle-based detection methods can help in the monitoring and detection of these compounds in industrial settings. In addition to these applications, gold nanoparticle-based detection methods can also be used in the development of new drugs and therapies for the treatment of diseases caused by organophosphate exposure. The high sensitivity and selectivity of these detection methods make them a promising tool for the detonation and monitoring of organophosphates in various fields.

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