Towards the Detection of Lead Contaminates in Water Using Functionalized Gold Nanoparticles

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Abstract

Lead contamination poses serious health and environmental risks. In water, lead is dangerous because it is colorless, odorless, and tasteless. Currently, there are few easy methods of detecting lead in water that can be done without the use of sophisticated equipment. This research is to review the current methods of using different functionalized gold nanoparticles (AuNPs), which exhibit a colorimetric response in the presence of lead contaminated water, in the field. At present, there are several methods of functionalizing gold nanoparticles for the detection of lead, but many of these methods require complex procedures and expensive components. Here, we will focus on two emerging nanoparticle functionalizers, 11-mercaptoundecanoic acid (MUA) and glutathione (GSH). Future applications of nanoparticles functionalized with these compounds would involve dispersing them in a membrane, which could be used anywhere from household faucets to water treatment plants, and could act as a simple, cost-effective sensing device in the presence of lead contamination

Why Gold Nanoparticles?

Localized Surface Plasmon Resonance

Free electrons on the surface of gold nanoparticles oscillate at a specific wavelength in resonance with incident light. The wavelength of these oscillations lie in the visible range of the electromagnetic spectrum. These wavelengths, and the resultant color of solution, can change depending on:

- A change in the dielectric constant of the solvent
- A change in the diameter of the nanoparticles
- Aggregation

Certain functionalizers can be added to the surface of the gold nanoparticles which will aggregate in the presence of lead, which will lead to a visible color change. We can therefore use gold nanoparticles as a detection method for lead contamination in water.

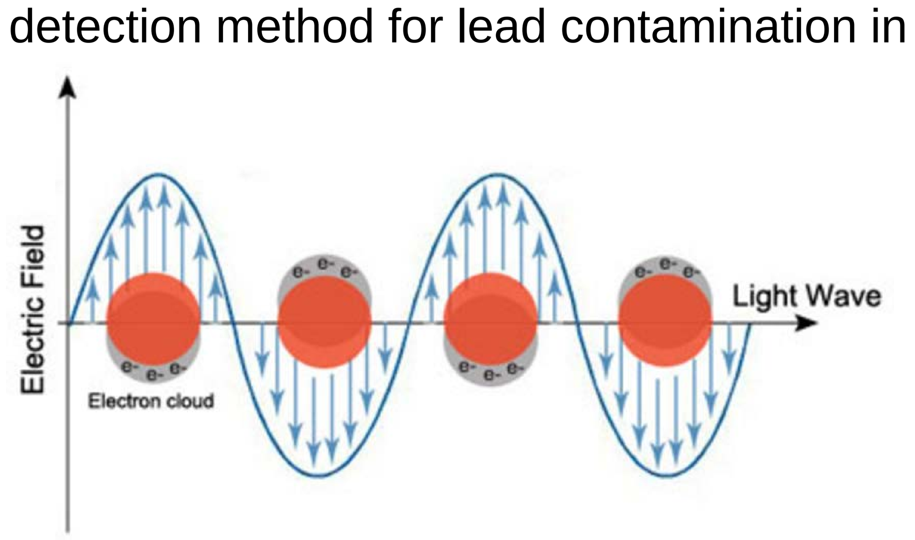
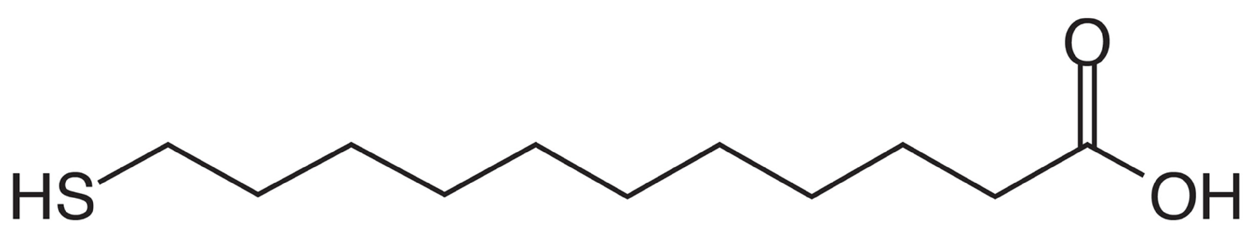


Figure 1: Basics of localized surface plasmon resonance (LSPR) of gold nanoparticles due to collective oscillation of surface electrons with incident light at a specific wavelength.

Acknowledgments: Tennessee Technological University, Nanofactory

11-Mercaptoundecanoic Acid capped Gold Nanoparticles (MUA-AuNPs)



Used by:

- Kim, Y., Johnson, R. C., & Hupp, J. T. "Gold Nanoparticle-Based Sensing of "Spectroscopically Silent" Heavy Metal Ions." [2]
- Fan, Chunhui, Shijiang He, Gang Liu, Lianhui Wang, and Shiping Song. "A Portable and Power-Free Microfluidic Device for Rapid and Sensitive Lead (Pb2+) Detection." [3]

Features:

- Upon addition of Pb^{2+}, a chelation process occurs leading to aggregation of AuNPs which yields a colorimetric response
- Color change confirmed by UV-Vis
- Addition of EDTA reverses Aggregation process and removes excess Pb^{2+} [2]
- Detection limit for Pb^{2+} found to be 400 μM using colorimetry and 25 μM using Hyper Rayleigh Scattering[2]

Disadvantages:

- -COOH groups may not be exclusively selective to Pb^{2+}

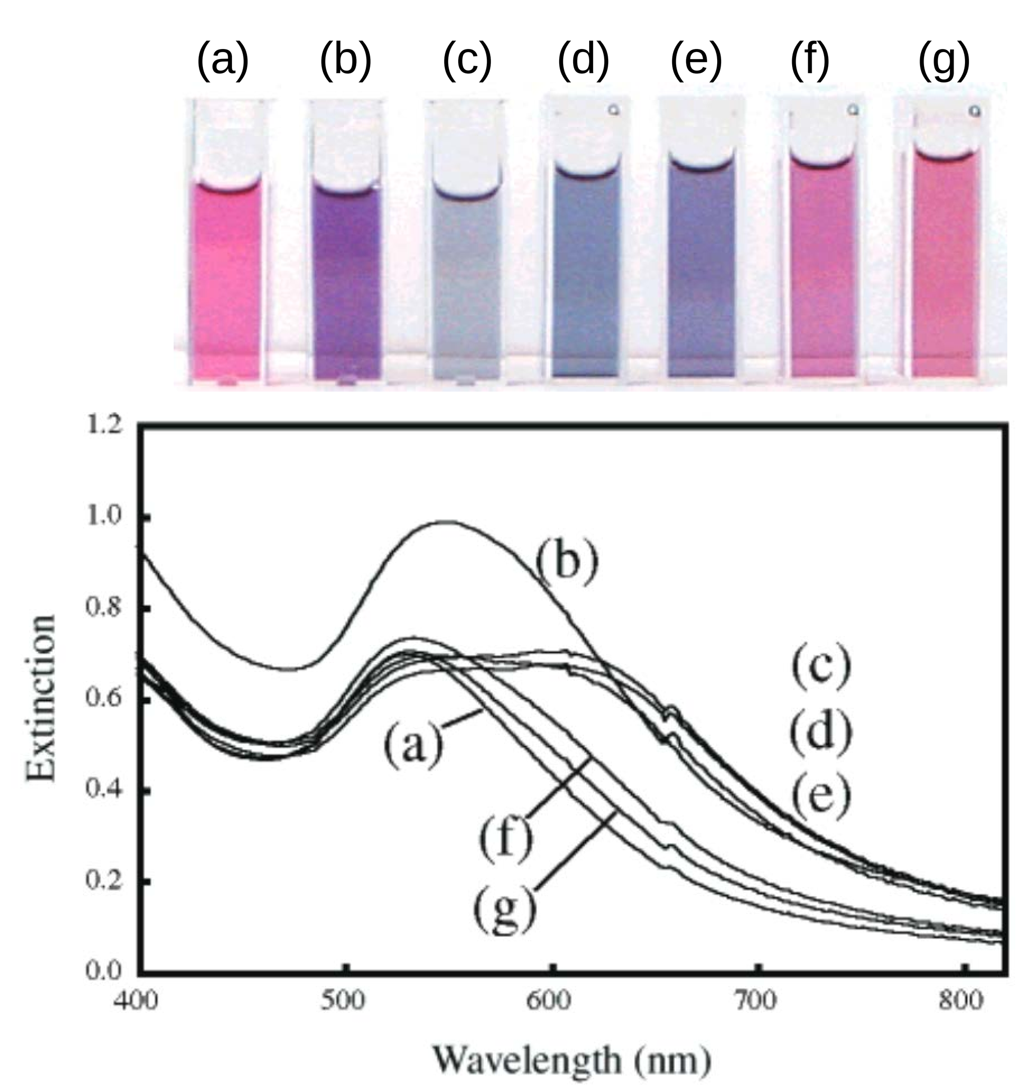
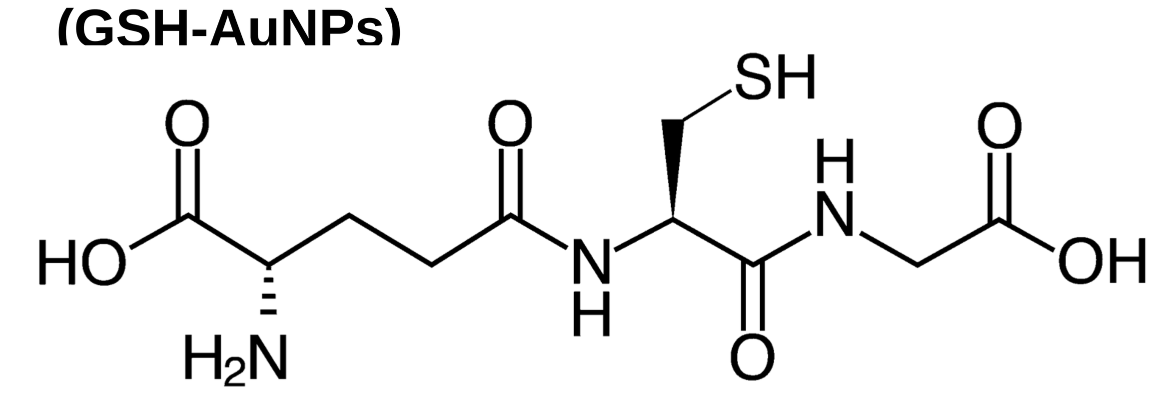


Figure 2: Colorimetric responses and UV-Vis spectra of MUA-AuNPs. (a)MUA-AuNP, (b)MUA-AuNP/ 0.67mM Pb^{2+} (c)-(g) increasing amounts of EDTA, 0.191, 0.284, 0.376, 0.467, 0.556 mM, respectively[2]

Glutathione Capped Gold Nanoparticles (GSH-AuNPs)



Used by:

- Beqa, L., Singh, A. K., Khan, S. A., Senapati, D., Arumugam, S. R., & Ray, P. C. "Gold Nanoparticle-Based Simple Colorimetric and Ultrasensitive Dynamic Light Scattering Assay for the Selective Detection of Pb(II) from Paints, Plastics, and Water Samples." [4]
- Chai, F., Wang, C., Wang, T., Li, L., & Su, Z. "Colorimetric Detection of Pb2+ Using Glutathione Functionalized Gold Nanoparticles" [5]

Features:

- Detection limit for Pb^{2+} found to be 1 ppm[4] and 100 nM[5] using colorimetry and 100 ppt using Dynamic Light Scattering [4]
- GSH-AuNPs shown to be selective towards Pb^{2+} when in basic (pH = 8.0) solution[4] [5]

Disadvantages:

- May not be as selective when in neutral solution
- Colorimetric detection limit does not detect minimum amount of lead contamination in water set by Environmental Protection Agency (15 ppb)[4]

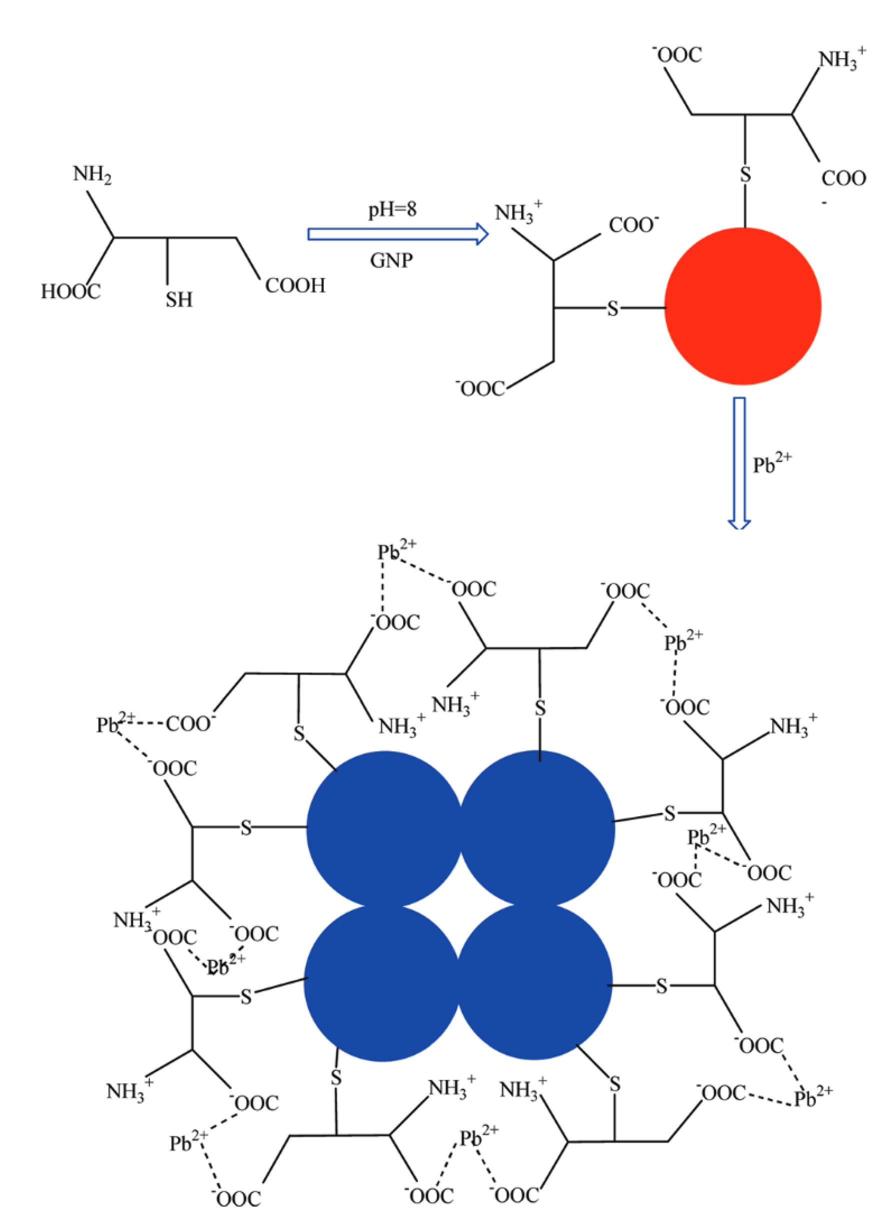


Figure 3: Process involving AuNP modification by GSH and aggregation in the presence of Pb^{2+} [4]

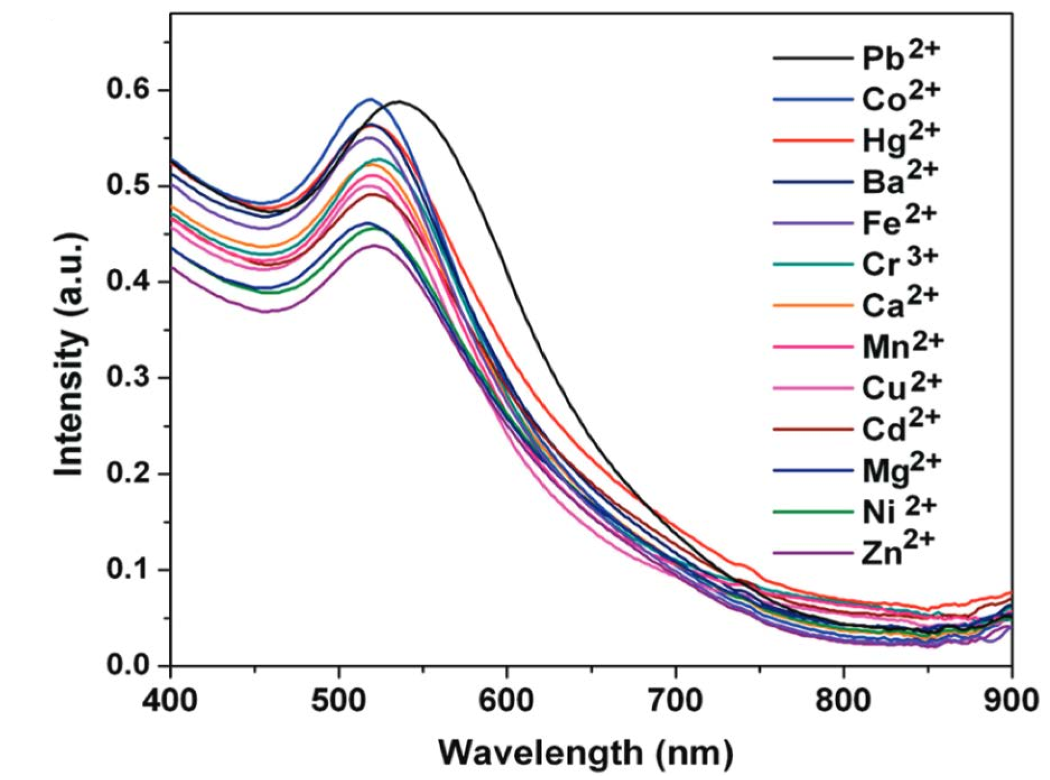


Figure 4: UV-Vis spectra of GSH-AuNPs containing 50 μM concentrations of various metal ions[5]

Future applications

1. Establish which functionalizer is the more selective and sensitive and the limits of detection of the functionalized AuNP
2. Investigate a method of dispersing the functionalized AuNPs into a membrane which will exhibit a colorimetric response in the presence of lead contaminated water.

References:

1) Gold Nanoparticle Properties - Cytodiagnostics. (n.d.). Retrieved March 27, 2017, from http://www.cytodiagnostics.com/store/pc/Gold-Nanoparticle-Properties-d2.htm
2) Kim, Y., Johnson, R. C., & Hupp, J. T. (2001). Gold Nanoparticle-Based Sensing of "Spectroscopically Silent" Heavy Metal Ions. Nano Letters, 1(4), 165–167.
3) Smith, A. M., Marbella, L. E., Johnston, K. A., Hartmann, M. J., Crawford, S. E., Kozycz, L. M., … Millstone, J. E. (2015). Quantitative Analysis of Thiolated Ligand Exchange on Gold Nanoparticles Monitored by 1H NMR Spectroscopy. Analytical Chemistry, 87(5), 2771–2778.
4) Beqa, L., Singh, A. K., Khan, S. A., Senapati, D., Arumugam, S. R., & Ray, P. C. (2011). Gold Nanoparticle-Based Simple Colorimetric and Ultrasensitive Dynamic Light Scattering Assay for the Selective Detection of Pb(II) from Paints, Plastics, and Water Samples. ACS Applied Materials & Interfaces, 3(3), 668–673.
5) Chai, F., Wang, C., Wang, T., Li, L., & Su, Z. (2010). Colorimetric Detection of Pb2+ Using Glutathione Functionalized Gold Nanoparticles. ACS Applied Materials & Interfaces, 2(5), 1466–1470. https://doi.org/10.1021/am100107k