Gold Nanoparticle Sensor

Learning Outcomes

- To understand and use a bottom-up approach for the synthesis of gold nanoparticles
- To observe the effect of size on optical properties of gold nanoparticles
- To create and test a gold nanoparticle-based "salt sensor"
- To use this nanoparticle-based sensor to detect the presence of salt in a series of unknowns

Washington EALR Alignment

9-12 INQC Conclusions must be logical, based on evidence, and consistent with prior established knowledge.

9-11 PS2B Atoms of the same element have the same number of protons. The number of electrons determines how the atom interacts with other atoms to form molecules and ionic arrays.

9-11 PS2D Ions are produced when atoms or molecules lose or gain electrons, thereby gaining a positive or negative electrical charge. Ions of opposite charge are attracted to each other, forming ionic bonds. Chemical formulas for ionic compounds represent the proportion of ion of each element in the ionic array.

9-11 PS2D Chemical reactions change the arrangement of atoms in the molecules of substances. Chemical reactions release or acquire energy from their surroundings and result in the formation of new substances.

9-11 PS2H Solution are mixtures in which particles of one substance are evenly distributed through another substance. Liquids are limited in the amount of dissolved solid or gas that they can contain. Aqueous solutions can be described by relative quantities of the dissolved substances and acidity or alkalinity.

9-11 PS2I The rate of a physical or chemical change may be affected by factors such as temperature, surface area, and pressure.

9-11 PS3D Waves (including sound, seismic, light, and water waves) transfer energy when they interact with matter. Waves can have different wavelengths, frequencies, and amplitudes, and travel at different speeds.

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Oregon Content Standards Alignment

H.1 P.1	Explain how atomic structure is related to the properties of elements and their position in the Periodic Table. Explain how the composition of the nucleus is related to isotopes and radioactivity.
H.1 P.2	Describe how different types and strengths of bonds affect the physical and chemical properties of compounds.
H.3 S.3	Analyze data and identify uncertainties. Draw a valid conclusion, explain how it is supported by the evidence, and communicate the findings of a scientific investigation.
H.3 S.4	Identify examples from the history of science that illustrate modification of scientific knowledge in light of challenges to prevailing explanations. (stained glass)
H.3 S.5	Explain how technological problems and advances create a demand for new scientific knowledge and how new knowledge enables the creation of new technologies.

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Background

There are two general approaches for the production of nanostructures: top-down and bottom-up. The top down approach uses tools to etch, shape, and cut material into desired shapes. Computer chips are made using photolithography, a top-down method. Also called the bench-top approach because of its use of chemistry, the bottom-up approach depends on atoms and molecules self-assembling themselves in a desired formation or structure based on chemical properties and reactions.

In this lab, gold nanostructures will be synthesized using the bottom-up approach to form a colloid solution, in which the particles do not aggregate, but are evenly dispersed throughout the mixture. Gold ions (Au^{3+}) are reduced by citrate ions to produce neutral gold nanoparticles (Au°).

One of the most captivating aspects of studying structures on the nanoscale is that they exhibit unexpected size-dependent properties. Gold absorbs certain wavelengths of light while reflecting others based on how photons interact with the surface of the material. In bulk, gold, like other metals, absorbs most light in the visible spectrum while reflecting infrared light giving it a shiny appearance. As the size of the particles decreases, the surface area of gold is increased (see Figure 1). This changes the spectrum of light that is absorbed and reflected.

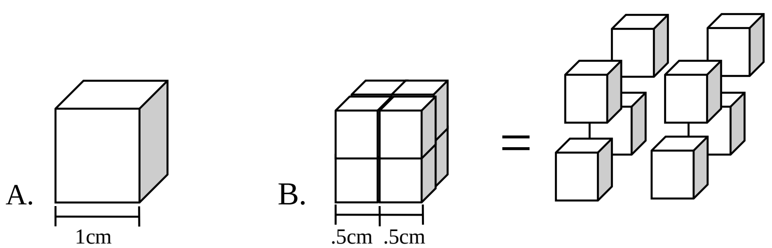

Figure 1. Sample A. and Sample B contain the same amount of gold. The surface area of Sample A is 6 cm^2. Although the volume is the same, the total surface area of the 8 particles that make up Sample B is 12 cm^2.

As nanoparticles approach the size of visible light, the nanostructures and light interact in interesting ways. Smaller gold nanoparticles exhibit a red color as they reflect red wavelengths and absorb shorter wavelengths of light. As gold nanoparticles increase in size, their color changes to a blue and then purple. (Figure 2.) The optical properties (and thus color) of certain nanostructures depend strongly on the nanostructures' sizes and shapes.

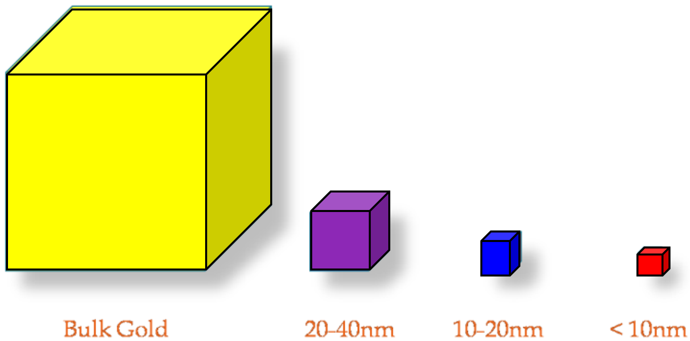

Figure 2. The color of gold is dependent on particle size.

The size-dependent optical properties of gold nanostructures can be exploited for a variety of applications, including as sensors.

Applications

- Home pregnancy tests
- DNA or antibody sensors
- Drug delivery
- Diagnostics
- Stained glass

Vocabulary

- Aggregate
- Bulk
- Colloidal Suspension (colloid)
- Material properties
- Oxidize / Reduce (Redox Reactions)
- Surface area
- Synthesize (chemistry)

MSDS/Safety

MSDS or other safety information sheets are provided at the end of this unit for all chemicals used. Waste materials should be collected in a waste container and properly disposed of as hazardous waste.

Materials

- Distilled water
- 5 Glass vials
- Scale
- Spatula
- Labels (tape and marker)
- Hydrogen tetrachloroaurate (III) hydrate ($HAuCl_4$ x H_2O), 1 mM solution
- Sodium citrate tribasic dihydrate ($Na_3C_6H_5O_7$ x $2H_2O$), 38.8 mM solution
- Sodium chloride (NaCl)
- Sugar (sucrose)
- Beaker (50 mL)
- 50 mL Graduated cylinder
- 10 mL Graduated cylinder
- 5 small test tubes
- Test tube rack
- Stir/hot plate, stir bar
- Pipettes
- Waste container

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Pre-Lab Preparations

Before the lab, 3 unknown solutions must be made: a salt solution, a sugar solution, and a salt/sugar solution.

Pre-Lab Materials

- Salt (NaCl)
- Sugar (sucrose)
- Distilled water
- Dropper bottles
- Scale
- Spatula
- Weigh boats
- Labels (tape and marker)

Pre-Lab Procedure

1. Prepare and label three unknown solutions in small dropper bottles:
    a. Unknown A: dissolve 0.5 g NaCl in 5 mL distilled water.
    b. Unknown B: dissolve 2 g sugar in 5 mL distilled water.
    c. Unknown C: dissolve 0.25 g sugar and 1 g salt in 5mL distilled water.

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Materials

- Hydrogen tetrachloroaurate (III) hydrate ($HAuCl_4$ x H_2O), 1 mM solution
- Sodium citrate tribasic dihydrate ($Na_3C_6H_5O_7$ x $2H_2O$), 38.8 mM solution
- Sodium chloride (NaCl)
- Sugar (sucrose)
- 50 Beaker mL
- 50 mL Graduated cylinder
- Spatulas
- Scale
- Weigh boats
- 10 mL Graduated cylinders
- 5 Small test tubes
- Test tube rack
- Stir/hot plate, stir bar
- Pipettes
- Distilled Water
- 2 Glass vials
- Unknown A
- Unknown B
- Unknown C
- Labels (tape and marker)
- Waste container

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Pre-Lab Question

When the gold nanoparticles are synthesized they are red in color. What do you think will happen when you add salt to the solution? Sugar?

Safety

All solutions should be collected in the waste beaker in the front of the classroom.

Procedure

1. Measure out 30 mL hydrogen tetrachloroaurate (III) hydrate solution into a 50 mL graduated cylinder.
2. Pour the measured hydrogen tetrachloroaurate (III) hydrate solution into a 50 mL beaker.
3. Add a magnetic stir bar and heat the solution to a gentle boil on a stir/hot plate while stirring.
4. After the solution begins to boil, add 3 mL of the sodium citrate tribasic dehydrate solution.
5. Continue to boil and stir the solution until it is deep red in color (about 10 min).
6. When the solution is a deep red color, turn off the hot plate and stirrer and let the solution cool to room temperature. While you are waiting, move on to step 7.
7. Prepare (and label!) two “standard” solutions in glass vials:
    a. ~2 M salt standard: dissolve 0.5 g NaCl in 5 mL distilled water.
    b. ~2 M sugar standard: dissolve 2 g sugar in 5 mL distilled water.

    Save these solutions for step 8.

8. Using a 10 mL graduated cylinders, measure 3 mL of the gold nanoparticle solution. Pour the measured solution into a test tube and add 3 mL of distilled water. Label test tube 1. Repeat with the other four test tubes 2-5 respectively.

9. Making sure to use a new dropper or pipette for each solution, add 5-10 drops of solution into the test tubes as described:

Test tube 1	Test tube 2	Test tube 3	Test tube 4	Test tube 5
Sugar solution	Salt solution	Unknown A	Unknown B	Unknown C

10. Record your observations in the data table.

11. When you have finished the lab, pour all of the gold nanoparticle solution into the waste container.

12. Record the spectrum for each sample.

13. Measure particle size using DLS.

Data and Discussion Questions

Test Tube Number	1	2	3	4	5
Testing Solution	Sugar	Salt	Unknown A	Unknown B	Unknown C
Observations (Color)					

Draw a quick sketch of each spectrum, noting any peak(s).

Sugar

Salt

Unknown 1

Unknown 2

Unknown 3

Conclusion 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 than adding the sugar solution? Remember that ionic and covalent solids dissolve in water in different ways.
3. From your data, is there a way to tell the difference between a sample that contains salt and a sample that does not contain salt? Explain your reasoning.
4. From your data, is there a way to tell the difference between a sample that contains sugar and a sample that does not contain sugar? Explain your reasoning.
5. From your data, what would you predict a sample would look like if it contained both sugar and salt?
6. Identify each of the unknowns and <u>explain your reasoning.</u> Don't just say "I can tell from the pictures I drew."

Extra credit: How could the optical property dependence of gold nanostructures be used to detect the binding of biomolecules, such as DNA or antibodies, which stick to one another or to other molecules? For example, how does an at-home pregnancy test work?

References

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New/Research Articles

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Video

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