Gold and Silver Nanoparticles
Description:
Students conduct a chemical laboratory activity in which they make nanoparticles and filter them to determine their relative sizes.

Prerequisites:
Students should have an introductory knowledge of nanotechnology that can be provided by the Introduction to Nanotechnology kit. Also, the Antimicrobial Effects of Silver Nanoparticles lab is a good companion activity.

Instruction Time:
Approximately two 50-minute class periods
The first period is for the PowerPoint presentation, and the second is for the lab.

Audience:
High school chemistry students

Lesson Objective:
Students will develop an understanding of the relationship between the sizes of particles and the properties of a mixture.

National Science Education Standards:
Content Standard A: Abilities Necessary to Do Scientific Inquiry
Content Standard B: Structure and Properties of Matter
Content Standard E: Understandings about Science and Technology

Illinois State Learning Standards:
11.A.4b Conduct controlled experiments or simulations to test hypotheses.
12.C.5b Analyze the properties of materials in relation to their physical and/or chemical structures.
13.B.5b Analyze and describe the processes and effects of scientific and technological breakthroughs.
Instructional Method:
The instructor gives a presentation on solutions, colloids, and suspensions. Students then do a chemistry laboratory activity in which they make and filter nanoparticles of gold and silver. The students draw conclusions about the size of the nanoparticles based on whether or not they pass through the 20 nanometer pores in the ceramic filters.

Background Information:
Solutions, colloids and suspensions are distinguished by the size of dispersed particles and their macroscopic properties. Colloids have dispersed particles with sizes between 1 and 1000 nm, making them nanoparticles. In this size range, the particles will not settle out of the mixture, and the Tyndall effect will be evident.

Colloidal gold and silver can be made using sodium citrate to reduce the metal ions and stabilize the nanoparticles. Citrate anions attach to the surface of the metal particle, blocking it from coagulating. Nanoparticles of silver are 20-50 nm and gold nanoparticles are about 13 nm.

Gold and silver nanoparticles are smaller than the wavelength of light. The color they display is a result of the interaction of light with the surface of the nanoparticles; this interaction is called Plasmon resonance. The color changes as the distance between the nanoparticles changes.

Citrate ions interact with the surface of the nanoparticles to form a barrier around the nanoparticle. This is what prevents nanoparticles from sticking together and clumping into larger particles. By adding sodium chloride, the relationship between citrate ions and the surface of the nanoparticles is disrupted, allowing nanoparticles to clump together. This changes the interaction between light and the surface of the nanoparticles, causing the red color to change to blue.

Nanoparticles of gold and silver are of interest in nanotechnology research because of their ability to self-assemble and because of their consistency in size and shape. Nanoparticles are being considered as a delivery mechanism for medicines.

The filters used in this experiment are enclosed ceramic filters which easily screw onto and off of a Luer-Lok™ syringe. Similar to marbles sliding through a tube with a slightly larger diameter, several nanoparticles can get wedged together and block the filter. This will happen when filtering a large amount of red gold nanoparticles. The blue gold nanoparticles are clumped and closer together, so they wedge together immediately and stop the nanoparticles from passing through the filter.
Overview:
In this lab students make and filter three different gold and silver colloidal mixtures. Gold and silver solutions are reduced and stabilized with sodium citrate in a boiling water bath. The colloidal dispersions formed are poured into petri dishes, drawn into a Luer-Lok™ syringe, and filtered through 20 nm pore size ceramic filters. The colloidal gold should be deep red in color and pass through the filter. Gold colloid particles are about 13 nm in size. The silver colloid should be yellow in color and get caught in the filter. Silver colloidal particles are 20-50 nm in size. If the silver filter is cut open along the seam with a single edged razor blade, the silver metal can be seen on the inside of the filter. Interestingly, the color will be the color of bulk silver, not the yellow color of the colloid. The red gold colloid in the filtrate can be coagulated into larger particles using sodium chloride. This changes the color of the gold colloid from red to blue. The blue gold colloid can then be refiltered and the students will find that the metal will be caught on the filter. Cutting open the filter will reveal the gold color of the metal. From their observations, students can draw conclusions about the sizes of the red and blue gold colloids and the yellow silver colloids.

Materials:
- Hydrogen tetrachloraurate (HAuCl₄)  CAS 16961-25-4
- Silver nitrate (AgNO₃)    CAS 7761-88-8
- Sodium citrate (Na₃C₆H₅O₇)    CAS 6132-04-3
- Sodium chloride (NaCl)    CAS 7647-14-5
- Distilled water
- Petri dishes
- Test tubes
- Disposable 3 mL pipettes
- Luer-Lok™ syringes
- Anotop® 10 filters
- Hot plates
- 250 mL beakers
- Razor blade
- Test tube holders
- Test tube rack
- Laser pointers

Safety:
Goggles, gloves and aprons should be worn as in all chemistry laboratory activities. The hot water baths should be handled with care to avoid burns. Any liquids spilled on skin can be washed off with water.

The most dangerous part of this lab is opening the ceramic filters to reveal the metals on the inside surfaces. This requires cutting open the filter while it is still attached to the syringe. Cutting along the seam of the filter with a single-edged razor blade will reveal the inside of the filter. Because of the danger of cutting oneself with the razor blade, this part of the procedure should be performed by the instructor.
Preparation:
You will need to prepare the following:
• PowerPoint presentation or transparencies
• Hot water baths consisting of 100 mL beakers half-filled with boiling distilled water on a hot plate
• Two petri dishes per group
• One syringe and three 20 nm ceramic filters per group
• Two 5 mL test tubes, one for silver and one for gold
• Test tube holders
• Graduated disposable pipettes for measuring and dispensing the chemicals (3 mL)
• Laser for detecting Tyndall effect

You will need to prepare stock solutions of:
• 0.5 mM HAuCl₄ (.1 g of HAuCl₄·3H₂O in 500 mL of distilled water)
• 0.5 mM AgNO₃ (.17 g of AgNO₃ in 2000 mL of distilled water)
• 1% Na₃C₆H₅O₇ (0.5 g of the solid in 50 mL of distilled water)

Procedure:
Make Gold and Silver Nanoparticles

1. Add 2 mL of 1mM AgNO₃ to a small test tube. Add 2 mL of 0.5mM HAuCl₄ to another test tube.
2. Place the test tubes in a 250-mL beaker of boiling water.
3. Leave the test tubes in a boiling water bath for 10 minutes.

4. Add 5 drops of 1% sodium citrate to both test tubes.

5. Continue to heat until the gold changes to a wine red color and the silver turns to a yellowish color. (~5 minutes for gold, ~15 minutes for silver)

6. Remove test tubes and set in a test tube rack to cool.
Determine Size of Nanoparticles

7. Check for the Tyndall effect by using a laser pointer. Check gold, silver, and a test tube of clean water.

8. Pour the test tube of gold nanoparticles into clean petri dishes.

9. Draw about 0.5 mL of gold nanoparticles into a syringe. Follow with about 1 mL of air.

10. Attach a filter to end of the syringe.
11. Push the nanoparticle solution through the filter. Try to determine if the nanoparticles pass through.

12. Cut open the filter across its seam by using a razor blade. Observe the colors and texture of the filter surface.

13. Pour the test tube of silver nanoparticles into clean petri dish.

14. Draw about 0.5 mL of silver nanoparticles into a syringe. Follow with about 1 mL of air. Attach a filter to end of the syringe.
15. Push the nanoparticle solution through the filter. Try to determine if the nanoparticles pass through.

16. Cut open the filter across its seam by using a razor blade. Observe the colors and texture of the filter surface.

Change the spacing between Gold Nanoparticles using NaCl

17. Add a few grains of NaCl to the gold nanoparticles.

18. Gently mix until a gray-blue color persists.
19. Draw up 0.5 mL of gold nanoparticles and NaCl solution into a syringe with 1 mL of air. Attach a filter.

20. Push the nanoparticle solution through the filter. Try to determine if the nanoparticles pass through.

21. Cut open the filter across its seam by using a razor blade.
Presentation Details:

Slide 1 (Gold and Silver Nanoparticles): Our focus today and tomorrow will be on gold and silver nanoparticles.

Slide 2 (Objectives): You will make gold and silver nanoparticles, determine their color, and measure their relative sizes. Nanoparticles are particles that are in the range of 1-1000 nanometers.

Slide 3 (How big is a nanometer?): Let’s look at some different metric units for length and get a feel for just how big (or small) a nanometer is. (Discuss the units.)

Slide 4 (Nanoparticles): Objects on the nanoscale exhibit behavior that can be very different than what is expected by properties on the bulk scale. For example, gravity is the dominant force at the macro scale, but at the nanoscale electrostatic forces and quantum effects become dominant.

Slide 5 (What color is gold?): Other physical properties, including electrical and chemical properties, may also be different at the nanoscale. This is very interesting to research scientists in the field of nanotechnology, because gold nanoparticles have very different properties depending on the distances between and the sizes of the nanoparticles.

Slide 6 (How big are the nanoparticles?): How can we hope to be able to tell the sizes of particles that are so small? Actually, the size of dispersed particles can be deduced by the physical properties of the mixtures. By experimenting on our mixture, we will be able to draw some conclusions about the sizes of the nanoparticles. We will look at settling, Tyndall effect, and filtering.

Slide 7 (Settling): If a mixture of a solid and a liquid has large solid particles, gravity will cause the particles to settle out as we see in the top picture. If you have colloidal (1-1000 nm) dispersed particles, collisions with the dispersing medium’s particles will help the particles stay mixed. This may result in a colored and/or cloudy mixture. A solution in which the dissolved particles are either ions or small molecules (< 1 nm) will remain dissolved and be clear. Note the difference between the terms clear and colorless.

Slide 8 (Tyndall effect): Dissolved particles are too small to be scattered by light. However, colloidal nanoparticles with sizes near the wavelength of light will interact with visible photons. When a laser or other beam of light is shown through a colloid, the light will scatter and the beam will be visible in the mixture.

Slide 9 (Classifying mixtures): In summary, solutions which have particles less than 1 nm in size are clear, show no Tyndall effect, and remain dissolved. The nanoparticles in colloids are larger than those in solutions (1-1000 nm) and will scatter light (Tyndall effect). However, the particles are small enough to remain dispersed without settling out. A colloid will typically look cloudy. Suspensions that have the largest particles (>1000 nm) will settle out over time and will scatter light while temporarily suspended.
Slide 10 (Solutions): We encounter solutions in everyday life, some examples are listed. Light passes through these without scattering. The particles in solution are small enough that Brownian motion keeps them suspended in solution.

Slide 11 (Colloids): Like solutions, colloidal particles as so small that they do not settle. These particles are large enough that they do scatter light, and the Tyndall effect is observable. There are many examples of colloids in daily life. For example, “homogenized” milk is a colloid of milk fat particles dispersed in water. Interestingly, fresh cow’s milk which has not been homogenized has larger fat particles that rise to the surface. Hence the phrase, “The cream always rises to the top.” Other examples of colloids are also listed here. Notice that none of these are clear. If a mixture is identified as a colloid, you only know the size range is somewhere between 1-1000 nm. Can we get a closer estimate?

Slide 12 (Suspension): Like colloids, the particles are large enough that light will scatter when passing through the fluid. However, gravity will overcome the Brownian motion and particles will settle to the bottom. Examples are listed.

Slide 13 (Get closer size estimate): Ceramic filters are available with pore (hole) sizes as small as 20 nm. If your nanoparticles were smaller than 20 nm, what would happen? What would happen if the nanoparticles were larger than 20 nm? Of course, we couldn’t tell unless the nanoparticles were colored.

Slide 14 (How to make gold nanoparticles): To make our gold nanoparticles, we will start with a gold compound named hydrogen tetrachloroaurate. This will give us gold +3 ions in solution.

Slide 15 (How to make gold nanoparticles): Heating the solution will speed up the particles, making them more ready to react.

Slide 16 (How to make gold nanoparticles): Sodium citrate is then added to reduce the gold ions to neutral gold metal nanoparticles. The citrate anions will also adhere to the surface of the nanoparticles, stabilizing them and blocking coagulation.

Slide 17 (How to make gold nanoparticles): Within 5 to 10 minutes of adding the sodium citrate, the final gold colloid/nanoparticle color will develop. I won’t tell you what that color is. I’ll let you see it for yourself in lab. Be sure to wait until the full color change has occurred.

Slide 18 (How to make silver nanoparticles): Silver nanoparticles can be made from silver nitrate using the exact same procedure.

Slide 19 (Size estimate): By using the Tyndall effect you can determine if there are particles larger than 1 nm in your mixture. If a mixture settles, its particles are larger than 1000 nm. Using these two tests we can see if we have a solution, a colloid, or a suspension.

Slide 20 (Filtering particles): We will next pour the gold and silver colloids into separate petri dishes, draw them up into a syringe, attach a special ceramic filter with 20 nm pore size to the syringe, and try to
force the liquid mixture through the filter. Whether or not the nanoparticles can go through will allow us to draw conclusions about the size of the particles.

**Slide 21 (Changing the spacing of gold):** Adding salt to the gold nanoparticle mixture destabilizes the colloid, causing coagulation. This should be seen as a color change and will also change the filtering characteristics of the mixture.

**Slide 22 (Seeing the particles):** What would it take to see these nanoparticles under a microscope? The light microscopes used in biology class would not have nearly enough magnification.

**Slide 23 (Seeing the particles):** A scanning electron microscope is a tool used by research scientists to “see” things on a very small scale. An SEM will detect at the nanometer level, small enough to see nanoparticles.

**Slide 24 (SEM picture of colloidal gold):** Here is an SEM image of colloidal gold on the filter surface. The holes in the filter are clearly visible in the background.

**Slide 25 (Early Nanotechnologists):** An example of the relationship between the size and color of nanoparticles is stained glass windows. Medieval glass makers found that they could make brilliant colors by adding small amounts of metals such as gold to the glass. In a way they were early nanotechnologists.

**Slide 26 (Using colloidal gold):** What are the potential applications for gold or silver nanoparticles? Electrical engineers are interested in them for their electrical properties. One exciting area is using nanoparticles as a delivery mechanism for drugs. Gold nanoparticles are currently manufactured for targeted delivery of biomolecules and drugs to selected cells. Trials are underway using this method to treat cancer cells in mice. The drug appears to accumulate in the tumor but not in the healthy cells.

**Slide 27 (Summary):** Today you learned about an emerging field called nanotechnology. You also made nanoparticles of gold and silver. You learned about the relationship between the sizes of particles and the properties of a mixture. Finally, you learned how nanoparticles may be very useful in the field of medicine in treating cancer.

**References:**

## Gold and Silver Nanoparticles – Quiz

Write the letter of the best answer on the line.

Use the following choices for numbers 1-8 below.

A. a compound  
B. a solution  
C. a colloid  
D. a suspension

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<tr>
<td>1</td>
<td>Milk</td>
<td>5</td>
<td>The yellow silver mixture for the lab</td>
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<tr>
<td>2</td>
<td>Salt water</td>
<td>6</td>
<td>The blue gold mixture for the lab</td>
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<td>3</td>
<td>Italian salad dressing (oil and vinegar)</td>
<td>7</td>
<td>The sodium citrate mixture for the lab</td>
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<td>4</td>
<td>The red gold mixture for the lab</td>
<td>8</td>
<td>A medicine that says “Shake well before use” is most likely a</td>
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<td>9</td>
<td>A nanometer is what part of a meter?</td>
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</table>
|   | A. one thousandth  
|   | B. one millionth  
|   | C. one billionth  
|   | D. one trillionth |

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<td>10</td>
<td>Which of the following is most appropriately measured by using nanometers?</td>
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</table>
|   | A. a human hair  
|   | B. a red blood cell  
|   | C. an electron  
|   | D. a protein molecule |

Write your answers in complete sentences. Use the back of this page if needed.

11. Give an example of something interesting you learned about how objects behave at the nanoscale.

12. Objects at the nanoscale are hard for the human mind to fathom. How could you explain a nanometer to your parents, grandparents, or neighbors?

13. What area of nanotechnology would you like to investigate further?
Gold and Silver Nanoparticles – Quiz

Write the letter of the best answer on the line.

Use the following choices for numbers 1-8 below.
   A. a compound
   B. a solution
   C. a colloid
   D. a suspension

C 1. Milk
B 2. Salt water:
D 3. Italian salad dressing (oil and vinegar)
C 4. The red gold mixture for the lab

C 9. A nanometer is what part of a meter?
A. one thousandth
B. one millionth
C. one billionth
D. one trillionth

D 10. Which of the following is most appropriately measured by using nanometers?
   A. a human hair
   B. a red blood cell
   C. an electron
   D. a protein molecule

Write your answers in complete sentences. Use the back of this page if needed.

11. Give an example of something interesting you learned about how objects behave at the nanoscale.
   
   Answers may vary

12. Objects at the nanoscale are hard for the human mind to fathom. How could you explain a nanometer to your parents, grandparents, or neighbors?
   
   Answers may vary

13. What area of nanotechnology would you like to investigate further?

   Answers may vary
Background:
Matter is often classified as elements, compounds, or mixtures. Elements and compounds are pure substances that have specific compositions, like copper or water. Mixtures have variable compositions and can be either homogeneous or heterogeneous depending on how intimately mixed the materials are. Mixtures that are mixed down to the atomic, molecular, or ionic level are called solutions. They are typically clear and do not settle out over time. Suspensions are temporarily blended mixtures in which at least one of the phases has particles larger than 1000 nm, large enough to reflect light. Suspensions do settle out over time. Colloids are often defined as having dispersed particles in the size range 1-1000 nm, between solutions and suspensions. In this size range, colloids scatter light (Tyndall effect), but do not settle out over time. Particles 1-1000 nm in size are called nanoparticles. Nanotechnology research is an emerging industry with many potential applications. Scientists are very interested in colloidal gold and silver as it pertains to nanotechnology. In this lab you will filter the colloids with 20 nm pore size ceramic filters and draw conclusions about the size of the dispersed nanoparticles.

Safety:
Goggles and aprons should be worn as in all chemistry laboratory activities. The hot water baths should be handled with care to avoid burns. Any liquids spilled on skin can be washed off with water. The most dangerous part of this lab is opening the ceramic filters to reveal the metals on the inside surfaces. This requires cutting open the filter while it is still attached to the syringe. Cutting along the seam of the filter with a single-edged razor blade will reveal the inside of the filter. Because of the danger of cutting oneself with the razor blade, this part of the procedure should be performed by the instructor.

Procedure:
1. Put 2 mL of the gold solution in a small test tube and place in the boiling water bath. Do the same for 2 mL of the silver solution. Heat for 5 minutes.
2. After 5 minutes, add 5 drops of the 1% sodium citrate to each test tube. Continue heating until full color change is observed (about 10-15 minutes).
3. Remove the test tubes from the water bath and shine a laser through each one. Note effect below.

<table>
<thead>
<tr>
<th>Tyndall effect</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>Gold colloid</td>
<td></td>
<td></td>
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<tr>
<td>Silver colloid</td>
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4. Pour the tubes into separate petri dishes. Do not mix the colloids.
5. Starting with the silver colloid, draw 1 mL of air and the silver mixture into a small syringe. Attach a filter.
6. Holding the syringe and filter vertically, slowly depress the plunger and force the mixture and the air through the filter. Observe the color of the filtrate (the liquid which passes through the filter).

   Color of the filtrate ___________________

7. Ask the instructor to cut open the filter and observe the color of the inside of the filter.

   Color of the filter ___________________

8. Rinse the syringe and draw in 1 mL of air and the gold mixture. Attach a filter.

9. Filter the gold mixture into a petri dish as you did above with the silver and note the color of the filtrate. The filter can be saved and reused.

10. Add 5 drops of 5% sodium chloride to the gold colloid filtrate and observe any color change.

    Color of the salt and gold colloid mixture _________________

Citrate ions interact with the surface of the nanoparticles to form a barrier around the nanoparticle. This is what prevents nanoparticles from sticking together and clumping into larger particles. By adding sodium chloride, the relationship between citrate ions and the surface of the nanoparticles is disrupted, allowing nanoparticles to clump together. This changes the interaction between light and the surface of the nanoparticles and causes the color to change.

11. Draw 1 mL of air and the new gold colloid into the syringe and attach a filter.

12. Refilter the gold colloid into the petri dish and note the color of the filtrate.

    Color of the filtrate ___________________

13. Ask the instructor to cut open the filter and observe the color of the inside of the filter.

    Color of the filter. _________________

14. Allow the filtrates in the petri dishes to dry out overnight and observe any residue left behind.

    Description of the residue ____________________________________________________________
Questions:

1. What conclusions can you draw about the sizes of the nanoparticles in the three different colloidal mixtures?
___________________________________________________
___________________________________________________
___________________________________________________

2. What did adding sodium chloride to the gold colloidal mixture do to the gold nanoparticles?
_______________________________________________________
_______________________________________________________
_______________________________________________________

3. What can you conclude about particle sizes from the residue left over after the filtrates are dried?
____________________________________________________________
____________________________________________________________
____________________________________________________________

4. What conclusions can you draw about the sizes of gold and silver nanoparticles from the SEM pictures below?
___________________________________________________________
___________________________________________________________
___________________________________________________________

SEM images of colloidal silver (left) and colloidal gold (right) on the surface of a 20 nm pore size ceramic filter.
**Background:**
Matter is often classified as elements, compounds, or mixtures. Elements and compounds are pure substances that have specific compositions, like copper or water. Mixtures have variable compositions and can be either homogeneous or heterogeneous depending on how intimately mixed the materials are. Mixtures that are mixed down to the atomic, molecular, or ionic level are called solutions. They are typically clear and do not settle out over time. Suspensions are temporarily blended mixtures in which at least one of the phases has particles larger than 1000 nm, large enough to reflect light. Suspensions do settle out over time. Colloids are often defined as having dispersed particles in the size range 1-1000 nm, between solutions and suspensions. In this size range, colloids scatter light (Tyndall effect), but do not settle out over time. Particles 1-1000 nm in size are called nanoparticles. Nanotechnology research is an emerging industry with many potential applications. Scientists are very interested in colloidal gold and silver as it pertains to nanotechnology. In this lab you will filter the colloids with 20 nm pore size ceramic filters and draw conclusions about the size of the dispersed nanoparticles.

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Goggles and aprons should be worn as in all chemistry laboratory activities. The hot water baths should be handled with care to avoid burns. Any liquids spilled on skin can be washed off with water. The most dangerous part of this lab is opening the ceramic filters to reveal the metals on the inside surfaces. This requires cutting open the filter while it is still attached to the syringe. Cutting along the seam of the filter with a single-edged razor blade will reveal the inside of the filter. Because of the danger of cutting oneself with the razor blade, this part of the procedure should be performed by the instructor.

**Procedure:**

2. Put 2 mL of the gold solution in a small test tube and place in the boiling water bath. Do the same for 2 mL of the silver solution. Heat for 5 minutes.

4. After 5 minutes, add 5 drops of the 1% sodium citrate to each test tube. Continue heating until full color change is observed (about 10-15 minutes).

5. Remove the test tubes from the water bath and shine a laser through each one. Note effect below.

   Tyndall effect   Yes   No
   Gold colloid   X   ____
   Silver colloid  X   ____

7. Pour the tubes into separate petri dishes. Do not mix the colloids.

8. Starting with the silver colloid, draw 1mL of air and the silver mixture into a small syringe. Attach a filter.
9. Holding the syringe and filter vertically, slowly depress the plunger and force the mixture and the air through the filter. Observe the color of the filtrate (the liquid which passes through the filter).

   Color of the filtrate _________clear_____________

8. Ask the instructor to cut open the filter and observe the color of the inside of the filter.

   Color of the filter _______silver_____________

9. Rinse the syringe and draw in 1 mL of air and the gold mixture. Attach a filter.

10. Filter the gold mixture into a petri dish as you did above with the silver and note the color of the filtrate. The filter can be saved and reused.

11. Add 5 drops of 5% sodium chloride to the gold colloid filtrate and observe any color change.

   Color of the salt and gold colloid mixture _______blue_________

Citrate ions interact with the surface of the nanoparticles to form a barrier around the nanoparticle. This is what prevents nanoparticles from sticking together and clumping into larger particles. By adding sodium chloride, the relationship between citrate ions and the surface of the nanoparticles is disrupted allowing nanoparticles to clump together. This changes the interaction between light and the surface of the nanoparticles and causes the color to change.

11. Draw 1 mL of air and the new gold colloid into the syringe and attach a filter.

15. Refilter the gold colloid into the petri dish and not the color of the filtrate.

   Color of the filtrate _______clear_____________

16. Ask the instructor to cut open the filter and observe the color of the inside of the filter.

   Color of the filter _______gold___________

17. Allow the filtrates in the petri dishes to dry out overnight and observe any residue left behind.

   Description of the residue _______small white translucent film of crystals_________________________

Questions:
2. What conclusions can you draw about the sizes of the nanoparticles in the three different colloidal mixtures?

   The silver nanoparticles are larger than the red gold nanoparticles, because they collect on the filter and the red gold nanoparticles do not. The blue gold nanoparticles also collect on the filter, because the gold nanoparticles aggregate together.

3. What did adding sodium chloride to the gold colloidal mixture do to the gold nanoparticles?

   It caused them to aggregate and collect on the filter.

4. What can you conclude about particle sizes from the residue left over after the filtrates are dried?

   The particles that make the residue are smaller than 20 nm. There were ions left in solution that crystallized after the water evaporated.

5. What conclusions can you draw about the sizes of gold and silver nanoparticles from the SEM pictures below?

   The gold nanoparticles are noticeably smaller than the silver nanoparticles. The gold nanoparticles are found in clusters, leading us to believe these were blue gold nanoparticles.

   SEM images of colloidal silver (left) and colloidal gold (right) on the surface of a 20 nm pore size ceramic filter.
Established in 2003, the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (NanoCEMMS) is funded by the National Science Foundation. Partnering Institutions include the University of Illinois, North Carolina Agriculture and Technical State University, Stanford University, University of Notre Dame, University of California – Irvine, and Northwestern University. Researchers are developing a nanomanufacturing system that will build ultrahigh-density, complex nanostructures. The Center’s research will ultimately result in a new way of working and has the potential to create millions of jobs for American workers. Our nation’s school children must be prepared to assume the new roles that will be the inevitable outcome of these emerging technologies.

This learning module is one of a series that is designed to interest middle and high school students in pursuing this new field. The Center also offers ongoing professional development for teachers through a continuous series of workshops and institutes. To sign up for a workshop or to order more learning modules, visit our website at http://www.nano-cemms.illinois.edu.

For more information, contact: Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems; University of Illinois at Urbana-Champaign, 4400 Mechanical Engineering Laboratory, 105 South Mathews Avenue, MC-244, Urbana, IL 61801

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