Energizing Engineering Education
Research Experience for Teachers

Using Lasers to Make the Invisible, Visible

Lesson 3: Measuring Concentration of Liquids Using a Laser Pointer

Subject Areas: Physical Science, Physics, Chemistry, Science and Technology, Measurement

Grade Level: 9-12

Time Required: 2-3, 1 hour class periods

Group Size 2 students

Summary
Many modern laboratory techniques, such as biological assays, depend on using a refraction pattern to determine the concentration of molecules in a solution. For example, immunoassays are often used to determine the titer of antibodies in a person's blood to diagnose them as having or been exposed to certain diseases.

Engineering Connection
Students will investigate how they can use the refraction of laser light to determine the concentration of sugar in liquid water.

Engineering Category

2. Engineering analysis or partial design

Keywords
Refraction, Snell's Law, angle of incidence, index of refraction, prism, density

Educational Standards
State STEM Standard

II.I.II.10. Explain how wavelengths of electromagnetic radiation can be used to identify atoms, molecules, and the composition of stars.
II.I.II.11. Explain how the interactions of waves can result in interference, reflection, and refraction.
II.I.III.12. Describe how waves are used for practical purposes (e.g., seismic data, acoustic effects, Doppler effect).

ITEEA Standard

FF. Complex systems have many layers of controls and feedback loops to provide information. *(Grades 9 - 12)*

Pre-Requisite Knowledge
Students should be familiar with laser safety. In addition, they should have a basic understanding of lasers in order to explain why lasers are used for this activity instead of normal light.

Learning Objectives

After this activity, students should be able to:

- Use Snell's Law to determine the concentration of sugar in different solutions.
- Understand why laser light is needed to perform this experiment rather than incandescent light

Materials List

Each group needs:

- Hollow prism (purchased or built)
- Laser pointer
- Cardboard box
- Piece of string
- Water
- Sugar
- Graduated cylinder (100 mL)

To share with the entire class:

- Tape
- Laboratory balance
- Calculators

Vocabulary / Definitions

Word	Definition
Refraction	the change in direction of a wave due to a change in its transmission medium
Snell's Law	a formula used to describe the relationship between the angles of incidence and refraction, when referring to light or other waves passing through a boundary between two different isotropic media, such as water, glass and air.
Angle of incidence	a measure of deviation of something from "straight on", for example :in the approach of a ray to a surface, or the angle at which the wing or horizontal tail of an airplane is installed on the fuselage, measured relative to the axis of the fuselage.
Index of refraction	is a dimensionless number that describes how light, or any other radiation, propagates through that medium. It is defined as n =c/v
Prism	a transparent optical element with flat, polished surfaces that refract light. At least two of the flat surfaces must have an angle between them.
Density	mass per unit volume

Procedure

Background

Students should have already performed lessons on the properties of laser light. They will use this lab activity to determine the concentration of sugar in different solutions. As a formative assessment, students will use this technique to determine the concentration of an unknown solution. Then, in the next lesson apply this technique to immunological testing.

Before the Activity

- Hollow prisms need to be purchased or built. Instructions for assembly can be found at the website immediately below.

(This procedure can be found at: http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p028.shtml#procedure)

Activity 1: Measuring the Index of Refraction of a Liquid

Note: Do this project in an area where you can put a table close to a flat wall or window, and where taping paper to the wall or window is allowed.

1. Figure 7, is a diagram of the setup you will use for measuring the index of refraction of a liquid. This is what the setup would look like if you were looking down on it from above. (Note that the diagram is not to scale.)

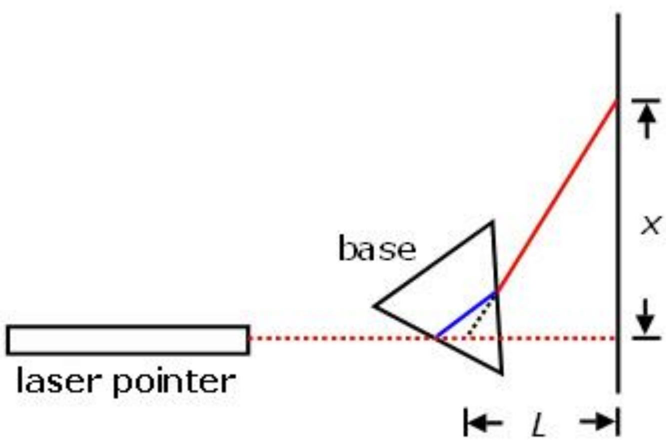

Figure 7. Diagram of setup for measuring the index of refraction of a liquid using a laser pointer and a hollow triangular prism(not to scale; based on the diagram in Nierer, 2002).

2. Lay the laser pointer on a table. The laser pointer should be set up so its beam (dotted red line in Figure 7) is perpendicular to a nearby wall.

3. Lay a piece of paper in front of the laser pointer. Tape it securely to the table. The paper will be used to mark where the laser beam enters and exits the prism.
4. Place the prism on top of the paper, a few centimeters in front of the laser pointer. One of the prism's triangular faces should be resting on the paper, as shown in Figure 8. Using a pencil, trace around the prism's base. If you move the prism, always return it to this location before rotating it, if needed, as explained in step 12.
5. Adjust the height of the laser pointer with pieces of cardboard until the laser's beam hits about halfway up the side of the prism. See Figures 8 and 9.

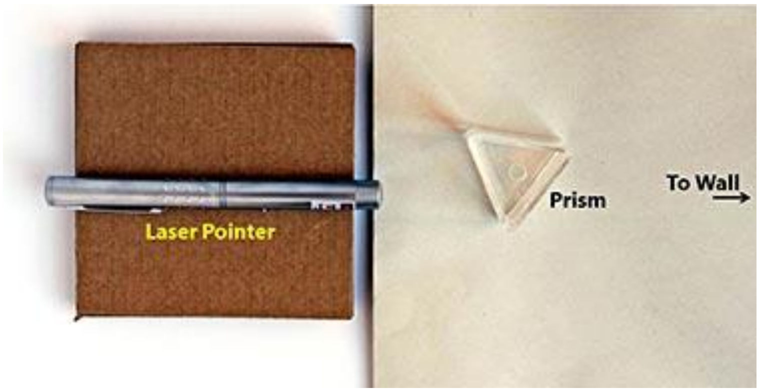

Figure 8. Photograph showing experimental setup for measuring the index of refraction of a liquid. The prism is a few centimeters in front of the laser pointer. The laser pointer is pointing perpendicular to a nearby wall.

Figure 9. Adjust the height of the laser pointer with pieces of cardboard. The beam of the laser should hit the prism about halfway up the prism's side.

6. Tape the cardboard to the table, and then tape the laser pointer to the cardboard. Make sure that neither the cardboard nor the laser pointer can move. If the laser pointer's position changes, your measurements will not be accurate.
    a. *Troubleshooting Tip:* If you have two or more sheets of cardboard stacked together, you may need to tape the pieces of cardboard together so that they do not slip.
7. Tape a big piece of paper to the wall in front of the laser pointer. You will use this paper to mark where the laser beam hits the wall.
8. To measure the angle of minimum deviation, θ_{md}, which you will use to calculate the index of refraction of the liquids that you test, you need to mark several points and measure the distances between some of these points. Figure 10, is a more detailed view of the prism and wall. It shows all the points you need to mark in order to measure the

angle of minimum deviation, θ_{md}. The procedure below explains how to mark these points and determine the angle of minimum deviation, θ_{md}.

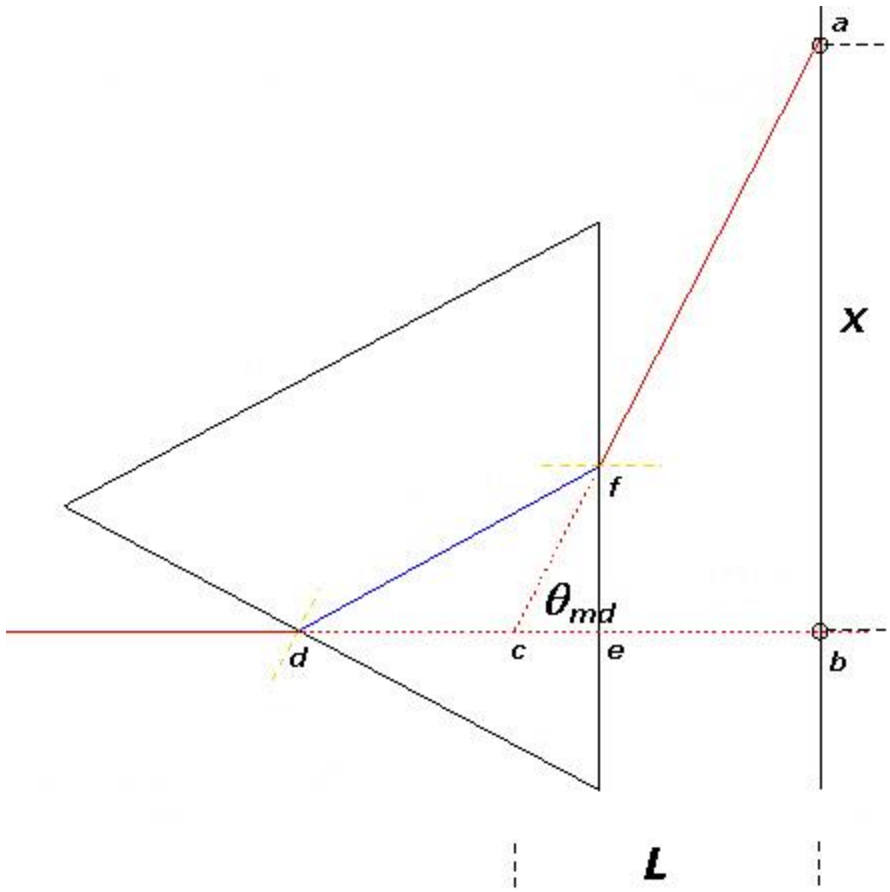

Figure 10. Detail diagram showing how to measure the angle of minimum deviation (not to scale; based on the diagram in Nierer, 2002).

9. When the prism is empty (filled only with air), placing it in the laser's path should not divert the beam. Turn the laser on, and mark the spot where the beam hits the paper taped to the wall. Mark this as point b (point *b* in Figure 10).
   a. *Troubleshooting Tip:* Before testing a new solution, turn on the laser and shine it through an empty prism to make sure that the laser beam still hits point b. If the laser beam no longer hits point b, your measurements will not be accurate. Adjust the laser's position, if necessary, until the undiverted beam hits point b.
10. With the prism empty, mark where the beam enters the prism on the paper the prism is sitting on (point *d* in Figure 10). Label it point d.
11. With the prism still empty, mark where the laser beam exits the prism on the paper the prism is sitting (point *e* in Figure 10). Label it point e.
12. Turn off the laser. Fill the prism with plain water. If you moved the prism to fill it with water, return it to the outline you made on the piece of paper. Turn the laser back on.

13. Rotate the prism so that the path of the refracted beam within the prism (solid blue line from *d* to *f* in Figure 10) is parallel with the base of the prism, the side of the prism that has no laser beam hitting it.
    a. *Troubleshooting Tip:* A pinch of non-dairy creamer in the liquid can help you see the beam within the prism, and should not have a significant effect on the index of refraction of the liquid. Or, if you do not have non-dairy creamer, take a straight edge and line it up with the laser beam's entrance and exit points (as seen when looking at the prism from a top view). Rotate the prism until the straightedge connecting those two points is parallel to the side of the prism that the laser beam does not hit.
14. When the prism is rotated correctly (as described in step 13), mark the position where the emerging beam hits the paper taped to the wall (point *a* in Figure 10). Label it point a.
15. On the paper on the table, mark the point where the beam emerges from the prism (point *f* in Figure 10). Label it point f.
16. Now you can move the prism aside. Leave the papers taped in place.
17. Use a ruler to draw a line from point *d* to point *e*. This marks the path of the undiverted beam.
18. Next, extend a line from point *a* (on the wall) through point *f* (on the table). To do this, stretch a string from point a so that it passes over point *f*. Mark the point where the string crosses the line between *d* and *e*. This is point *c*.
19. Measure the distance between points *a* and *b*, and record it in your lab notebook. This is distance *x* (see Figure 10).
20. Measure the distance between points *b* and *c*, and record it in your lab notebook. This is distance *L* (see Figure 10).
21. The distances you have measured define the angle of minimum deviation, θ_{md}. The ratio *x/L* is the tangent of the angle of minimum deviation, θ_{md}. To calculate the angle, use your calculator to find the arctangent of *x/L*. (The *arctangent of x/L* means "the angle whose tangent is equal to *x/L*.") Record the angle and its units (radians or degrees) in your lab notebook.
22. Now that you have the angle of minimum deviation, you can use Equation 5, to calculate the index of refraction, *n*, of the liquid in the prism.

Equation 5:

$$n = 2.00056 \times \sin[0.5(\theta_{md} + 60°)]$$

- **n** = index of refraction of solution (unitless, since it is a ratio)
- $\boldsymbol{\theta_{md}}$ = angle of minimum deviation (degrees)

23. Check that your setup is working correctly by measuring the index of refraction of plain water using steps 9 through 22 of this procedure. You should get an index of refraction of about 1.334.

Activity 2: Standard Sugar Solutions for Comparison

1. You will make three sugar water solutions, using the amounts of sugar and water shown in Table 1. Use the gram scale to weigh out the appropriate amount of sugar.
    a. *Troubleshooting Tip:* Using warm water will help the sugar dissolve more quickly.

Desired concentration (% mass/volume)	Amount Sugar (g)	Amount Water (mL)
10	10	90
20	20	80
30	30	70

Table 1. Amounts of Sugar and Water for Standard Sugar Solutions

2. Mix each of the solutions in Table 1 in a graduated cylinder or liquid measuring cup with metric units, using a stirring rod to dissolve the sugar. Once the solutions are made and the sugar is completely dissolved, set aside the 20% and 30 % solution and fill the prism with as much of the 10% sugar solution as possible.
3. Measure the index of refraction of the 10% sugar solution (following the steps in the "Measuring the Index of Refraction of a Liquid" section of the procedure, above). Repeat your measurements 4 more times for the 10% sugar solution, for a total of 5 replicates. Average your results.
4. Empty the prism and rinse it with plain water. Then repeat step 3 using 20% and then 30% sugar solutions.
5. Now measure the index of refraction of a solution with unknown sugar concentration (e.g., a clear soft drink or fruit juice). If you measure a carbonated beverage, make sure that there are no bubbles in the path of the laser (gently dislodge them from the side of the glass, if necessary).
6. With the index of refraction of the unknown solution, combined with the data you have from your known sugar solutions, you should be able to estimate the sugar concentration of the unknown solution.

Safety Issues

- Anytime laser pointers are used, student should be reminded of the dangers of working with lasers.
- The classroom should be arranged in a way so that refracted and reflected beams will not contact other students.

Assessment
Students should be able to closely determine the concentration of sugar in the unknown solution.

In the next activity, students will be performing ELISA assays and use this technique to determine whether an imaginary patient is carrier for a certain diseases.

I recommend a reflective activity that has students describe why lasers must be used for this procedure as opposed to another light source.

References
http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p028.shtml#procedure

Contributors
Andres Plaza, South Valley Academy, Albuquerque, NM
sciencebuddies.org

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