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Teacher's Guide

Particle Size and Spectral Analysis of $AgNO_3$ and Cu: Design Challenge Activity

Grade Level: High school

Subject area(s): Chemistry

Time required: (5) 50 minute classes

Learning objectives: Through inquiry students will understand: the nature of reduction of an ion by a metal; how particle size determines the perceived color of the deposited metal; and observe spectral changes in a reaction.

Summary: When the traditional silver nitrate reduction by copper is performed, students are often puzzled by the black appearance of the silver when it first is observed. In this activity, students will research two questions about the reaction, develop a viable system of gathering data, and investigate the relationship between the silver particle size and time. They will also observe the absorption spectra as the solution changes from silver nitrate to copper (II) nitrate. The student group will then produce a poster display and verbal presentation of the work they did and the results of their observations. This activity will be done as a design challenge/inquiry type exercise in which the teacher gives an introductory overview then acts as mentor and consultant as students develop, conduct, analyze and present their work.

NOTE: This lesson uses Vernier Labquest 2 and SpectroVis Plus Spectrophotometer. In addition, it includes access to a scanning electron microscope (SEM). The Remotely Accessible Instruments for Nanotechnology (RAIN) allows schools to remotely use spectrophotometers, SEMs, and an optical microscope free of charge. Sessions can be scheduled using RAIN's online system at: https://nano4me.org/remoteaccess#NanoTools.

Lesson Background: In all oxidation-reduction reactions, an exchange of electrons occurs with one substance losing electrons while another one gains them. When an ion gains an electron, it is said to be reduced. When a substance loses an electron, it is said to be oxidized.
You may wish to have students watch the *Oxidation Reduction Reaction* videos on YouTube (see Resource Section) prior to giving them an in-class overview of redox reactions. As seen in the YouTube video, when an aqueous silver nitrate solution comes in contact with a copper wire, a single replacement reaction occurs. This demonstrates a redox reaction where two elements swap places.

The metallic bond is mentioned only briefly in many chemistry classes, even though it is of critical importance in defining the macro characteristics of metals (conductivity, thermal conduction, etc.). The bonds occur at the nanoscale yet determine the nature of the material at macroscale. Equally important, is the emerging potential to use the surface systems of electrons on various metals in new technology, perhaps even in the development of quantum computing.[1]

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Plasmons are nano-sized groupings of the surface electrons in a metal. Electromagnetic energy in the visible region (380-700nm) can excite these groupings causing the emergence of a resonating wave that absorbs various wavelengths of the incident light, causing them to appear black (in some cases) or sometimes yellow for silver.[1] Thus, when the particles of silver are in the nanoparticle range, their color does not appear as the "silver" we commonly observe. At the nanoscale there can be size dependent properties or properties that change with scale. In this case, nanosized silver interact with light differently than at the macroscale resulting in a different color for silver nanoparticles.

Interestingly, when silver nitrate is exposed to light the silver nitrate decomposes into free silver, nitrogen (IV) oxide, and oxygen.[2] Thus, skin turns black when silver nitrate is spilled and not immediately rinsed off. The black is observed because the silver nanoparticles, acting as plasmons, absorb incident light into their surface electron structure. By definition, nanoparticles have a size less than 100 nm, thus even with an optical microscope we are unable to observe silver particles in that range. Optical microscopes are limited to examining materials within the range of visible light. We can, however, use the Scanning Electron Microscope (SEM) to observe particles smaller than those observed by an optical microscope.

The reason an SEM can be used to observe nanoparticles is that electrons have a much shorter wavelength than visible light, thus enabling detection of particles of 100 nm or less.[3] The resolution of an SEM is dependent on the wavelength of the electrons and the system which produces the scanning beam. A short explanation of an SEM is found at the website listed below with other sources about SEMs noted in the Resource Section.

Students sometimes fail to process the fact that the silver nitrate solution has chemically changed into copper (II) nitrate, even though the solution appearance and color has changed. By performing an absorption spectrum analysis on the solutions as a function of time, it is possible to observe the identifying spectrum changing from that characteristic of silver nitrate to that of copper (II) nitrate.

The spectrophotometer is used extensively in research labs. Every substance reflects, absorbs or transmits light based on the electron energy levels within the atomic structure and the energy band transitions allowed. Once the absorption spectrum is determined for any substance, subsequent analysis can be used to identify components in a solution.

Spectrophotometers can be used in a quantitative manner (e.g. Beers' Law), but this lab exercise uses it in a qualitative fashion to show the translation from one solution to another.

Sources:

1. Natelson, Douglas. "What is a Plasmon?" http://nanoscale.blogspot.com/2009/02/what-is-plasmon.html
2. Clifton, Jessica. "What happens when you put copper wire in silver nitrate?" ReAgent, The Chemistry Blog. https://www.chemicals.co.uk/blog/what-happens-when-you-put-copper-wire-in-silver-nitrate

3. Nanoscience Instruments. Scanning Electron Microscope. https://www.nanoscience.com/techniques/scanning-electron-microscopy/

Prerequisites Knowledge:

- Know basic chemistry lab procedures and lab safety rules.
- Understand the types of chemical reactions and signs of chemical reactions.
- Understand chemical equations

Materials: (per group)

- Safety goggles
- Lab apron or coat
- Rubber gloves
- 1 150 mL beaker
- 6 test tubes: 15 X 10 cm
- 6 pieces of copper wire, 15 cm long
- Sandpaper or wire gauze
- Test tube rack
- 80 ml of 0.1 M. $AgNO_3$ freshly prepared
- Graduated cylinder
- Access to Scanning Electron Microscope or Optical Microscope (see RAIN above)
- Access to a Spectrophotometer (see RAIN above)
- Watch or clock
- Laser
- Cell phone camera

Teacher:

- Silver nitrate 0.1 M solution (to be made)
- Amber bottles to store solution
- Aluminum foil to wrap solution bottles

Advance Preparation:

- Make sufficient 0.1 M AgNo3 solution so that each lab group has 80mL of the solution. The final solution should be stored in amber bottles and wrapped in aluminum foil.
- If using the Vernier spectrophotometer, have it ready for use. If not, schedule a time with one of RAIN's spectrophotometers. You may also schedule access to an SEM.
- Pre-cut copper wire
- Assemble all glassware and other materials in a central location.

Safety Information: Use gloves and safety glasses when using silver nitrate. Refer to the MSDS for this chemical solution. Warn students to use caution when working with silver nitrate and to wear required lab safety equipment.

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Vocabulary and Definitions:

- *Electron energy levels* - A quantum-mechanical concept for energy levels of electrons about the nucleus; electron energies are functions of each particular atomic species.
- *Plasmons* - A quantum of plasma. A plasmon is the gas particle equivalent of a photon, which is a light particle. Surface plasmons, which reside on the surface of materials, are expected to yield terahertz transmission speeds within electronic circuits some day.
- *Photosensitive Reactions* - Any chemical reaction that responds and reacts when in the presence of visible light.
- *Valence band electrons* - Those electrons found in the valence (or outer energy level) of an atom.
- *Metallic bond* - The type of chemical bond that is present in all metals, and may be thought of as resulting from a sea of valence electrons which are free to move throughout the metal lattice.
- *Spectrophotometer* - Instrument for measuring and comparing the intensities of common spectral lines in the spectra of two different sources of light.
- *Absorption spectrum* - A plot of how much radiation a sample absorbs over a range of wavelengths; the spectrum can be a plot of either absorbance or transmittance versus wavelength or frequency.
- *Energy level transition* - An allowed energy of a physical system; there may be several allowed states at one level.
- *Orbitals* - Mathematical expression, called a wave function, that describes properties characteristic of no more than two electrons near an atomic nucleus or molecule. An orbital can be considered a three-dimensional region in which there is a 95% probability of finding an electron.
- *Scanning Electron Microscope* - An electron microscope that forms a three-dimensional image on a cathode-ray tube by moving a beam of focused electrons across an object and reading both the electrons scattered by the object and the secondary electrons produced by it.
- *Dual nature of matter* - The concept that matter (mass) can exist both as a particle and as a wave. Photons of electromagnetic energy can also have both a wavelike and particle-like nature.
- *Wavelength of light* - When light has a wavelike character we can measure its wavelength, normally in the range of 400 to 700 nanometers.
- *Nanometer* - one billionth (10^{-9}) of a meter
- *Nanoparticles* - a particle with dimensions less than 100 nanometers.
- *Solution* - A homogenous mixture of a solvent and a solute.
- *Colloid* - A solution in which the particles are large enough (in the nanoparticle range) to reflect a laser beam
- *Tyndall Effect* - The visual indication of a laser beam as it travels through a colloid.

Suggested Instructional Procedure: A suggested timeline for this project is shown below, but obviously can be modified to fit the situation of individual schools. Since this is an inquiry-based laboratory exercise, the teacher should provide an overview of the proposed activity, and then

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give suggestions of keywords to use in the research process. Some of those keywords are listed in the vocabulary section above.

Time	Activity
Day 1	Overview of the Research Process and Start Student Planning
	Review the Research Process (i.e. applied scientific method) Students begin planning and preparation. Teacher acts as roving mentor.
Day 2	Finalize plans, gather equipment and prepare for lab work
	Student groups finalize plans and get teacher approval
	Gather all equipment
	Write step by step plans in journals Intro to activity and vocabulary
Day 3	Perform laboratory activity
Day 4	Finish experiment and analyze results; Prepare presentation
Day 5	Complete presentation and present

Suggested Teaching Strategies:
Since this is an inquiry-based exercise, the teacher must be wise in giving enough information to enable critical thinking, yet not be too quick to correct wrong thinking or even incorrect technique. Obviously, unsafe technique must be corrected but often following an incorrect strategy can have long-term learning benefits.

It is important to stress the proper use of smart phones and computers as research instruments. Effective group dialogue and journaling should also be emphasized and modeled. This is also an interesting way in which to model the real use of the scientific method without formalizing the process.

Some degree of specific information needs to be given in the use of instruments, preparation of samples for microscopic analysis and emphasis on proper journaling. Some examples of this specific information are listed below, although each teacher or lab situation may have their own talking points.

- Technique for sharing information with the Labquest2 (see Vernier manual)
- Technique for preparing samples for electron or optical microscope (see operation manuals or RAIN requirements)
- Proper strategies for recording lab operations and data (use of tables, clear writing, dates, etc.)

Directions for the Activity:
Since this is an inquiry-based lab, procedures will vary by group of students and classroom. One possible setup is indicated below of photographs taken during the performing of the lab activity by my students. The student guide will explain to students the task and assigned problems. It is up to them to design their experiments to answer the problems. The problems the students will be required to investigate:

1. Using a laser, determine if the silver nitrate solution is a colloid. Do the same with the copper nitrate solution at the conclusion of the experiment.

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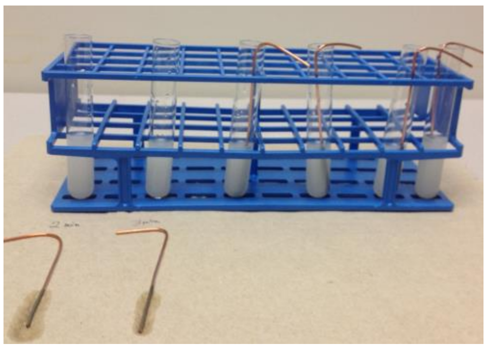
2. Using the Labquest2 and the SpectraVis, display the absorption spectrum of the silver nitrate solution at the beginning of the reaction and the copper nitrate solution at the conclusion of the reaction.
3. Using standard mass-mass Stoichiometric procedures, determine the ratio of the moles of copper to silver produced. Compare this to the expected values as indicated by the balanced equation.
4. Using Beer's Law, determine the concentration of the copper(II)nitrate solution. Then compare the molar ratio of the experimental value to the theoretical value based on the balanced equation.
5. Observe the final silver particles produced using whichever microscope is available for your use.



Three minutes into process

Experiment after two hours

Going Further: Students who have a good grasp of the content of the lab can be further challenged with these questions:

1. What reactant do you think is the limiting reagent in this reaction. *The limiting reagent is the substance that is consumed first in the reaction. Since there is still copper left after the reaction is finished, the copper is the limiting reagent.*
2. How would you modify the experiment to determine if the temperature of the silver nitrate solution affects the reaction rate? *To determine how temperature affects the reaction rate one could use beakers placed on different hotplates, measure the temperature of each solution, then observe which system went to completion first and in what order the systems progressed.*

Assessment: The following are some suggestions for items that should be included in an assessment rubric, both for daily activity and final presentation poster. The assessment of student success can be done by evaluating their daily class participation, journals and poster presentation.

- Is each member of the lab group actively engaged?
- Is the journal completed daily?
- Is the journal complete?
- Does the poster meet size requirements? (will vary according to teacher)
- Is the poster complete? (i.e. all required elements present)

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- Is the information on the poster correct?
- Does the poster have positive visual appeal?

Additional Resources:

- YouTube: Oxidation-Reduction Reactions https://www.youtube.com/watch?v=ba_dPxTZb30 and https://www.youtube.com/watch?v=dC41uXYb7Dg
- Swapp, Susan. Scanning Electron Microscopy. https://serc.carleton.edu/research_education/geochemsheets/techniques/SEM.html
- My Scope Virtual SEM. myscopeoutreach.org/virtualSEM.html
- The strange new world of Nanoscience. YouTube: https://www.youtube.com/watch?v=70ba1DByUmM
- Nanotech 101 by the National Nanotechnology Initiative: https://www.nano.gov/nanotech-101
- How Nanotechnology works from How Stuff Works https://science.howstuffworks.com/nanotechnology.htm
- Introduction to EDS by Oxford Instruments: Introduction to Energy Dispersive Spectroscopy (EDS) - YouTube
- Introduction to Energy Dispersive X-ray Spectrometry (EDS) by Emily Krull: Introduction to Energy Dispersive X-ray Spectrometry (EDS) - YouTube
- Atomic Absorption Spectroscopy (HSC chemistry): https://www.youtube.com/watch?v=j68xgp64L40
- YouTube has several videos on how scanning electron microscopes work

Next Generation Science Standards:

- **HS.PS1.A** Structure and Properties of Matter
- **HS.PS1.B** Chemical Reactions
- **HS.PS2.B** Types of Interactions

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