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# Recovery of Gold Nanoparticles from Industrial Waste using Electronic Plates by a Novel Reducing Agent and Continuous Approach

**Alireza Fotovat*, Alireza Feizbakhsh**
Department of Chemistry, Islamic Azad University, Tehran, Iran

***Corresponding author:** A Fotovat, Department of Chemistry, Islamic Azad University, Tehran, Iran. E-mail: Ali.fb1973@yahoo.com

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## Abstract

**Electronic plates are among the common and exploitable sources of gold that are widely used in several types of industry. Gold (Au) element is an electronic particle that can be used in a variety of applications such as medicine, engineering, and biology by adjusting its surface functionality and particle size. A noteworthy feature of this material is the changes in its properties that occur with the variation in its particle size. In other words, by transferring its particle size from micrometer to nanometer, the surface-area-to-volume ratio increase such that new structural properties emerge, change, or improve. Various physical, chemical, and biological methods are used to make these particles. Among these methods, chemical and multi-material combinations are used as reductants. Tests such as Fourier-Transform Infrared (FTIR) spectroscopy, X-Ray Diffraction (XRD), and Field Emission Scanning Electron Microscopy (FESEM) have confirmed high-quality production and proper extraction of gold particles on a nanometer scale from electronic plates.**

***Keywords:** Gold recovery; Waste electronics; Nano dimension; Gold crystals*

## Introduction

Recycling of precious metals such as silver, gold, and platinum is widely practiced by various industries. Today, recycling these metals from secondary sources is highly regarded because of numerous applications and high cost of it. Among the benefits of secondary resources are profitability, employment, and environmental assistance so that the use of scrap will reduce the harmful reactions caused by the presence of these substances in the environment. The United Nations E-Scrap Monitor shows that the world has 44,700 billion unused electronic devices including mobile phones, computers, and televisions. Inside each of these devices, there are a considerable amount of valuable minerals. However, only 20% of them are recycled, and the rest are abandoned [1]. In this regard, the use of metals in the medical field will lead to the detection of diseases such as cancer using the concept of reduced toxicity, selectivity, and high viability. Various chemical, physical, and biological methods are available to recycle these particles from electronic scrap plates and secondary sources. In the conventional chemical method, a reductant such as Citrate or Sodium Borohydride is used. In recent years, the use of organic salts and ionic liquids has also been considered. Among these methods, the micro emulsion method has attracted much attention owing to its more uniform particle size and morphology. Studied the effects of various reductants for recovering gold from electronic computer plates. Recovered gold particles by the green synthesis method using a reductant by the chemical method. In the present study, we used an iron compound, which is the main gold reductant after zinc, to recover the particles. This material has a high voltage difference with gold and can achieve a good result in the recovery process. Reported an effective, simple and highly selective nylon-12-based three-dimensional (3D)-printed scavenger objects for gold recovery from an aqua regia extract of a printed circuit board waste. Using the easy to handle and reusable 3Dprinted meshes or columns, gold can be selectively captured both in a batch and also continuous processes by dipping the scavenger into the solution or passing the solution containing gold through the column [2]. The possibility to optimize the shape, size, and flow properties of scavenger objects with 3D printing enables the gold scavengers to match the requirements of any processing plants. The binding mechanism between the amide group and has been estimated to be related to hydrogen bonding between the hydrogen of the protonated amide group and the chlorides of the gold complex. The cause for selectivity toward gold could potentially be because of 1 charge of the complex and square planar geometry. Synthesized a novel chiral 3D functional channels with thio-alkyl chains derived from the natural amino acid L-methionine. The well-known strong affinity of gold for sulfur derivatives, together with the extremely high flexibility of the thioether "arms" decorating the channels, account for a selective capture of gold (III) and gold (I) salts in the presence of other metal cations typically found in electronic wastes. The X-ray single-crystal structures of the different gold adsorbates AuIII1 and AuI1 suggest that metal capture occurs in a metal ion recognition process somehow mimicking what happens in biological systems and protein receptors. Both AuIII and AuI1 display high activity as heterogeneous catalyst for the hydro alkoxylation of alkynes, further expanding the application of these novel hybrid materials. Another objective of this study is to extract gold particles on a nanometer scale. To synthesize nanoscale materials, different approaches such as top-down, bottom-up, and nanostructured models are available. In the top-down approach, nanoparticles are made by modifying and forming a mass material. In this method, a large-scale material (in macrometer or micrometer dimensions) is selected, and a nano-sized product is achieved by reducing its size and shape. In the bottom-up approach, the finished product is made up of simpler materials, and a nano-sized product is achieved by bringing together atoms and molecules (with dimensions smaller than nanoscale). As mentioned earlier, there are various methods for making gold nanoparticles (AuNPs). A novel approach is utilized in this research to prepare AuNPs using gold electronic scrap, Aqua regia as a solvent, and ferrous sulfate as a gold reductant.

## Literature Review

Hydrochloric acid 37%, electronic plates, Aqua regia, urea (Merck), ferrous sulfate (Merck), and deionized water were used without additional purification and upon arrival. In this study, reductants (reducing compounds) were used for the extraction of Au NPs. First, five electronic plates were boiled in 200 ml of 1 M hydrochloric acid solution at 100℃ for 15 min. After cooling, the solution was passed through a filter and gold plates were separated. The gold plates separated in the first stage were mixed with Aqua regia and subjected to stirring (for 10 min) at 100℃ until the full dissolution of gold in the solution. After 10 min, the solution was cooled to 70℃ and then [NO3]- was formed. To neutralize the solution, 200 ml of 1 M urea was added to the said solution and stirring was continued for 10 min at 100℃ until the reaction between urea and gold was complete. Next, 150 ml of 0.1 M ferrous sulfate was added to the system, and the resulting solution was stirred for 15 min. The solution was finally filtered and washed, and the resulting solid containing Au NPs was dried for 24 h under ambient conditions. An overview of the electronic plates used and the solid gold extracted. Furthermore, reactions 1 to 3 (dissolution of gold in hydrochloric acid) were carried out to make Au NPs.

The DR 500 UV-Vis (UV-Visible Spectroscopy) Laboratory Spectrophotometer Spectrum RXI was used to investigate the presence and successful production of Au NPs. The size of the synthesized nanoparticles was also investigated using the HORIBA Light Diffraction Particle Size Analyzer LB-550. Morphology, microstructure, and size of the synthesized Au NPs were analyzed using a Digital Scanning Electron Microscope. XRD (Philips PW-180) test was also applied to find out the crystalline structure and chemical composition of the synthesized nanoparticles. Finally, to observe the mass and intra-structural morphology of the synthesized nanoparticles, Transmission Electron Microscopy test was used [3]. Moreover, elements were tested to ensure the presence of gold in the system after being extracted from electronic plates. The results confirm the presence of gold and copper in the system after the synthesis of nanoparticles, indicating their proper synthesis and extraction. The presence of copper in the results is also due to its presence in the electronic plate structure.

The nanoparticles produced by the subtraction method using a reductant exhibit a peak of about 400–700 nm in UV visible spectroscopy. As shown the peak at 670 nm supports this claim. Therefore, it can be stated that the reductant of ferrous compounds was able to contribute to the extraction of Au NPs from electronic plates. To obtain optimum quality images, thin smooth specimens were prepared and adhered using carbon adhesive to the specimen holder and inserted together with gold into the deposition chamber. Next, the specimens were placed in the compartment and exposed to the electron beam under vacuum. As can be seen hemispherical Au NPs were well synthesized. The semicircular nanoparticles have a homogeneous smooth surface and uniform particle size distribution. In some areas, they became clumped, indicating the integration of several particles. Furthermore, by measuring the particle, the presence of particles on a nanometer scale can be clearly observed. Therefore, it can be stated that the synthesis method is of good quality such that homogeneous hemispherical particles are synthesized.

As shown in previous sections, gold nanoparticles derivation process was an effective one and can be used as a useful method for gold extraction. In next step, parametric study should be executed on various variables and their effect on gold recovery from waste electronics [4]. For this purpose, calibration plots should be plotted and driven. For aforementioned objective, a standard solution of gold nanoparticles (100 ppm) has been prepared and by assistance of atomic adsorption technique, adsorption amount for all samples was recorded. Using this standard solution, solutions with different concentration of 10,20,30,40 and 50 ppm were prepared and adsorption peaks were recorded. The main reason for using calibration curves is concentration calculation in recovery process which has a great importance in this research. Besides gold concentration, gold adsorption at different concentrations was investigated. For this purpose, all parameters such as solution volume, pH, time and experiment temperature was assumed constant and the only non-constant variable was gold ion concentration. Experiment time was 30 minutes and concentration varies from 3 to 20 ppm of standard gold nanoparticles and pH was about for investigating volume effect, five solutions in different volume of 5,10,15,20 and 25 ml of gold standard solution have been prepared and all other parameters have assumed constant.[26] As it is obvious by increasing solution volume, recovery percent has been decreased [5].

## Conclusion

In this study, gold nanoparticles were extracted from electronic plates using a reductant made of ferrous compounds. The XRD results showed a crystalline structure with the peaks of (1 1 1) and (0 2 2) for the nanoparticles. UV-Vis spectroscopy also revealed a peak of the gold particle in the range of 400-700 nm. Finally, to ensure the morphology, microstructure, and size of the synthesized gold particles, SEM and TEM tests were performed. The results show that the Au NPs are homogeneous and uniform.

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