Measuring Sugar Content of a Liquid with a Laser Pointer

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Experimental Procedure

Laser Pointer Safety

Adult supervision recommended. Even low-power lasers can cause permanent eye damage. Please carefully review and follow the Laser Safety Guide (http://www.sciencebuddies.org/science-fair-projects/references/laser-safety-guide).

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 6, 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.)

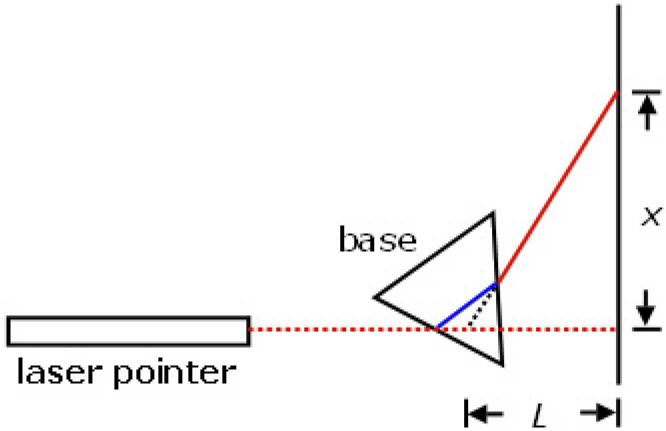

Figure 6. Diagram of setup for measuring the index of refraction of a liquid using a laser pointer and a hollow triangular prism (not to scale; based on the diagram in Nierer, 2002).

2. Lay the laser pointer on a table. The laser pointer should be set up so its beam (dotted red line in Figure 6) 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 7. 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 7 and 8.

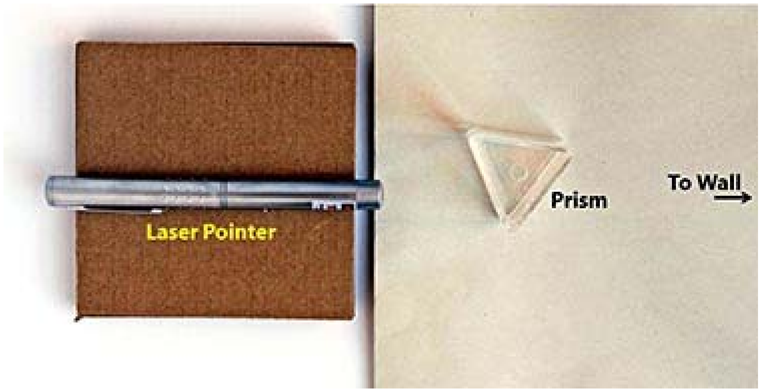

Figure 7. Photograph showing experimental setup for measuring the index of refraction of a liquid. The prism is a few centimeters in front of the laser pointer. The laser pointer is pointing perpendicular to a nearby wall.

Figure 8. 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 9, 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}.

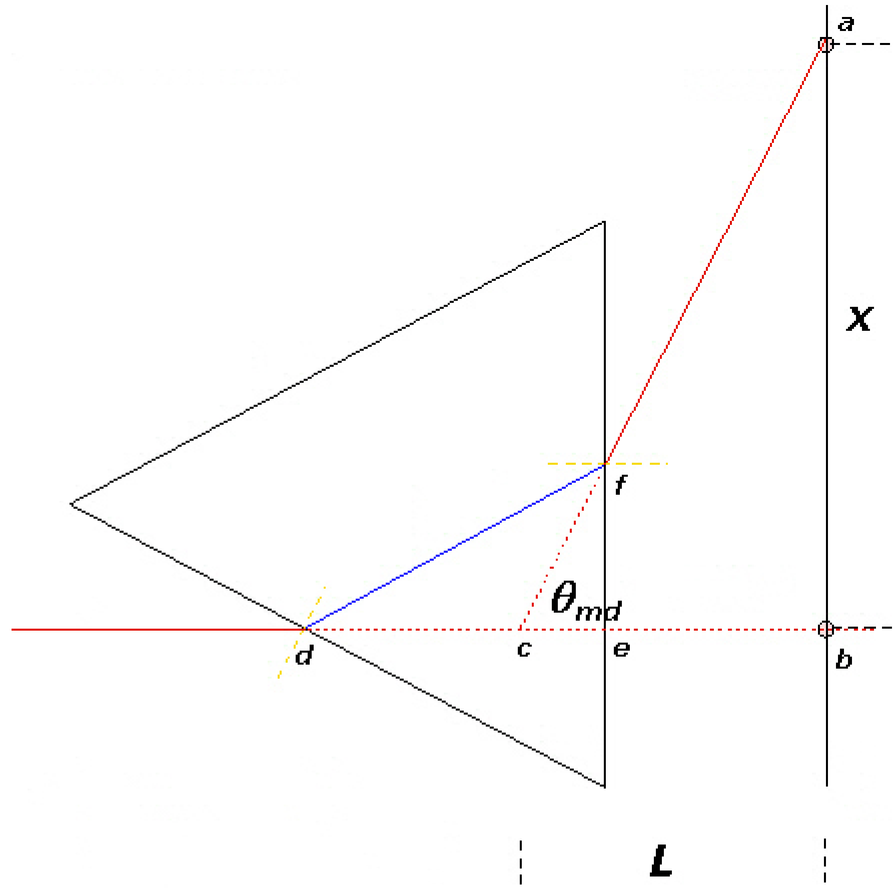

Figure 9. Detail diagram showing how to measure the angle of minimum deviation (not to scale; based on the diagram in Nierer, 2002).

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 9).
    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 9). 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 9). 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 9) 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 9). 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 9). 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 9).
20. Measure the distance between points *b* and *c*, and record it in your lab notebook. This is distance *L* (see Figure 9).
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.

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.

Frequently Asked Questions (FAQ)

FAQ for this Project Idea available online at https://www.sciencebuddies.org/science-fair-projects/project-ideas/Phys_p028/physics/measuring-sugar-content-of-a-liquid-with-a-laser-pointer#help (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Phys_p028/physics/measuring-sugar-content-of-a-liquid-with-a-laser-pointer#help).