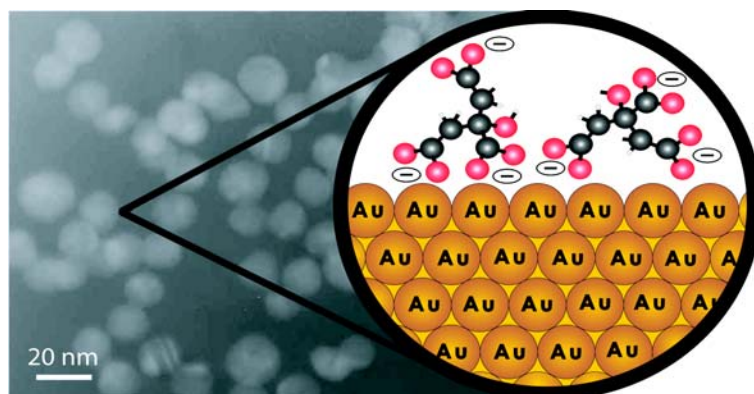


Color My Nanoworld

One nanometer is 10,000 times smaller than the diameter of a human hair. Can you imagine producing and using nanometer-sized materials? Nanoscience investigates the properties of these materials. By understanding these properties and learning how to utilize them, scientists and engineers can develop new types of sensors and devices. This technology could have a huge impact on diagnosing diseases, processing and storing information, and other areas.

Physical and chemical properties are size-dependent over a certain size range specific to the material and property. When a particle of gold metal is similar in size to wavelengths of visible light (400–750 nm), it interacts with light in interesting ways. The color of a gold nanoparticle solution depends on the size and shape of the nanoparticles. Consider this analogy: tapping a spoon on a glass bottle partly filled with water generates a sound. Vary the volume of water in the bottle and the tone of the sound changes. The tone is dependent on the volume of water. Similarly, the volume and shape of a nanoparticle determines how it interacts with light. Accordingly, this determines the color of a nanoparticle solution. For example, while a large sample of gold, such as in jewelry, appears yellow, a solution of nano-sized particles of gold can appear to be a wide variety of colors, depending on the size of the nanoparticles. In this Activity, you will work with a type of suspension called a colloid. As a suspension, a colloid is one phase of matter (in this case, a solid—gold) dispersed in another phase (in this case, a liquid). A colloid is distinguished from other types of suspensions by the smallness of the particles—so small that they do not separate from the continuous phase due to gravity. In other words, they do not settle to the bottom or rise to the top. The smallest colloid particles are ~1 nm in size. If they were smaller, they would not be a separate phase; they would be part of a solution. The gold particles that you will work with have diameters of ~13 nm. Thus they are nanoparticles. The gold nanoparticles are covered with citrate anions. This prevents them from aggregating, i.e., from becoming bigger particles. You will explore how the size of the gold nanoparticles can be changed and how changing their size affects their color.



Left: A transmission electron micrograph (TEM) of 13 nm-diameter Au nanoparticles. **Right:** An illustration of an Au nanoparticle surface. Each nanoparticle is made of many (more than 500,000) Au atoms. Citrate anions cover the nanoparticle surface.

Try This

You will need: 1.0 mM HAuCl₄ and 38.8 mM Na₃C₆H₅O₇ (sodium citrate) solutions from your instructor, 50-mL beaker, magnetic stir bar, stir/hot plate, distilled water, table salt (NaCl), table sugar (sucrose), four glass vials or clear, colorless plastic cups, two small containers, dropper, balance, and graduated cylinder.

A. Preparation of 13 nm-Diameter Gold Nanoparticles

- ___1. Pour 20 mL of 1.0 mM HAuCl₄ (from your instructor) into a 50-mL beaker. Add a magnetic stir bar. Heat the solution to boiling on a stir/hot plate while stirring with the magnetic stir bar.
- ___2. After the solution begins to boil, add 2 mL of 38.8 mM Na₃C₆H₅O₇ (from your teacher). Continue to boil and stir the solution until it is a deep red color (about 10 min). As the solution boils, add distilled water as needed to keep the total solution volume near 22 mL. How does the solution visibly change? The sodium citrate reduces the Au ions to nanoparticles of Au metal. Excess citrate anions in solution stick to the Au metal surface, giving an overall negative charge to each Au nanoparticle.
- ___3. When the solution is a deep red color, turn off the hot plate and stirrer. Cool the solution to room temperature before using it in Part B.

Be Safe! Gloves should be worn when working with the nanoparticle solution. Rinse used solutions down the sink. If substances other than salt and sugar are added to the nanoparticle solution, dispose of the nanoparticle solution using methods appropriate for solutions containing those substances.

B. Effect of Particle Size on the Color of a Gold Colloid

- ___1. Make a predication: read over the procedure. Think about the composition of each solution that will be added to the gold colloid: table salt (sodium chloride, NaCl) and table sugar (sucrose, C₁₂H₂₂O₁₁). Recall that the gold nanoparticles in the colloid are negatively charged. Are there components in either solution that are charged? Predict whether the addition of each solution to the colloid will affect the size of the gold nanoparticles. Predict whether the color of the colloid will change. (Think back to the DNA-coated gold nanoparticles described in the Introduction.) Give reasons for your predictions.
- ___2. Make a datatable.
- ___3. In a small container, dissolve 0.5 g of table salt (NaCl) in 10 mL of distilled water to make a ~1 M solution.
- ___4. In another small container, dissolve 2 g of table sugar (sucrose) in 10 mL of distilled water to make a ~1 M solution.
- ___5. Label the four glass vials or clear, colorless plastic cups: *control*, *salt*, *sugar*, and *test*, respectively.
- ___6. Into each vial, place 3 mL of the gold nanoparticle solution you prepared in Part A. Add 3 mL distilled water to each vial.
- ___7. With a dropper, add 5–10 drops, one at a time, of the salt solution from part B, step 3 to the salt-labeled vials. Record your observations. (Refer to the control solution for comparison.) What is happening to the nanoparticles in solution?
- ___8. Using a clean dropper, add 5–10 drops, one at a time, of the sugar solution from part B, step 4 to the sugar-labeled vial. Record your observations. (Refer to the control solution for comparison.)
- ___9. Choose another substance to add to the fourth vial. One suggestion is a household liquid such as vinegar. Check with your instructor about your choice. Before adding the substance, predict whether or not a color change will occur.

Questions

1. Based on the fact that the citrate anions cover the surface of each nanoparticle, explain what keeps the nanoparticles from sticking together (aggregating) in the original solution.
2. Why does adding the salt solution produce a different result from adding the sugar solution?
3. How does the color of gold colloid you worked with compare to that of a gold coin? Why is there a difference?
4. How did your observations compare with your predictions? Give possible reasons for any differences.
5. The system you worked with in this activity involves huge numbers of nanoparticles. How might scientists be able to detect individual nanoparticles?
6. How could the effect in part B be used to detect the binding of biomolecules, such as DNA or antibodies, that stick to one another or to other molecules? How could these molecules be used to cause aggregation of the nanoparticles?

Information from the World Wide Web

1. A tutorial and simulation of Au nanoparticle aggregation on the National Center for Learning and Teaching (NCLT) in Nanoscale Science and Engineering's NanoEd Resource Portal://nanoed.org
2. Very good resource for all levels of education from the National Science Foundation:
<http://www.nsf.gov/news/classroom/nano.jsp>
3. Good introduction for students, especially relevant topics and very short explanations:
<http://www.sciencemuseum.org.uk/antenna/nano/>
4. Variety of educational materials on nanoscience and nanotechnology (including slides and short videos) from the Materials Research Science and Engineering Center at the University of Wisconsin, Madison:
<http://mrsec.wisc.edu/Edetc/>
5. Award-winning site; sort of an introductory science and technology encyclopedia with an emphasis on nano:
http://nanoatlas.ifs.hr/index_2.html
6. A nice intro to nano, and more: <http://nanopedia.case.edu/NWPPage.php?page=nanopedia>