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Demonstration

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Demonstrating the Many Possible Colors of Gold-Supported Solid Nanoparticles

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Supporting Information

ABSTRACT: Introducing nanotechnology topics by demonstrating several colors of gold nanoparticles resulting from their size-dependent optical properties provides an easy, original, and appealing way to engage students in nanotechnology. In this classroom demonstration, solid gold nanoparticles were prepared by depositing gold nanoparticles on white solid supports, namely, TiO_2, $Mg(OH)_2$, $CaCO_3$, Al_2O_3, and MgO. The color of the gold nanoparticles was changed by adjusting the type of supports or the concentrations of gold(III) solution. The gold nanoparticles exhibited many different colors, including purple, pink, gray, brown, dark red, and red. Typically, the preparations can be completed in less than 1 h, which makes this a feasible classroom demonstration.

KEYWORDS: *High School/Introductory Chemistry, Demonstrations, First-Year Undergraduate/General, Colloids, Materials Science, Nanotechnology, Physical Properties*

INTRODUCTION

Nanomaterials have developed at a fast pace in recent years.[1−3] Furthermore, the concept of nanomaterials has been introduced in chemistry textbooks for high school and middle school studies. In high school and middle school chemistry textbooks of China, the term nanomaterials is mentioned more than six times. For example, in the junior middle school chemistry textbook,[4] the specific property of nanosized copper, that is, superplastic ductility, is introduced. In a chemistry textbook for high school (I),[5] the concept and development of nanomaterials and nanotechnology are presented. Although the properties of nanomaterials have been extensively introduced in high school and middle school chemistry textbooks of China, experiments relating to nanomaterials are not conducted for high school students. The textbooks only state that the size of nanoparticles is roughly equivalent to that of colloidal particles and that the principle and method of colloidal chemistry is useful for the development of nanotechnology.[5] This information was gathered from an experiment involving $Fe(OH)_3$ colloids. Thus, designing chemistry experiments is critical for providing students with class demonstrations on nanomaterials.[6]

Several excellent experiments about nanomaterials have been published for high school and undergraduate students in recent years. These reports describe experiments conducted by students relating to the preparation and study of the properties of iron oxide,[7] ZnO,[6] gold,[8] and silver[9] nanoparticles. The volume and shape of a nanoparticle determine its interaction with light and consequently its color. For example, nanosized particles of gold can exhibit diverse colors, whereas bulk gold, such as jewelry, appears yellow.[10] On the basis of the size-dependent optical properties of gold nanoparticles, several experiments relating to gold nanoparticles were designed for high school or college science courses.[8−10] In an experiment, the obtained nanoparticles were colloids and well dispersed in solution. To our knowledge, there are no educational papers on Au-supported nanostructures, that is, solid nanoparticles. Moreover, the gold nanoparticles in the reported experiments typically displayed a single color, usually red.[8] Thus, the spectrum of colors exhibited by gold nanoparticles has not been effectively demonstrated in such experiments.

Freshly prepared gold nanoparticles rapidly undergo agglomeration if they are not adequately stabilized by supporting the particles on a solid surface.[11] The primary role of the support is to inhibit coalescence and agglomeration of the gold nanoparticles. In this work, solid gold nanoparticles were prepared by depositing gold nanoparticles on white solid supports: TiO_2, $Mg(OH)_2$, $CaCO_3$, Al_2O_3, and MgO. Two methods were used to obtain gold nanoparticles of different colors. The prepared gold nanoparticles were purple, pink, gray, brown, dark red, or red. These preparations provide an avenue to introduce solid gold nanoparticles with different colors via a classroom demonstration.

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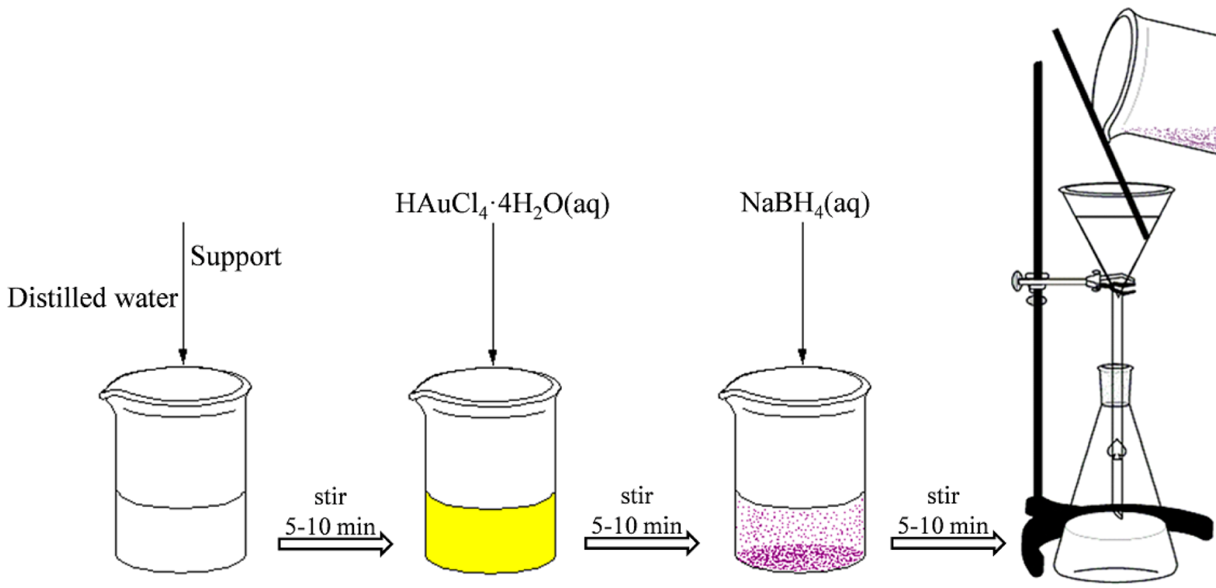

Figure 1. General procedure to prepare gold nanoparticles.

■ PREPARATIONS FOR THE DEMONSTRATION

Two methods were used for preparing gold nanoparticles of different colors. The materials and associated details are presented in the Supporting Information. The general procedure is shown in Figure 1. In Method 1, different types of supports were used, and the concentration of gold(III) solution was kept constant. In Method 2, the amount of distilled water (concentration of gold(III) solution) was varied while the type of supports employed was kept constant. As such, the instructor can select either method or both methods according to the practical situation of the laboratory. Method 2 is advised if the supports are scarce. Prior to the actual demonstration, it is advisable to prepare 1 wt % gold(III) solution and 0.1 mol/L sodium borohydride solution.

Method 1

The following steps entail multiple supports for demonstrating the different colors of gold nanoparticles.

Step 1: Add 30 mL of distilled water and 1 g of support (TiO_2, $Mg(OH)_2$, $CaCO_3$, Al_2O_3, or MgO) in a 100 mL beaker.

Step 2: After stirring for 5−10 min at room temperature, add 2.2 mL of aqueous gold(III) solution (1 wt %) to the above mixture.

Step 3: After stirring for 5−10 min at room temperature, add 2.5 mL of sodium borohydride solution (0.1 mol/L) to the beaker. After adding sodium borohydride solution, gold nanoparticles of different colors were obtained, depending on the type of supports employed. The formation of the gold nanoparticles resulted from a redox reaction between gold(III) and sodium borohydride (eq 1)[12]

$$2Au^{3+} + 6BH_4^- + 24H_2O \rightarrow 2Au + 6B(OH)_4^- + 21H_2 + 6H^+ \quad (1)$$

Step 4: After stirring for 5−10 min at room temperature, the supported gold nanoparticles were filtered.

The final gold nanoparticles obtained using different types of supports are shown in Figure 2.

Figure 2. Photograph of gold nanoparticles deposited on different supports.

Method 2

In Method 2, only one type of support (i.e., MgO) was used.

Step 1: Water at varying amounts of 2−30 mL was added to 1 g of support. Variations in the amount of water result in different gold(III) solutions of varying concentrations.

Steps 2−4 from Method 1 were undertaken subsequently.

The final gold nanoparticles obtained using varying amounts of water are shown in Figure 3.

■ HAZARDS

Gold(III) chloride hydrate may cause irritation to the skin, eyes, and respiratory tract, and may be harmful if swallowed or inhaled. Sodium borohydride is toxic and flammable. Sodium borohydride is a source of basic borate salt, which can be corrosive. Spontaneous ignition can result from solution of sodium borohydride in dimethylformamide. There is a

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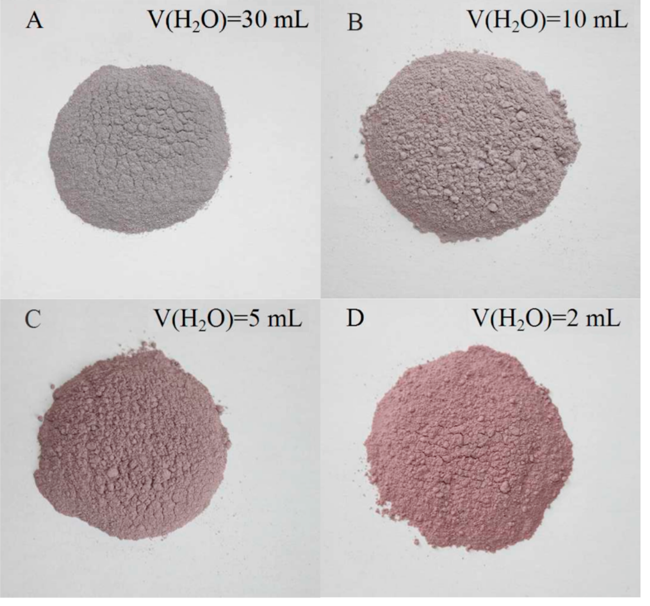

Figure 3. Photograph of Au/MgO using different volumes of distilled water.

flammability hazard associated with the production of hydrogen from the reaction between gold(III) and sodium borohydride (eq 1).

Common compounds may present unexpected health risks when they are fashioned as nanoscale building blocks. Particularly, for isolating gold nanoparticles, instructors should wear suitable eye protection, wear gloves, and work in a well-ventilated area (e.g., fume hood). Alternatively, the isolation step can be omitted and the gold nanoparticles can be observed in the reaction beaker.

■ RESULTS AND DISCUSSION

White supports were used in this work. After depositing the gold nanoparticles, different colors were observed. As shown in Figure 2, Au/TiO_2 was purple, Au/$Mg(OH)_2$ was pink, Au/$CaCO_3$ was gray, and Au/Al_2O_3 was red. Figure 3 shows images of Au/MgO prepared by varying the concentration of gold(III) solution. With increasing concentrations of gold(III) solution (corresponding to decreasing volumes of distilled water), Au/MgO changed from blue to gray−red, brown, and red. These results indicated that variations in the type of supports or concentrations of gold(III) solution could cause a corresponding color change of the gold nanoparticles. The different supports have different surface area and surface properties. The surface property affects the interaction between the gold particles and supports. Both the surface area and interaction influence the dispersion of gold particles on the support and the color of gold particles.[11] The mechanism associated with the relationship between the color and concentration of gold(III) solution can be referred to in an analytical chemistry textbook for undergraduates.[13] In order to show the size of gold nanoparticles, the scanning transmission electron microscope images and Au particle size distributions for gold nanoparticles were tested and are shown in the Supporting Information.

■ CONCLUSIONS

A simple and fast preparation of solid nanoparticles was developed. As observed, the color of the gold nanomaterials was dependent on either the support or gold(III) concentration. This preparation was typically completed in less than 1 h and, thus, is suitable for a class demonstration.

■ ASSOCIATED CONTENT

Supporting Information

Student handout and instructor notes associated with this demonstration. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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