Refraction Action!

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Learning Experience Description:

This laboratory will introduce Snell's Law using pure compounds and simple equipment. The lab will incorporate chemistry, physics, and trigonometry. This lesson is intended for high school science or math students. Students may use calculators and/or Excel spreadsheets.

Bioscience Connection:

Byproducts of biodiesel production include a homogenous mixture of glycerol, water, and methanol. A way to determine the percent methanol of a solution is to measure the solution's index of refraction. It is important to know how much methanol is left in byproducts so that it can be repurposed. The glycerol is not useable unless the methanol is removed.

Background Information:

The speed of light changes depending on the medium through which it is traveling. When light moves from one substance to another, this change in speed causes light to bend. It possible to measure the angle at which light enters and exits a substance. A Dutch scientist, Willebrord Snellius (1580-1626), explained the relationship between the angle that light enters a substance and the angle at which the light bends.

The relationship is know as "Snell's Law:"

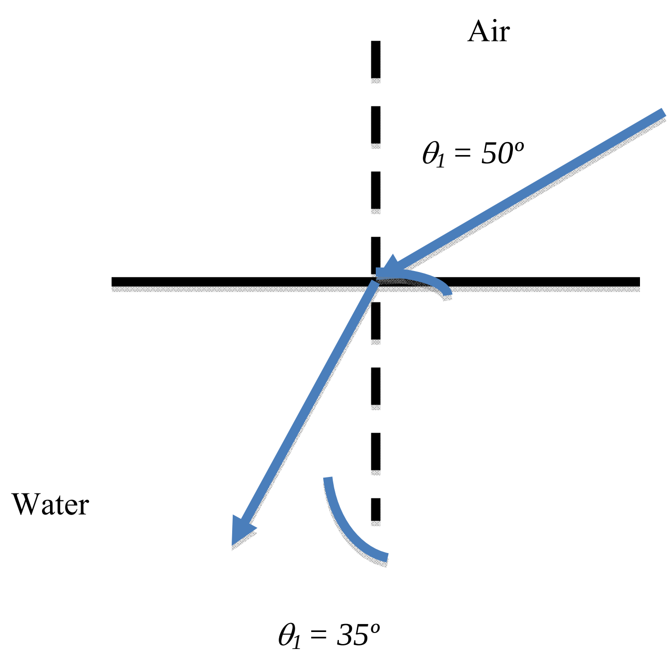
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

n_1 = index of refraction for substance #1

$\theta_1 = n_2$ = index of refraction for substance #2

θ_1 = angle of incidence

θ_2 = angle of refraction



Grade Level:

High school physical science, chemistry, physics, trigonometry

Duration of Learning Experience:

This learning experience is recommended to follow the "Make Biodiesel and 'Still' Use the Methanol" lesson. This lesson will take 1-2 typical 50-minute class periods.

Pre-Visit Classroom Information:

It is recommended that students make biodiesel and distill the glycerin from the biodiesel before this lesson. Students should have a basic understanding of the concept of sine and measuring angles using a protractor. The instructor may wish to review the relationship between speed of light, frequency, and wavelength prior to the lab.

Post-Visit Classroom Information:

Scientists use a hydrometer as another way to test density of solution. Hydrometers measure the specific gravity of solutions. Use a hydrometer in class to measure the specific gravity of various solutions. Compare the specific gravity to the refractive index for the solution.

Concept / Topic:

- Refraction
- Snell's Law
- Optical Density
- Physical Properties of Matter
- Speed of Light

Vocabulary:

- Angle
- Biodiesel
- Density
- Distillation
- Frequency
- Homogeneous
- Refraction
- Refraction
- Sine
- Snell's Law
- Theta
- Wavelength

Content Standards, Benchmarks, and Indicators Addressed:

Kansas Common Core Math Standards (www.ksde.org)

Define trigonometric ratios and solve problems involving right triangles.

6. Understand that by similarity, side ratios in right triangles are properties of the angles in the triangle, leading to definitions of trigonometric ratios for acute angles.

Apply trigonometry to general triangles.

11. (+) Understand and apply the Law of Sines and the Law of Cosines to find unknown measurements in right and non-right triangles (e.g., surveying problems, resultant forces).

Interpret the structure of expressions.

1. Interpret expressions that represent a quantity in terms of its context.

a. Interpret parts of an expression, such as terms, factors, and coefficients.

b. Interpret complicated expressions by viewing one or more of their parts as a single entity. *For example, interpret P(1+r)n as the product of P and a factor not depending on P.*

2. Use the structure of an expression to identify ways to rewrite it. For example, see $x^4 – y^4$ as $(x^2)^2 – (y^2)^2$, thus recognizing it as a difference of squares that can be factored as $(x^2 – y^2)(x^2 + y^2)$.

Kansas State Science Standards

▲ S.HS.1.1.2

The student actively engages in investigations, including developing questions, gathering and analyzing data, and designing and conducting research.

▲ S.HS.1.1.3

The student actively engages in using technological tools and mathematics in their own scientific investigations.

▲ S.HS.2B.3.2

The student understands waves have energy and can transfer energy when they interact with matter.

▲ S.HS.5.1.1

The student understands technology is the application of scientific knowledge for functional purposes.

Technology Standards Addressed:

▲ S.HS.5.1.1

The student understands technology is the application of scientific knowledge for functional purposes.

Learning Experience Objectives:

Students will be able to determine the index of refraction of a liquid using Snell's Law.

Students will be able to identify an unknown homogeneous solution using Snell's Law.

Students will be able to interpret an index of refraction calibration curve.

Required Materials:

- Scientific Calculator
- Corn oil
- Distilled water
- Refraction and Total Internal Reflection –
  (One Individual Kit per lab group)
- One drinking straw
- Glycerin, 500 mL
- Methanol (Methyl Alcohol), 500 mL
- 1,000 mL borosilicate beaker*
- 600 mL borosilicate beaker*
- 250 mL borosilicate beaker*
  *You may use various combinations of beakers

Optional Materials

- Computer with Microsoft Excel
- Beaker with no markings (400 mL)
- Reichert r^2mini Digital Pocket Refractometer
- Optical calcite

Lab Safety:

- Students should wear goggles at all times during the lab.
- Glycerol is viscous and sticky. Students may want to wear an apron or lab coat.
- Methanol is extremely flammable and burns with a nearly invisible flame. Methanol is toxic by ingestion and may cause blindness if ingested. When not in use, store methanol in a flammables cabinet.
- The laser included in the refraction kit is a Class IIIA laser. The laser beam is harmful if viewed directly but not harmful if viewed indirectly.

MSDS Links

Methanol	http://www.midi-inc.com/pdf/MSDS_Methanol.pdf
Glycerin/Glycerol	http://www.sciencelab.com/xMSDS-Glycerin-9927350

Technology Connection:

Students may use an Excel spreadsheet or scientific calculator to calculate the index of refraction. Students may also use an online simulator (see Extension) to determine the index of refraction of various materials.

Anticipatory Set:

The teacher should prepare this demonstration before class begins.

Preparation:
Warning – this is messy! It may be best to prepare this demonstration on a tray covered in paper towels.

Fill a 1,000 mL borosilicate (Pyrex®) beaker approximately half full of corn oil. Next place a 600 mL beaker inside the 1,000 mL beaker and oil. Make sure the inside beaker is completely covered in oil. You may want to purchase the "beaker with no markings" found in the optional materials section. This demonstration will work fine with a regular beaker as well.

Presentation:
Show the students the beaker full of corn oil and ask students to make some observations about the beaker. Then, with gloves on, pull the smaller beaker out and lay it on the tray. Ask students to give an explanation as to why the beaker is visible outside of the beaker and invisible inside of the beaker.

Pour a glass of water and place a drinking straw in it. Students will notice that the straw appears bent. Discuss reasons why the straw appears to be different in the air and water. Does light travel through air or water more quickly?

Step-By-Step Procedures:

To start the lesson the teacher will perform "The Disappearing Beaker" demonstration. A PowerPoint presentation for the basic concepts of index of refraction and Snell's Law is included in Appendix A.

Teacher Set-Up "A": This set up is intended for small classes or large classes where plenty of semi-circle refraction dishes are available. The dishes can be pre-poured and labeled so that there is minimal exposure to chemicals, smaller amounts or chemicals are needed, and less time is spent cleaning up. It is recommended that each group start with at least one sample.

Example Set-up for class of 24 students (12-2 person groups):

- Four semi-circle dishes filled with methanol
- Four semi-circle dishes filled with ethanol
- Four semi-circle dishes filled with water
- Four semi-circle dishes filled with glycerol (glycerin)

Teacher Set-Up "B": This set-up is intended for classrooms with fewer materials available. Each group is given a semi-circle dish and asked to test each of the three chemicals. Each group trades semi-circle dishes with another group testing different chemicals until all chemicals have been tested. Semi-circles are cleaned up and returned to the instructor for use with the next class.

For Teacher Set-Up "A" and "B":

A laser pointer is available for each group. The semi-circle is placed on top of the "protractor" paper (see attached). The teacher should demonstrate where to place the laser on a portion of the degree line. Students will notice the angle at which the laser exits the semi circle of fluid and record that angle. It was discovered during research that the angles of 50°, 55°, and 60° provide data that is fairly close to the accepted values for water, methanol and glycerol. Once the angle of refraction for each solution is observed and recorded, the index of refraction can be calculated using Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

n_1= index of refraction for substance #1 (for this experiment air)

n_2 = index of refraction for substance #2 (unknown)

θ_1 = angle of incident (angle in)

θ_2 = angle of refraction (angle out)

Students will compare the measured index of refraction with the accepted values and calculate error using the following equation:

% Error = [(actual value – experimental value) / actual value] X 100

Sample data of this experiment is provided below. Please note that all angles are recorded in radians. This calculation can be performed in degrees, but not in a Microsoft Excel Spreadsheet.

Substance	**sinθ_1**	**n_2**	**sin θ_2**	**Accepted Index of Refraction**	**Average Average using Flinn manual**	**Average Refractometer**	**Error Flinn**
water	0.8727	1.3356	0.6109	1.3300	**1.3345**	1.3327	**-0.340%**
water	1.0472	1.3335	0.7069				
methanol	0.8727	1.3699	0.5934	1.3288	**1.3586**	1.3285	**-2.243%**
methanol	1.0472	1.3473	0.6981				
glycerol	0.8727	1.4456	0.5585	1.4746	**1.4777**	--------------	**-0.212%**
glycerol	1.0472	1.5099	0.6109				

*This sample experiment was performed using 50° and 60° readings. In the initial trial, these angles were closest to the known values.

Extension: If the lab is equipped with a refractometer (see "optional materials"), students may use the refractometer to measure index of refraction of water, methanol, and glycerol.

Students could be given a clear unknown and asked to identify it using index of refraction. The students could be given more than one unknown. Have students try various concentrations of salt water or sugar water, or think of a substance they might want to test.

The index of refraction of a substance is temperature dependent. Students may explore this by cooling down solutions and measuring index of refraction. Be aware that methanol is flammable and heating it to determine index of refraction is not recommended.

Assessment:

A summative quiz and answer key can be found in Appendix B. As an alternative assessment, the teacher may wish to have students measure the index of refraction of additional substances listed in the lab document.

Closure (Reflect Anticipatory Set):

Students now have practice measuring the index of refraction. Refer to the beginning of the lesson and the “disappearing beaker” demonstration. Ask students to predict the index of refraction of corn oil based on what they know about methanol, water, and glycerol.

In groups or as a class measure the index of refraction of corn oil in a semi-circle dish. Take multiple measurements and average the indices of refraction.

Questions to ask:

How does the index of refraction of corn oil compare to air? Compare to water? The index of refraction of corn oil n = 1.474, air = 1.000, water = 1.330

How does the index of refraction of corn oil compare to Pyrex (n = 1.474)? The index of refraction is the same so the eye can’t tell the difference between the oil and the glass.

What factors might change the index of refraction of a solution of 95% methanol in water? The temperature of the solution changes the index of refraction. Increasing the temperature of the solution decreases the index of refraction.

What are some other ways scientists might use index of refraction to identify materials? Scientists use refractometers in industry to determine the amount of sugar in a solution. The weight percent of sucrose in solution is called “Brix.” This measurement is used primarily in the beverage industry to determine sugar content. Scientists can also measure salt content in water using a refractometer.

More information on refraction:

The University of Colorado maintains a website with several chemistry and physics simulations. Students may use the refraction simulation found here: http://phet.colorado.edu/en/simulation/bending-light.

The concept of refraction can also be used to describe the speed of light in solids and gases. Transparent solids bend light more sharply because atoms are packed together tightly and in more uniform patterns than liquids or gases. Gemstones have unique indices of refraction. It is possible to use the index of refraction to determine the difference between cubic zirconium (n = 2.14-2.20) and diamond (2.41) to determine the difference between the gems. Optical calcite ($CaCO_3$) exhibits birefringence, or double refraction. Hold a piece of optical calcite up to a printed page and notice the image produced. A prism is also a great example of refraction. Each wavelength of white light is refracted at a different angle, so it is possible to see a rainbow of colors.

Light propagates through the near vacuum of space at approximately 3.0×10^8 m/sec. It travels through the Earth’s atmosphere more slowly because of the various atmospheric gases. The color of a sunset is due to the density of the atmospheric gases between the eye and the sun. Mirages appear because of the density and temperature of air. Stars twinkle when viewed from Earth because the light from stars is refracted as it travels through the layers of the atmosphere.

Materials:

Scientific Calculator

Corn oil	Grocery store	
Distilled water	Grocery store or lab	
Refraction and Total Internal Reflection – Individual Kit	Flinn Scientific AP7269	$31.65
Glycerin, 500 mL	Flinn Scientific G0007	$11.50
Methanol (Methyl Alcohol), 500 mL	Flinn Scientific M0055	$5.95
1,000 mL borosilicate beaker*	Flinn Scientific GP1050	$20.20
600 mL borosilicate beaker*	Flinn Scientific GP1049	$10.60
250 mL borosilicate beaker*	Flinn Scientific GP1047	$7.00

*You may use various combinations of beakers as long as the beakers will all fit inside each other.

Optional Materials

Computer with Excel

Beaker with no markings (400 mL)	Educational Innovations GL-500	$9.95
Reichert r^2mini Digital Pocket Refractometer	Cole-Palmer R-81030-60	$295.00
Optical calcite crystal	Educational Innovations PF-2	$6.95