Determining the Impact of Water Salinity on the Water's Refractive Index

Name

Institution

Course

Professor

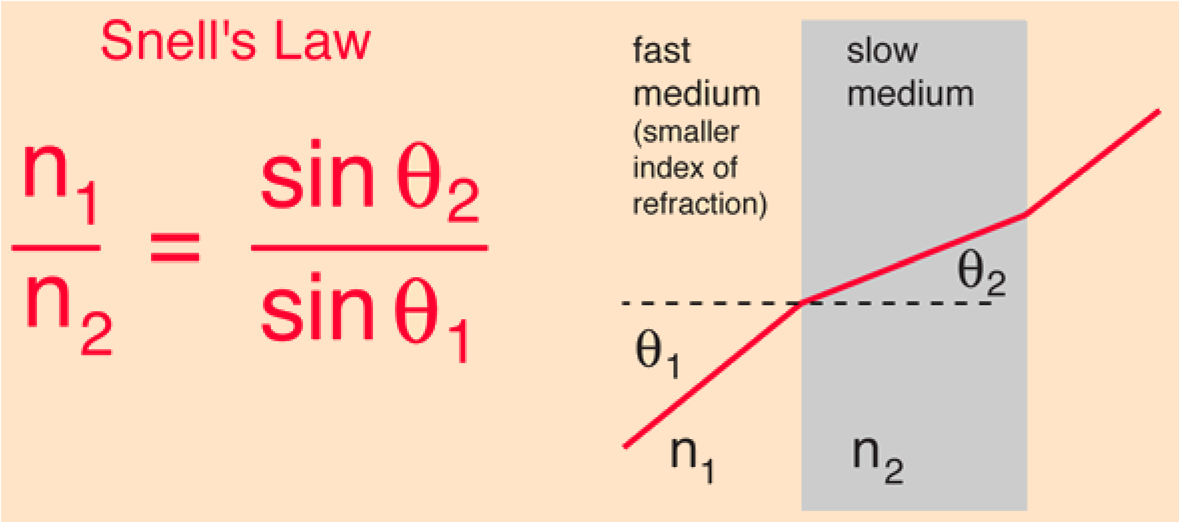
Due Date

Research Question

What is the effect of various salt concentrations (0g/L, 60g/L, 120g/L, 180g/L, 240g/L, and 300g/L) of water on the refractive index of water?

Introduction

Various aspects of life are affected by water salinity. The salinity of water refers to the amount of salt dissolved in a water body. The salinity of water has a particular relationship with the refractive index of water. There are various aspects of our daily lives that require the knowledge of this relationship. For example, scientists require this knowledge in environmental studies and oceanography to determine salinity levels in oceans and seas to aid in investigating the health of ecosystems, patterns of weather and climate, and ocean currents. The knowledge is also required in the process of desalination, instrumental and optical engineering, assessment of water quality, fishery management, and aquaculture (Velasco et al., 2018). In optical and instrumental engineering, this knowledge can be used when designing and calibrating optical instruments that operate in water and around water. The refractive index can also be utilized to identify potential safety issues in water to ensure that the water is safe for drinking (Environmental Protection Agency, 2022). This exploration, therefore, seeks to use Snell's law to explore if there is any significant association between water salinity and the water's refractive index. Snell's law states that the ratio of the sine of incidence angle to the sine of refraction angle is a constant in any particular media (Kurtus, 2022). It is demonstrated as follows (GSU, 2022):



Aim of the Study

To investigate the association between water salinity and water's refractive index

Hypothesis

The hypothesis of the study is that water's refractive index increases with an increase in pure water's salt concentration.

Methodology

Variables of the Study

Independent variable: water salinity (concentration of salt in g/L)

Dependent variable: water's refractive index

Controlled Variables

Variable	**Method of Control**
Temperature	Using a constant room temperature Keeping the windows and doors open
Volume of water	Using a calibrated measuring cylinder to measure the volume of water before dissolving it

Pressure	Using the same room for the experiment. The assumption was that pressure remains constant in the same room if the time interval is small.

Apparatus

5 litres of pure water	Needle
30 Beakers	A4 Paper
Tape	Straw
Laser	Angle meter
500 grams of salt	Semi-circular beaker
Heating mixer	Thermometer
Weighing machine	Ruler

Uncertainties of the Instruments and Apparatus

Instrument	**Uncertainty**
Graduated cylinder	± 0.5 ml
Ruler	± 0.5 mm
Thermometer	± 0.5 ℃
Angle meter	± 0.1 °
Weighing machine	± 0.5 g

Procedure

1. Begin by constructing the system for observing the water's refractive index at various salinity levels.
    a. Stable a cardboard on a stable table
    b. Attach an A4 paper on the cardboard using glue for purposes of calculating the angles.
    c. Draw the side of the paper by taping a semi-circular beaker to it, with the semicircle line parallel to the side of the paper.
    d. Mark the circle's center on the paper.
    e. Draw a line through the center of the circle and perpendicular to the side. This line serves as the normal, which will help in the measurement of the angles.
    f. Stable the laser near the semi-circular beaker while aiming the semi-circular beaker's center
    g. To get the incident angle, draw the line that the laser goes through
    h. Then carry the table holding the system to a darker place to enhance the clarity and visibility of the laser light
2. When the system is completed, measure 100 ml of pure water using a measuring cylinder and pour it into a beaker. Pour the water into 30 identical beakers.
3. Brand the beakers into 6 groups based on the concentrations of salt that the beakers will be holding.
4. Then, using the weighing machine, measure 6 grams of salt and pour it into the first beaker. Fill the other 4 beakers in that group with 6 grams of salt.

5. Then weigh 12 grams of salt and add it into the 5 beakers of the next group. Repeat this step for three more groups using 18 grams, 24 grams, and 30 grams of salt, respectively. Add no salts in the last group so that it serves as the control group.
6. Using the mixer, heat the solutions in various beakers. The mixer to be used for this experiment is unique such that it heats the solution while stirring it using electromagnetic forces. A magnetic fish will be used to provide these forces. Locate a heater under the beaker to heat the beaker.
7. Open the laser and fill the semi-circular beaker.
8. Then use a needle to mark the laser light that goes through the semi-circular beaker.
9. After the light passes inside the beaker, jab the needle on the way of the light to measure where this light goes through. Do this step without water to ensure that the laser targets the semi-circular beaker's center to avoid changing direction.
10. Do the first control group's experiment with the heater of the mixer still open. Heat the beaker on the mixer until it gets to 30 ℃. Use the thermometer to read when the beaker reaches 30 ℃.
11. After heating, pour the water into the semi-circular beaker.
12. Turn off the lights and open the laser. Then open a hole in the paper by jabbing a needle in the light's way.
13. After the marking, use the straw to remove the water from the beaker. As you suck the water from the beaker, spit it into the sink. Repeat this step for the other four beakers with 0g/L concentration of salt.
14. Drop a magnetic fish into a beaker in the second group and start the mixer to heat while stirring.
15. Prick a thermometer into the heater and close the heater when the thermometer reads 30 ℃.

16. Pour the contents of the beaker into a semi-circular beaker after all the salt is mixed. Again, turn off the lights and open the laser. Then mark the light ray using the needle.
17. Then use a straw to sick water from the semi-circular beaker. Repeat this step for the other four beakers in the second group.
18. Repeat steps 14 to 17 for the beakers in the remaining four groups. Heat each beaker up to 30 ℃, pour the water, and measure the refraction.
19. Now remove the paper from the system after removing the beaker from the paper's top.
20. Use a ruler to connect the hole created by the needle to the intersection of the beaker's sideline and the normal line.
21. Use the angle meter to measure the diffraction angles and record them in tables.

Data and Results

Raw Data

Table 1: Refraction angle of 0g/L concentration of salt at a temperature of 28 ℃ and in 100 ml of water

Trial	Angle of Incidence	Angle of Refraction
1	44.0	35.8
2	44.0	35.2
3	44.0	35.5
4	44.0	35.6
5	44.0	35.5

Table 2: Refraction angle of 60g/L concentration of salt at a temperature of 28 ℃ and in 100 ml of water

Trial	Angle of Incidence	Angle of Refraction
1	44.0	34.8
2	44.0	35.1
3	44.0	34.9
4	44.0	34.9
5	44.0	35.2

Table 3: Refraction angle of 120g/L concentration of salt at a temperature of 28 ℃ and in 100 ml of water

Trial	Angle of Incidence	Angle of Refraction
1	44.0	34.3
2	44.0	34.5
3	44.0	34.6
4	44.0	34.4
5	44.0	35.3

Table 4: Refraction angle of 180g/L concentration of salt at a temperature of 28 ℃ and in 100 ml of water

Trial	Angle of Incidence	Angle of Refraction
1	44.0	33.7
2	44.0	34.3
3	44.0	34.0
4	44.0	33.9

5	44.0	34.1

Table 5: Refraction angle of 240g/L concentration of salt at a temperature of 28 ℃ and in 100 ml of water

Trial	Angle of Incidence	Angle of Refraction
1	44.0	33.6
2	44.0	33.3
3	44.0	33.9
4	44.0	33.4
5	44.0	33.5

Table 6: Refraction angle of 300g/L concentration of salt at a temperature of 28 ℃ and in 100 ml of water

Trial	Angle of Incidence	Angle of Refraction
1	44.0	32.9
2	44.0	32.7
3	44.0	33.3
4	44.0	33.3
5	44.0	32.6

Processed Data

Table 7: Average of the raw data for the angles of refraction of the various salinity levels of water

Temperature (℃)	Concentration (g/L)	Angle of Incidence	Angle of Refraction
28.0	0	44.0	35.5
28.0	60	44.0	35.0
28.0	120	44.0	34.6
28.0	180	44.0	34.0
28.0	240	44.0	33.5
28.0	300	44.0	33.0

The averages were calculated by taking the sum of the refraction angles from the five trials and dividing by five (the number of trials). The following is a sample calculation of the average for the control experiment:

Average = $\frac{a+b+c+d+e}{5}$

$= \frac{35.8+35.2+35.5+35.6+35.5}{5}$

$= \frac{177.6}{5} = 35.52 = 35.5 \; to \; 1 \; d.p$

After calculating the averages, we can use Snell's law to get the water's refractive index. Let the sine of incidence angle be sin i and the sine of refraction angle be sin r, then, the Snell's law for this experiment shall be as follows:

$n_1 \sin i = n_2 \sin r$ (1)

Where n_1 and n_2 are the refractive indices of air and water, respectively. Assuming that the experiment was carried out in ideal air, we use 1 as the refractive index of air (Wanstall et al., 2020). Substituting 1 in the Snell's law, we get the following:

$1 \sin i = n_2 \sin r$ (2)

Dividing both sides by sin r, we get:

$$n_2 = \frac{sinsin\, i}{sinsin\, r} \qquad (3)$$

We now use the equation in 3 above to calculate the refractive index of water for every concentration of salt in water. The following is a sample calculation of the refractive index of 0 g/L concentration:

$$n_2 = \frac{sinsin\, i}{sinsin\, r}$$

$$= \frac{sinsin\, 44}{sinsin\, 35.5}$$

$$= \frac{0.6947}{0.5807}$$

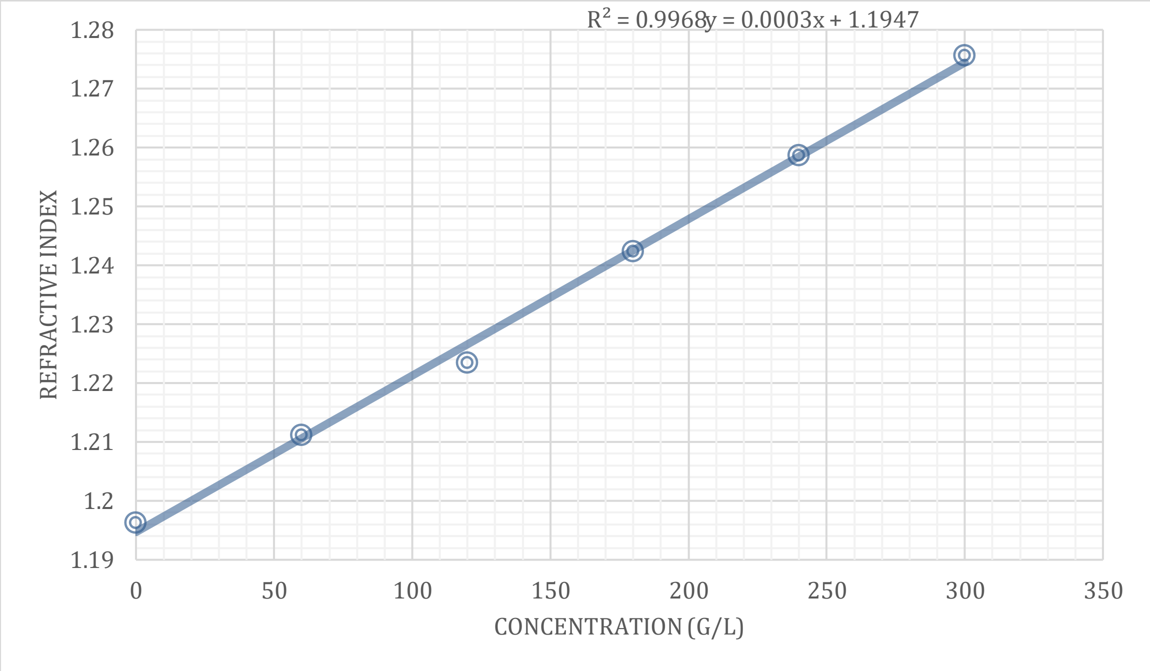
$$= 1.1963$$

The refractive indices of the other concentrations are given in the table below:

Table 8: Refractive indices of saline water

Concentration of salt in water (g/L)	Angle of Incidence	Angle of Refraction	Sine of the angle of incidence	Sine of the angle of refraction	The refractive index of saline water
0	44.0	35.5	0.6947	0.5807	1.1963
60	44.0	35.0	0.6947	0.5736	1.2111
120	44.0	34.6	0.6947	0.5678	1.2234
180	44.0	34.0	0.6947	0.5592	1.2423
240	44.0	33.5	0.6947	0.5519	1.2587
300	44.0	33.0	0.6947	0.5446	1.2756

Graph 1: Graph of the association between water salinity and the water's refractive index



Conclusion and Evaluation

The primary objective of this exploration was to study the association between the salinity of water and its refractive index using Snell's law. From the above data tables and the graph, it can be clearly seen that the objective of the study has been achieved, and the study hypothesis has been answered. The trend line developed in Graph 1 indicates that the water's refractive index increases with an increase in salt concentration. Furthermore, the equation of the trend line has a positive gradient, suggesting a positive linear relationship between the two variables. The value of R^2, the determination coefficient, also indicates a significant relationship between the two variables. The value is positive and very close to +1, suggesting a strong positive association between water salinity and its refractive index. The research question and hypothesis have, therefore, been answered. As the water salinity increases, the refractive index also increases. This is also observed in real life in seas and oceans. These water bodies' salinity varies from one body to another, affecting the light refracted from the water body's surface. This, in turn, affects the aquatic life.

However, despite the success of the experiment and the achievement of the objective, there are some strengths and weaknesses that should be considered when examining the findings. One weakness is the slight changes in the room temperature and the temperature of the water. These changes could affect the results since temperature affects the refractive index. Similarly, the stability of the semi-circular beaker was also affected by the table, which could still shake when touched despite being more stable. Some salt particles were also observed after the solution had cooled, indicating that the solution was not properly stirred during the heating. However, to overcome these challenges, I did five trials for every concentration before taking the averages. Using the averages for analysis increased the accuracy and validity of the findings. The knowledge obtained from this study can be used in aquaculture and fishery management to monitor and maintain optimal salinity levels in ponds and other water bodies to enhance aquatic species' health and productivity.

References

Environmental Protection Agency. (2022, July 11). *Indicators: Salinity*. US EPA. Retrieved June 15, 2023, from https://www.epa.gov/national-aquatic-resource-surveys/indicators-salinity

GSU. (2022). *Refraction of light*. Georgia State University. Retrieved June 15, 2023, from https://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/refr.html

Kurtus, R. (2022, January 6). *Snell's law for the refraction of light*. School for Champions by Ron Kurtus - online lessons for those seeking success. Retrieved June 15, 2023, from https://www.school-for-champions.com/science/light_refraction_snell.htm

Velasco, J., Gutiérrez-Cánovas, C., Botella-Cruz, M., Sánchez-Fernández, D., Arribas, P., Carbonell, J. A., Millán, A., & Pallarés, S. (2018). Effects of salinity changes on aquatic organisms in a multiple stressor context. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *374*(1764), 20180011. https://doi.org/10.1098/rstb.2018.0011

Wanstall, C. T., Agrawal, A. K., & Bittle, J. A. (2020). Implications of real-gas behavior on refractive index calculations for optical diagnostics offuel–air mixing at high pressures. *Combustion and Flame*, *214*, 47-56. https://doi.org/10.1016/j.combustflame.2019.12.023