Student Guide

Name:________________________________Date:_______________Class:___________

Sand and Multiple Light Scattering (with Answers in Red)

Safety

1. Silica sand: avoid prolonged breathing of any fine sand particles that may become airborne.
2. Toluene, acetone, and other organic solvents: use in a fume hood. Chemical resistant gloves should be worn when pouring or transferring solvents.
3. Dispose of toluene in an approved solvent waste container which will be disposed of in accordance with school regulations.

Introduction: Nanoparticles are very small bits of matter, typically less than 100 nanometers across. This is 1/1000 the thickness of a human hair! A nanometer is $1x10^{-9}$ meters or one billionth of a meter. Nanoparticles are increasingly being used in many consumer products, such as sunscreens, skin creams, and food additives. When they work with nanoparticles, scientists and engineers must measure several key properties, especially the size distribution of the particles. Since these particles are so small, they cannot be seen even with a good light microscope. Instead, such tiny particles are often analyzed through the specialized use of light scattering.

This lab introduces concepts of particle light scattering, using somewhat larger particles that you can more easily see. In this lab you will study the optical properties of various materials: sand, air, water, and toluene. You will then use your observations to predict the optical properties of a Mystery Liquid. Do you notice that when things get wet, they change color - for example, when you spill water on your jeans? Today we will work to discover why this happens, and to further explore this phenomena of light scatter.

Light scattering occurs when a given material interacts with light rays. The figure below shows a ray of light striking the boundary between two different materials, for example, air and water. You can easily observe that light appears to bend at the interface between the two materials. If we measure the angles that the ray makes with a line drawn perpendicularly to the interface (called the "normal"), we find that the angle in air $Ø_1$ and the angle in water $Ø_2$ are related by Snell's Law:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

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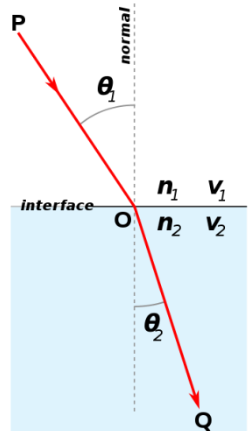
Figure 1: Light striking an interface between air and water. The light bends as it passes from one material to the other.



Snell's law states that the ratio of the sines of the angles of incidence and refraction is equivalent to the ratio of phase velocities in the two media, or equivalent to the reciprocal of the ratio of the indices of refraction. Snell's Law says that this bending of light is related to the *index of refraction* of each material, labeled n_1 and n_2 in the figure. The property of refractive index acts as a fingerprint of individual materials. It may be used to provide precise and repeatable data on the identity of a given material. It is also a key predictor of how light will scatter from a material, as you will see.

Question: How is light scattering involved with our ability to see objects illuminated by a light source?
The light you see is reflected or scattered off the object back to your eyes.

Make a prediction of what the sand will look like

1. **as we add water to the sand**
2. **as we add toluene to the sand**

I think that the sand will get darker with the water and lighter with the toluene.
Answers will vary and may include color changes or wetness

Materials:

- Safety goggles
- Petri dishes (3)
- 10ml graduated cylinders (3)
- Sand – enough to fill Petri dishes
- Ruler to level sand in dish
- Distilled or deionized water (3ml)
- Toluene (3 ml)
- Mystery Liquid (3ml)
- Black paper or cardstock
- 3x5 cards
- marker

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Procedure:

1. Using the Internet, research the refractive index of air, sand, water, and toluene. Complete the Research column in the Observation Table below.
2. Complete the Prediction Column in the Observation Table below.
3. Gather your materials. Add sand to each of the Petri dishes, tamp it down, and smooth the surface across the top with the side of a ruler.
4. Place the dishes on a black paper background. Using a piece of paper or 3x5 card, label the dishes as “1-water”, “ 2-toluene”, “3-mystery”.
5. For the first dish, use a graduated cylinder to add 3 ml of water to the sand in one half of dish #1. (Use just enough water to wet the sand—do not add so much that the water pools in the sand.)
6. Describe and record the different appearance between the dry and water-wetted sides. An example is shown in Figure 2.

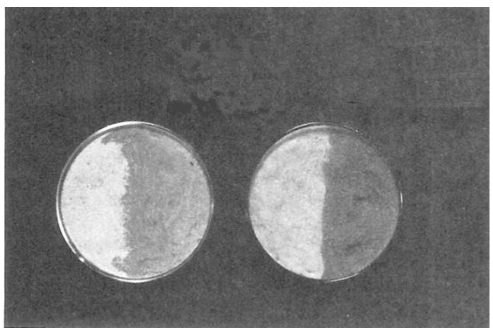

Figure 2. Left: Comparison of sand in air to sand in the mystery liquid. Right: Comparison of sand in water to sand in toluene

7. For dish #2, use a different graduated cylinder to add 3 ml of toluene to the sand in one half of the dish. Describe the different appearance between the dry and toluene-wetted sides.
8. Compare the appearance of the dry, water-wetted, and toluene-wetted sand samples. Which one is darker or lighter?
9. Compare the observation results with the index of refraction information you researched. Explain the different appearances of the sand samples in terms of the index of refraction of sand versus the surrounding material.
10. Your instructor will give you a “mystery liquid”. Add 3 ml of this liquid to the sand in one half of dish #3. Describe the different appearance between the dry and liquid-wetted sides.
11. Based on your analysis in step 9, estimate the value of the index of refraction of the mystery liquid. Is it greater or lower than air, toluene, or water?

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Observation Table

	Observation	Amount of Liquid Added	Research: Refractive Index	Prediction: Lighter or Darker?
Sand with Air	*Sand is taupe colored*	Not applicable	*The refractive index of air* is 1.0003. *The refractive index of sand* is 1.54427.	
Sand with Water	*Sand is medium taupe colored*	*3mL*	*The refractive index of water is 1.33.*	The sand with the water compared to the sand with air with will be ________________.
Sand with Toluene	*Sand is very dark taupe colored*	*3mL*	*The refractive index of toluene* is 1.4969.	The sand with the toluene compared to the sand with air with will be ________________.
Sand with Mystery Liquid	*Sand is medium taupe colored. Close to the color with water, perhaps a shade darker.*	*3mL*	*The refractive index of the Mystery Liquid is 1.35916.*	The sand with the mystery liquid compared to the sand with air with will be ________________.

In your lab Notebook

Analyze Results:

What did you observe and why?

The closer the optical properties of the liquid are to the sand, the more forward the light will be scattered. The more forward the light is scattered, the darker the sand will appear.

Draw Conclusions:

1. Is a chemical reaction taking place that would explain the observation? Support your reasoning. *Chemical reactions occur when the reactants (particles) come into contact with each other and form new products. No new products are being formed. There is only a change in color observed.*
2. Sketch a possible photon path through the sand for each of the trials using a cut away side view that would explain your observations. *Sketches will be similar to Figure 3 in the Teacher's Guide, with the toluene trial showing progressively more light scattering forward as compared to the air and water trials, respectively.*

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3. Why did the water in the sand create the smallest color difference as compared to the dry sand? *Water has the lowest refractive index of all the materials tested, so it acted more like air: light scattered from the water-sand interfaces was more likely to be scattered in all directions, and less light was absorbed in the sand. This results in a lighter appearance than with the other liquids.*
4. Which liquid has a refractive index that is closest to that of sand? *The toluene produces the most forward scatter and absorption, and so it results in the darkest shade of sand. Therefore, toluene has a refractive index closest to that of sand.*

5. Based on your observations, comment on the refractive index of sand and the Mystery Liquid. Include in your discussion the accuracy of your predictions of comparing the Mystery Liquid to the other liquids. Once the identity of the mystery liquid is revealed by your instructor, look up its refractive index. Does this explain what you observed? *The RI of the Mystery Liquid is not as close to sand as that of toluene, but its RI is closer to sand than is the water.*
6. Was it critical to add a precise and consistent amount of liquid to each sample in this lab? *No. As long as the sand was adequately wetted, the amount of liquid was not a strong determining factor. The color change showed immediately as the liquid was added.*
7. If you were given a liquid with the same refractive index as the sand, would you be able to see the sand? *No. The sand would appear invisible, for the light would continually travel through the sand and liquid mixture. No light would scatter out of the mixture so as to be seen by an observer.*
8. At what scale are the optical properties of this lab occurring at? At what scale are you making your observations? *The optical properties are occurring at a nanoscale and the lab observations are occurring at a much larger scale: the smallest object resolution of the human eye is ~ 0.116 mm. Sand particles range in size from 75 microns (.075mm) to 4.75 millimeters in diameter.*

Clean up: Sand wetted with water or the solvents can be dried and re-used. Allow the solvent-wetted sand to dry in a fume hood. Extra organic solvents should be collected as solvent waste and disposed of in compliance with your school's hazardous waste procedures.

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