Lesson Title: Characterization of Gold Nanoparticles with a Papercraft Spectrometer

Lesson Overview:
Nanostructured materials are being used to reduce the weight of cars, buildings, and other infrastructure reducing the amount of materials needed and saving energy. Unintentional nanomaterials, such as nanoplastics, are also proving to be hazardous to the environment. In the first activity we will discuss some of the properties of light, describe how these can be used to characterize nanomaterials, and build a papercraft spectrophotometer for measuring the light emitted by different sources. In the second activity, we will discuss how nanoparticles can be formed and synthesize gold nanoparticles in the lab.

Topic(s): Chemistry

Grade or Grade Band: High School Physical Science

Lesson Objectives:
- Describe how a spectrophotometer works.
- Define which wavelengths of light correspond to visible colors.
- Describe how light interacts with matter.
- Describe the components used during nanoparticle synthesis.

Next Generation Science Standards:

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

North Dakota Standards:

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Time Needed (estimate): 2 50-minute class periods

Lesson Author: Jeni Peterson
Jeni Peterson is an Instructor of Education and the Director of the Center for Teaching and Learning at Mayville State University. Jeni collaborates with STEM Ecosystems throughout North Dakota to provide STEM learning activities and resources to K-12 partners in the Mayville region. She teaches course related to foundations of education, educational technology and elementary science methods. Jeni is a graduate of Mayville State and holds a Master's in Education from Minot State University.

Scientist Bio/Research: Dr. Alex Parent

Alex Parent, is an Assistant Professor of Chemistry and Biochemistry at NDSU. He grew up on the east coast and attended Clark University in Massachusetts for a Bachelor of Arts degree in chemistry and Yale University in Connecticut for a Doctor of Philosophy degree in chemistry. Alex then spent two years working in Fukuoka Japan researching sustainable energy. He is an avid hiker, and loves walking the many parks in Fargo and occasionally getting out to the Badlands and upstate Minnesota to experience more vertical trails. (The things he misses most about New England and Japan are the easy access to hills and mountains!) Alex is an avid board gamer, with Uwe Rosenberg games being favorites. His research focuses on methods of generating materials from renewable resources, particularly on using air in chemical synthesis. Current projects include developing new catalysts for activating oxygen from the air and studying the process by which current catalysts utilize air to effect chemical transformations in paints.

Preparation/Materials

Background knowledge students must have to be successful:

Visible light is a small segment of the electromagnetic spectrum that is visible to the human eye. When visible light travels through a prism the wavelengths separate into a rainbow of colors. A spectrometer can be designed to serve particular functions by considering properties of different materials, and how materials can be shaped and used.

Differentiation and accommodation to support learning for all students:

- Use visuals and pictures whenever possible to create a clearer image for the students.
- Record the instructions so students can playback difficult to understand directions.
- Allow students to dictate answers.
- Create smaller groups to increase engagement.
- Highlight important words for students.

Essential terminology:

Nanoparticle- a small particle that ranges between 1 to 100 nanometers in size. It is undetectable by the human eye.

Precipitating- to cause a substance to be deposited in solid form from a solution.

Surfactants-a substance used to reduce the surface tension of a liquid in which it is dissolved

Colloid- a substance with gel like consistency including gels, sols and emulsions.

Resources:
Papercraft Spectrometer Template
Spectrometer Observation handout

Websites:
https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_en.html
https://publiclab.org/notes/warren/11-30-2017/build-a-papercraft-spectrometer-for-your-phone-version-2-0.
https://spectralworkbench.org/

Materials needed:

Lesson 1: Building a Papercraft Spectrometer

- 1 Papercraft Spectrometer Template Sheet
- 1 Piece of Black Cardstock
- 1 DVD-R
- 1 Smartphone with Camera
- Tape
- Ruler or straightedge
- Scissors

Lesson 2: Synthesizing and Characterizing Gold Nanoparticles

- Safety Glasses
- Gloves
- Papercraft Spectrometer
- 1 mL 5 mM Chloroauric Acid Solution (caustic!)
- 1 mL Tea
- 100 mL Deionized Water
- 6 Small Erlenmeyer Flasks or Beakers
- Stir Rod
- Pasteur Pipette
- 3 10 mL Graduated Cylinders
- Light source

Procedure/Activities

Lesson sequence:

- Lesson 1: Building a Papercraft Spectrometer
- Lesson 2: Synthesizing and Characterizing Gold Nanoparticles

Lesson 1: Building a Papercraft Spectrometer

Engage:

Ask students if they have ever put on a piece of clothing thinking it was one color only to get out into the sun and it looks a different color. Present ppt. slide 3 and ask the students the following questions.

- Light has multiple components (colors)
- What happens when light interacts with matter?
- What color do objects appear to us?
- How do different light sources affect color?
- Predict the difference between sunlight and a fluorescent light bulb.

Explore:

Present ppt slide 4 explain to students that light behaves like a wave. When waves pass through slits, they diffract. Direct students to log on to: https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_en.html and explore the wave simulators and how they interact at different frequencies or when different obstacles are introduced.

Present ppt slide 5 to students. Explain to students that humans can see color between 400 and 700nm. Nanomaterials are about the same size and can diffract light giving things like the Blue Morpho Structural color. Present the movie: What Gives the Morpho Butterfly its Magnificent Blue: https://youtu.be/29Ts7CsJDpg

Handout the Papercraft Spectrometer pdf and direct students to the Papercraft Spectrometer website to assemble the spectrometer: https://publiclab.org/notes/warren/11-30-2017/build-a-papercraft-spectrometer-for-your-phone-version-2-0

Once students have assembled the spectrometers, distribute the Spectrometer Observation handout. Following the instructions on the handout, students will calibrate their spectrometers and then take pictures of both a fluorescent light and the sky. Direct students to write down their observations of the similarities and differences between the two pictures.

Explain:

Present ppt slide 7 to the students and discuss the components of the spectrometer.

1. What does the spectrometer slit do? (students should be able to explain that the slit directs the light to the DVD lens.
2. What does the DVD do? (students should be able to explain that the DVD breaks the light into spectral components.)

3. What does your cellphone camera do? (students should be able to explain that the camera captures the image of the separated spectral components)

Present ppt slide 8. Allow students several minutes to write down the differences they see from the picture on the left and the picture on the right. After the allotted time has passed, display the third picture with the differences in the two pictures subtracted one from the other. Explain to students that a difference spectra can be used to detect changes in scientific measurements.

Extensions for learning more about this topic:

Science enthusiasts from around the world have submitted an extensive online list of ideas to explore spectrometry: https://publiclab.org/wiki/spectrometry

Evaluation of learning

On the Spectrometer Observation sheet, students should note in the similarities and differences that a fluorescent light bulb will only produce a limited amount of color with lines that seem to puncture the color. Some may notice that the fluorescent light gives off "colder" more green hues. The sunlight will produce a continuous spectrum with "warmer" colors.

Lesson 2: Synthesizing and Characterizing Gold Nanoparticles

Engage:

Ask students "What are Nanoparticles and How are they made?" Students may be prompted to recall the nanostructures on the Morpho Butterfly. Tell students that particles with three dimensions between 1 and 100 nm are considered nanoparticles.

Present ppt slide 10 to help students understand how nanoparticles are made.

- Particles with three dimensions between 1 and 100 nm
- Produced naturally during combustion (of wood, coal, etc.)
- Can be made synthetically via a top-down (wearing-away) or bottom-up (growing) approach
- Colloids are suspensions of nanoparticles in a solution.
- Typically formed via bottom-up approach
- To make a colloid need to keep nanoparticles from:
    1. Getting too big
    2. Sticking to one another
    3. Precipitating out of solution

Present ppt slide 11 to help students understand how to make colloids.

- To make a colloid need to keep nanoparticles from:
    1. Getting too big
    2. Sticking to one another
    3. Precipitating out of solution

- Capping molecules can keep nanoparticles from getting too big and sticking to one another
- Surfactants keep nanoparticles from precipitating.
- What is a surfactant?
- Molecule that stabilizes the interaction between a liquid and another substance

Explore:

Distribute the Synthesizing and Characterizing Gold Nanoparticles handout to each student. Emphasize to students that we will be using caustic materials, safety glasses and gloves must be worn at all times during this lab.

Each student will have a copy of the instructions on their Synthesizing and Characterizing Gold Nanoparticles handout:

Instructions:

- Before entering the lab, write down how much deionized water your group will be using.
- Put on your gloves and safety glasses.
- Collect 1 mL of chloroauric acid solution, 1 mL of tea, and 100 mL of deionized water from the front of the room using 3 of your flasks/beakers.
- Take a picture of a light source using your papercraft spectrometer.
- Place the beaker containing the chloroauric acid solution between the light source and your papercraft spectrometer and take another picture.
- Compare the two pictures, what is different? Record your answer in number 1 below.
- Using your graduated cylinders, add 1 mL of tea and ___ mL of water to a small flask or beaker and stir gently. (Be sure to list how many mL of water used!)
- While stirring, add dropwise 1.0 mL of 5 mM chloroauric acid to your diluted tea using your graduated pipette.
- Record your observations in number 2 Below.
- Compare your solutions to those of other groups. Can you see any difference? Record your observations in number 3.
- Place the beakers containing your gold nanoparticle solutions between your papercraft spectrometers and your light source and take a picture. (Note, it can be difficult to get a good picture, try different positions for your spectrometer/beakers).
- Compare your pictures to your picture of the light source.

Explain:

Present ppt. slide 13 Making Gold Nanoparticles to help students understand how the gold nanoparticles are formed.

- Start from a molecular gold source: $HAuCl_4$
- React with tea, which contains:
    - A) Antioxidants
    - B) Surfactants
- What will happen when the gold and tea are mixed?

- $HAuCl_4$ will *oxidize* (remove electrons from) the antioxidants in the tea, forming gold metal
- As gold metal forms, it will be capped by surfactants, preventing the gold from growing larger than the nanoscale

Extensions for learning more about this topic:

Science enthusiasts from around the world have submitted an extensive online list of ideas to explore spectrometry: https://publiclab.org/wiki/spectrometry

Evaluation of Learning:
Once students have completed the lab, use the following questions as prompts for discussing what was discovered.

- How did the colors of the gold nanoparticle solutions differ between the two solutions?
- Why were the colors different?
- Could you detect these differences using your spectrometer?
- What was the greatest limitation of your spectrometer for measuring the color of the solutions?
- What are some other experiments you could use your spectrometer for?

Additional Lesson Resources / Materials

References:

"Preparation of Gold Nanoparticles Using Tea: A Green Chemistry Experiment" Sharma, R. K., Gulati S., Mehta S. *J. Chem. Educ.* 2012 **89** (10), 1316-1318 DOI: 10.1021/ed2002175.