Varying Water Temperatures and Salinities and Their Effect on Refracting Light

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1 Purpose

The purpose of this project is to investigate how altering the temperatures and salinities of water affects water's refractive index. Web research indicates that the more dense the fluid, the higher the index of refraction. Therefore the hypothesis was that hot water would have a lower refractive index than cold water, and that water of high salinity would have a greater refractive index than water of low salinity.

2 Equipment

Quantity	Description	Origin	My Cost
3 8"x8"x1/8" plastic squares and 1 12"x12"x1/8" plastic square	Used to Make Triangular Prism	Homemade	$6
1 tube	Silicon Caulking	Home Depot	$4
1	Laser	Home	$0
450 g	Sodium Chloride	Lab-Pro, Inc.	$20
1	Digital Scale	Friend	$0
1	Digital Thermometer	Friend	$0
1	Tape Measure	Home	$0
2 ft	Plastic Tubing	Walgreens	$10
15 L	Water	Home	$0
1	Beaker (measure 1 L)	Friend	$0

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3 Methodology

A triangular prism was set up so that a laser could shine through it onto a blank wall. First, the point where the laser hit on the wall without the prism was recorded. Then water was poured into the prism, and the point on the wall was recorded again. A known amount of sodium chloride (to reach a specific salinity) was added and the new point was recorded. This was repeated six times with increasing amounts of salt. Each time the water was drained, new room-temperature water was added, and the measurement of the refracted point noted. The process was then repeated another three times, this time varying the water temperature instead of the salinity. After the data was recorded, the index of refraction was calculated using trigonometry and Snell's Law.

4 Detailed Procedure

I. Make the prism:

1. Glue the three smaller squares together (edge to edge, at a 60° angle) with acetone to make a triangular shape. Duct tape the edges to add extra security.

2. Use the acetone to attach the triangle to the bigger square, which will be the base.

3. After the acetone has dried, use the caulking around the base to ensure that water will not leak out.

4. Let dry overnight before adding water.

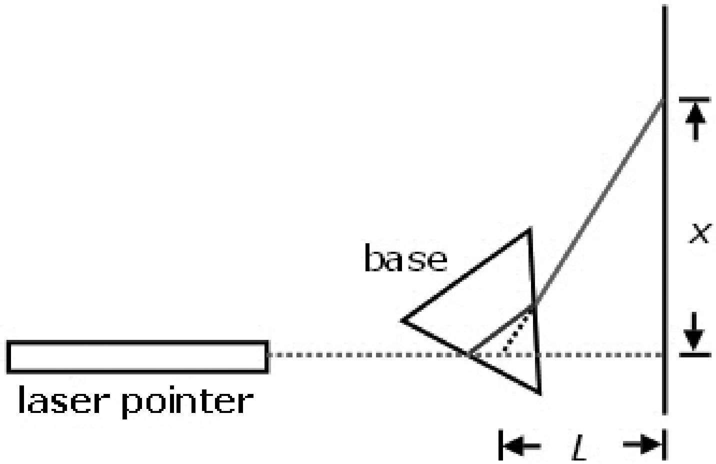

Figure 1: *Laser and prism position [1]*

II. Gather Data

1. Position the laser and prism as shown in Figure 1. The laser should shine perpendicular to the wall. The larger the distances between the wall, prism, and laser the easier it will be to see a change in the refraction. Secure the laser so that it does not move during the experiment.

2. Remove the prism from the setup. Shine the laser and mark where it lands on the wall. This is the origin. Replace the prism in its spot, but on top of a piece of paper, and tape it down so it remains stationary.

3. Check to make sure that the laser's point is still shining on the same spot (while the prism is down), but mark it if it has moved.

4. Now pour 3 L of room-temperature water into the prism. Shine the laser and mark the new position on the wall. Measure and record the temperature. Label this Trial 1.
Note: Remember to label your points as you mark them.

5. Add 60 g of salt to the water and mix the water until the salt is mostly dissolved. Shine the laser and mark the new point again. Measure and record the temperature, and record the amount of salt added. Label this Trial 2.

6. Repeat Step 5 four more times.
The first time, add another 60 g of salt.
The second time, add 60 g of salt.
The third time, add 180 g of salt.
The fourth time, add 90 g of salt.
(You will now have a total of six trials)

7. Siphon out the water using the rubber tube.
(While one end of the hose sits in the water, suck the other end of the hose until the water begins to flow, remove the hose from your mouth, and let the water continue to flow out until the prism is empty.)

8. Refill the prism with 3 more liters of room-temperature water and repeat Step 4. (Label this either Trial 1 of a new table, or Trial 7 of the same one.)

9. Repeat Steps 7 and 8 two more times: first with hot water, then with cold water.

10. Siphon the water out and shine the laser through the plastic one more time. It should be in the same spot as it was in Step 3. This is to certify that the point has not drastically moved. If it has, then your setup was bumped during the experiment and you will end up with a large error.

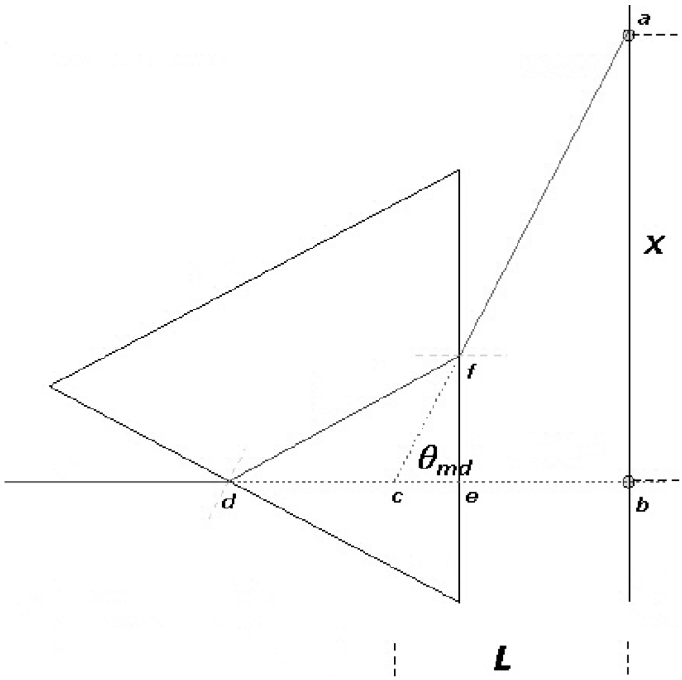

Figure 2: *Diagramming the lengths and angles [1]*

III. Find θ_{md}:

The following refers to Figure 2.

Finding length c-b:

1. With no water in the prism, mark on the sheet of paper the point where the beam enters the triangular prism (Point d). Then put a mark where the point exits the prism (Point e). The line between d and e is the path of the undiverted beam.

2. Mark where the undiverted laser lands on the wall.

3. Add three liters of water to the prism. Mark the point that the laser hits the wall. (This is Point a). Rotate the prism so that the path of the refracted beam (Points d to f) is parallel with the base of the prism. (You can see the base in the first diagram of the procedure).

4. Move the prism aside. Connect Points d and f along with points d and b.

5. Attach a string to Point a and bring the string so that it passes through Point f, and then crosses line d-b. Mark where the string crosses line d-b and label this Point c.

6. Measure the distance from Point c to Point e.

7. Add this distance to line e-b. You now have length L, which you will use in trigonometry along with length X to find θ_{mb}.

5 Data

Salinity (ppt)	Temperature (°C)	Distance from origin (in)
0	21	37.375
20	21	38.0
40	21	38.438
60	21	38.75
120	20	40.0
150	20	40.625
0	22	37.438
0	92	34.875
0	5	36.875
vinegar	21	37.938
oil	21	59.0

Figure 3: *Salinity vs. temperature vs. distance from origin*

6 Calculations

For the full calculations, see the online version of the *Roundtable* at http://roundtable.menloschool.org.

7 Discussion

The purpose of the experiment is to investigate the relationship that increasing salinity and changing temperature have upon the refractive index of water. In order to determine how varying the temperature and salinity of water affects its index of refraction, I aimed a laser through a water-filled prism and changed its salt content and temperature, examining how the laser beam moved. Specifically, the laser was shone through the prism and onto a wall, and then I marked the place where the laser came into contact with the wall. First I altered the salinity of the water, adding a certain amount of salt for each trial, so that I was able to calculate the salinity every time data was collected. Then I siphoned out the salt water, replaced it with fresh water, and altered the temperature of the water, recording the new data points. To be more precise, I used cold water, room-temperature water, and hot water for this part of my procedure. After I was finished marking the points on the wall, I measured the distances from each point to the origin (which was where the laser's end was when there was no prism disrupting its path). With this and the length to a specific part of the prism from the origin, I was able to use trigonometry to find the angle of refraction. Lastly, with my newly found angle of refraction, I used Snell's Law to calculate the experimental index of refraction for each salinity and temperature.

Before conducting this experiment, my hypothesis was that higher salinity would lead to a higher refractive index, and a colder temperature would cause a higher refractive index. My reasoning for this expectation was based on what we learned in class about density's relationship to the index of refraction: the higher the density, the higher the index of refraction. A higher-salinity water is denser than a lower-salinity water, and low-temperature water is denser than high-temperature water. With this hypothesis, I dove into my experiment and discovered that the data very closely matched my expectation.

7.1 My results

Salinity (ppt)	Temperature (°C)	Refraction Index
0	21	1.3374
20	21	1.3420
40	21	1.3452
60	21	1.3475
120	20	1.3565
150	20	1.3609
0	22	1.3379
0	92	1.3187
0	5	1.3337

Figure 4: *Salinity vs. temperature vs. refraction index*

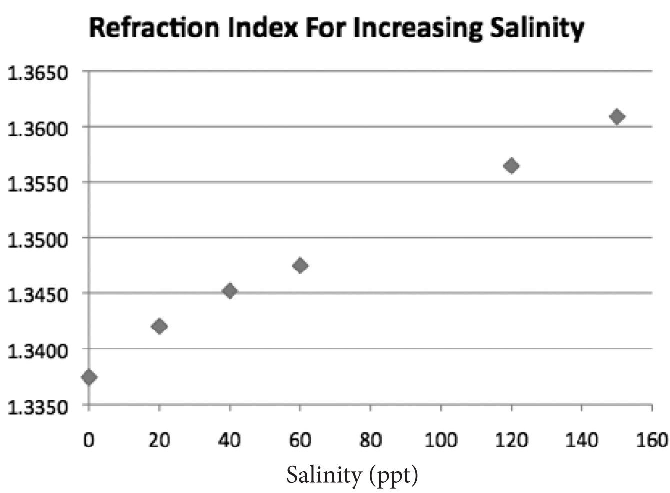

Figure 5: *Refraction index for increasing salinity*

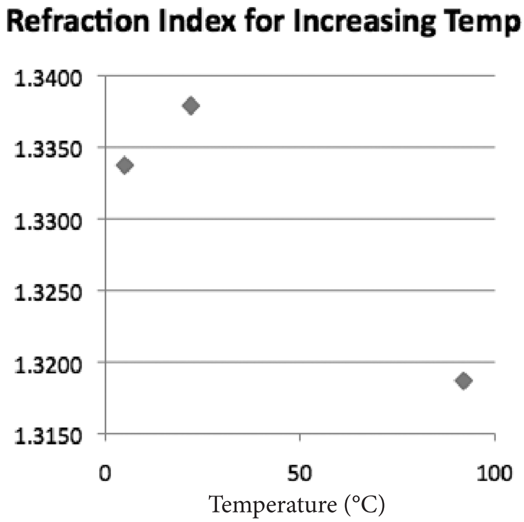

Figure 6: *Refraction index for increasing temperature*

From Figure 5 it is clear that the index of refraction and the increase of salt content have a linear relationship, as the points form a nearly straight line. This relationship is what I had expected and proves my hypothesis partially correct. However, when it comes to the temperature, the experimental results did not conform to all of my expectations. The hot water and room-temperature water lie on the graphs exactly where I expected them to: the hot water at a lower index of refraction than the room temperature. The cold water for some reason has a lower refractive index than the room-temperature water, which is odd, because it has a higher density. This was unexpected, and without further experimentation I cannot be sure of the reasons, but my guess is that it was a result of experimental error. The difference in temperature between the room-temperature and the cold water is only 15 degrees and the difference in the observations is only a refractive index of 1.3379 vs. a refractive index of 1.3337. These small differences are easily within the range of experimental error, but without additional data it is impossible to know whether error or some other explanation is the actual cause of the divergence from the hypothesis.

7.2 Error

In order to calculate the percent difference due to error, I had to do some online research. For the salinity trials, I based my theoretical refractive indexes on a graph at www.reefkeeping.com. [3] For the temperature trials, I was only able to find the theoretical refractive index of one temperature, which I found at www.thermo.com. [2] Using these two sources I was able to calculate my percent difference for each trial, and the average of them all was 0.25%.

Many likely sources of error could be eliminated or reduced by improvements in the experimental design. One source of error that I encountered was the fact that the set up was not extremely stable. Any extraneous weight or pressure applied to the table that the laser and prism were on would thereby tilt the table slightly and change where the laser entered and exited the prism. Another source of error was that the laser had to be held down for it to remain steady on the table. Although this was almost impossible to avoid, there were other experimental errors that occurred. I observed that the prism's walls bowed due to water weight. This changed the shape of the prism slightly and affected where the laser hit the wall. This distortion of the prism wall was exacerbated by the hot water test as the walls bowed significantly more in the hot water test and subsequent tests than in the earlier trials. The fact that I used the hot water before the cold could have caused the deviation of the cold-water observation from my hypothesis. After I finished collecting my data, I played around with the prism walls a bit. I noticed that as the walls bowed they caused a noticeably large height difference, but I did not see it affecting the x-axis displacement. Hence in my measurements I measured the x-axis displacement only and ignored the y-axis displacement to eliminate as much of this error as possible. Lastly, another source of error was the siphoning of the water. When I siphoned out the water, I was unable to remove all the salt that remained from the salty water. The small amount of remaining salt affected the density of the water, which in turn affected the index of refraction.

8 Conclusion

Despite these inaccuracies, by the end of the experiment it was clear that salinity and temperature do affect the refraction of light in water. Although errors were present, I consider this experiment to be an overall success. Still, if I had the opportunity to perform it again there are a few things I would change. First, I would have taped down the "on" button on the laser so that no external force could accidentally move it as it was being pressed on and off. Additionally, I would have made the prism with thicker walls so that the water weight and heat would not be able distort it as easily. Even if the bowing did not affect the x-axis displacement per my observations, it would still be a good factor to remove. Lastly, I would pour in clean water and siphon it out a few times before switching to the temperature alternation so as to minimize the amount of residual salt. I would hope these alterations would allow the calculations and results to be even more precise.

As I finished my data collection, I also investigated what the refractive index would be for vinegar and oil. My results for vinegar were as expected, but I was surprised that the oil exhibited a much higher refractive index than water. Oil is less dense than water because it floats (and separates) when the two are put together. So why does the lighter-density fluid have a higher index than the heavier one? I asked myself if my hypothesis was something that only applied to materials of the same substance (i.e., if you had oil with a high density and oil with a low density, would the higher density oil refract more?). It would be very interesting to measure refraction indexes with a number of different substances, and would be a good way to take this experiment to the next level. ●

9 Citations

[1] Olsen, Andrew. 2006. Measuring Sugar Content of a Liquid with a Laser. http://www.sciencebuddies.org/mentoring/project_ideas/Phys_p028.shtml (accessed May 15, 2010)

[2] Keppy, Nicole Kreuziger and Locke, Laurence. 2008. Obtaining Accurate Measurements with Refractometry and Constant Temperature Control. http://www.thermo.com/eThermo/CMA/PDFs/Product/productPDF_50654.pdf (accessed May 15, 2010)

[3] Reef Keeping. 2008. Refractometers and Salinity Measurement. http://reefkeeping.com/issues/2006-12/rhf/index.ph p (accessed May 15, 2010)