PHYSICS RESEARCH PAPER

Title: Effect of different Concentrations of Sugar on the Refractive Index of a solution.

Research Question: How do different Concentrations of Sugar affect the Refractive Index of the Solution? Using a He-Ne (Helium-Neon) Laser.

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1.Introduction

Commercial sugar solutions have long been recognized as being turbid, which is basically their light-scattering behavior; something that has never been thoroughly studied. Light scattering by industrial sugar liquids, however, has recently gained increased attention. It is an overly sensitive indicator of colloidal impurities, and it has a significant effect on the quality of products such as sugar-containing beverages. The refractive index (n) is a fundamental characteristic for materials that have optical characteristics and its accurate value is required in many subdivisions of physics and chemistry, as it has many applications which help us understand the clarity of many materials used in industrial productions. One can determine the contents of a solution by calculating the refractive index of a binary solution. In many industrial and research applications, refractive index measurements are also commonly used to assess the concentration of the solution.

2. Background Information

There are several methods that are well known for calculating the refractive index of a liquid solution. In application aspects, the varieties of methods is largely due to differences. Systems designed to analyze liquids in cuvettes that are particularly made of glass, quartz or other see-through materials constitute a different type of equipment for calculating the refractive index of transparent liquids. A variety of devices used for practical purposes, have been built to evaluate the refractive index based on the theories using different types of cuvettes.

Refractive Index can be affected by changes in Concentrations, Temperatures, Strains, and Wavelengths. Detailed research has been carried out on concentration by mapping and calculating the Refractive Index of liquids recently. In terms of Temperature, a co-efficient of Refractive Index can be determined through the thermal expansion co-efficient. There are various procedures for calculating the relationship between Concentrations and Temperatures of different solutions on the refractive index of different materials or liquids. Some of these include Inter digital capacitor sensors which is an instrument used to determine sugar concentration in solution, Optical Coherence Tomography; a medical tool used to determine blood glucose levels in diabetic patients and also in commercially sold sugary drinks with the help of concepts like density, refractometer and infrared spectroscopy.

The techniques described above are industrial instruments used to assess the sugar content in the solution. This type of instrument is very costly and is not available in most laboratories either. In order to determine the parameters like concentrations, temperatures and wavelengths that depend on the sugar solution's contents and the refractive index of the sugar solution in different concentrations of solutions, I will be using Snell 's law which will be used in applying onto a reasonably economical and simply constructed equilateral hollow beaker along with a very sensitive laser light source; Green Diode, with a wavelength-dependent refractive index of sugar solution empirical expression formulated by combining Cauchy 's equation to the experimental data using a non-linear curve.

Since I was little I used to be really interested in Lasers. I used to buy different types and colored lasers. When I got a bit older, I started getting interested in dismantling a lot of old technological hardware at home. Lasers usually produce a different lighting atmosphere when an external cap is placed. This information interested me a lot. As I started to search more regarding that, I found out that there were several types of prism involved to bring out the needed patterns. Therefore, the fact that light and prisms go hand in hand, I decided to stick with a topic relating to both.

For this experiment, having a prism is incredibly necessary, without which this experiment cannot proceed further. There are various types of prism normally used in different kinds of scientific experiments. The one I specifically needed for this experiment was a **hollow prism.** The triangular hollow prism also has the bonus of using the most conventional light refraction geometry. If the prism is made of flat glass plates and used correctly, the glass does not add to the total refraction of the device. Measured refraction is caused only by a wedge-shaped liquid; practically, we have a "liquid prism".

Due to lack of popularity and suppliers in the city for this particular equipment needed, after months of trying, it was still unavailable. Due to the time constrain and the pandemic's social restrictions, I came up with the idea to make my own hollow prism, with the help of various YouTube tutorials. After long days of meticulous work, I had finally accomplished in making it using slides of glass, epoxy, and super glue. The final outcome was better than I expected because it had reached a point where the characteristics of the self made hollow prism matched the commercially sold one accurately.

This experience really taught me the value and lesson that, every problem if thought and directed in a positive direction will have a solution to it. This made me proud that I could come up with an alternative and make sure I conducted the experiment on one of my most interested topics.

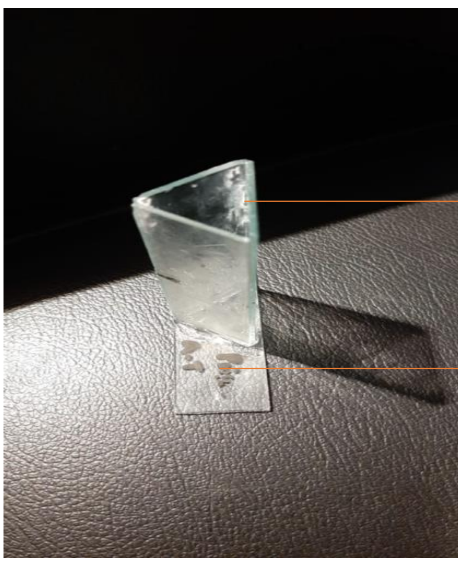


Figure.1

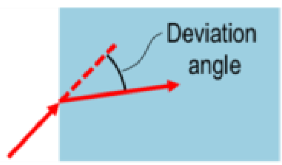
2.1 Derivation of The Refractive Index of a Prism in terms of Minimum Deviation and Angle.

In a Prism, the deviation angle[1] denoted by (Δ) tends to decrease with an increase in the incidence angle to a given angle, denoted by *i*. This incidence angle, is where the angle of deviation in the prism is at its minimum, and this is what is considered the Position of the Minimum Deviation of the prism. This same angle of deviation is defined as the Minimum Deviation Angle, represented by Δmin, or Dm.

[1] https://en.wikipedia.org/wiki/Minimum_deviation

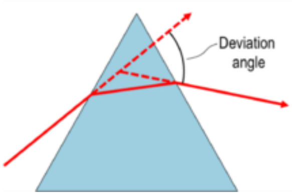
The angle of the minimum deviation is related to the refractive index as:

$$\therefore n = \frac{\frac{\sin(A + Dm)}{2}}{\sin(\frac{A}{2})}$$

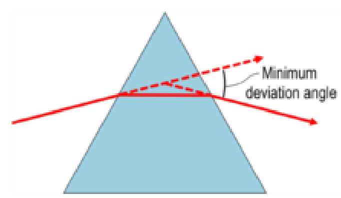


Light gets deflected as it enters a material. This makes its refractive index >1

In Minimum Deviation, the ray getting refracted inside the prism is parallel to the base of the prism. We can say that the light ray is proportioned around the axis of symmetry of the prism. Also, the angles of the quantity of the refractions are equal. This means that r1 = r2. And the incidence angle and the emergence angle are equal to each other I = e). The formula given to describe the minimum deviation can be obtained by the application of the geometry of a prism. The solution includes substituting the variables in the Snell's Law, making it in terms of the Deviation and Angles of the Prism, with the help of prism geometry or characteristics.



In terms of a prism, Light is deflected twice inside the prism. The total addition give us the **deflection angle**



As the angle of incidence and angle of emergence is **equal**, the angle of deviation that passes through the prism will be **minimum**

The formula for the minimal deviation could be derived by applying the geometry of the prism. The solution includes substituting the factors in the Snell's Law in the terms of divergence and the angle of the prism.

Sample Calculations:

Angle sum of ΔOPQ

$$A + \angle OPQ + \angle OQP = 180°$$

$$\rightarrow A = 180° - (90 - r) - (90 - r)$$

$$\rightarrow r = \frac{A}{2}$$

Exterior Angle Theorem ΔPQR

$$Dm = \angle RPQ + \angle RQP$$
$$\rightarrow Dm = i - r + i - r$$
$$\rightarrow 2r + Dm = 2i$$
$$\rightarrow A + Dm = 2i$$
$$\rightarrow i = \frac{A + Dm}{2}$$

Derivation by placing *i=e* in the <u>prism formula</u>, *where i+e = A+Dm*

$$n = \frac{\sin i}{\sin r}$$

$$\therefore n = \frac{\dfrac{\sin(A + Dm)}{2}}{\sin(\dfrac{A}{2})}$$

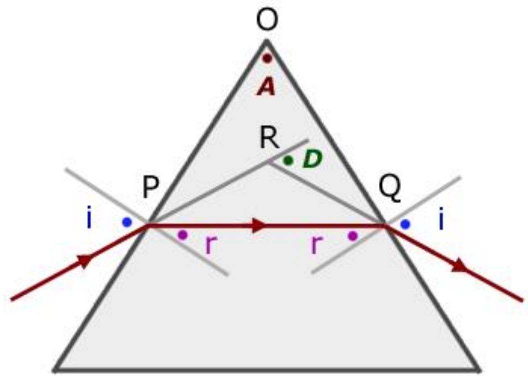


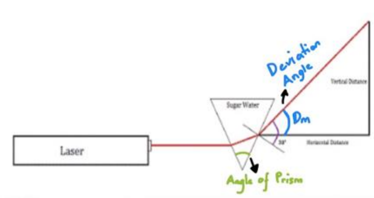
Diagram to be referred while reading the sample derivations

Figure.2

3. Research Question

How do different Concentrations of Sugar affect the Refractive Index of the Solution? Using a He-Ne. (Helium-Neon) Laser.

Figure.3:



Depiction of the hypothesized result

4.Hypothesis:

As the sugar percentage increases in water, the refractive index of the solution will also increase. The reason behind this may be because the solution is getting **thicker** producing a **denser medium** with a higher **refractive index**.

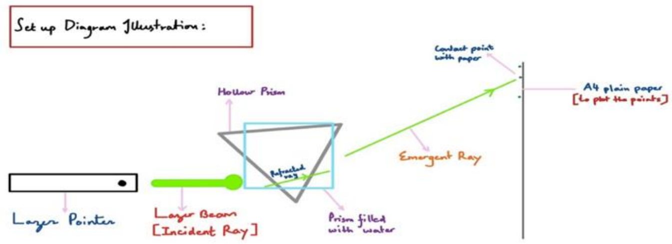
Experimental Design

<u>4.1 Variables:</u>

Variables	Manipulation
Independent Variable(s) *<u>Mass of sugar added into the water</u>*	- The mass of the sugar will be measured using a digital weighing balance with 2 grams' intervals - It is essential to keep the sugar concentration same, as this will be the main aspect that will directly impact the refractive index of the solution. This factor is straightforwardly relational to the refractive index
Dependent Variable(s) *<u>Refractive index of the solution</u>*	- It will be found out by using the derivation mentioned above
Constant Variable(s) *<u>Distance between screen to prism, and prism to laser</u>* *<u>Wavelength and Type of Laser</u>* *<u>Material of screen to plot the points</u>* *<u>Type of distilled water</u>* *<u>Temperature</u>* *<u>Amount of water</u>*	- It will be measured using a ruler and a marking will be drawn to make sure the distance remains the same - The laser used will be of the same company and type, which in this case is a green laser. Along with the same wavelength of 532nm - The medium used to mark the points were A4 sized papers. All were taken from the same package - The type and amount of distilled water used was kept constant by using bottles manufactured by the same company - by using the same space, by treating it as an independent structure, by keeping doors and windows closed. Trying to perform the experiment at a room temperature - by weighing the volume of water with a graduated cylinder before dissolving the sugar in it. (5ml) - Setting of the weighing balance to the same scales (g)

Figure.4:

Experimental Setup:



4.2 Materials & Apparatus

- Pure distilled water (2L)
- Measuring cylinder (±0.5 ml)
- Beaker
- Green Laser 532nm (±10nm)
- Prism
- Sugar (1kg)
- Digital weighing scale (±0.5g)
- A4 Papers
- Marker
- Tape
- Ruler (±0.5mm)
- Protractor (±0.5°)

4.3 Method

Set-Up Procedure –

- An equilateral hollow prism is placed on the table to conduct the experiment.
- The Green He-Ne laser at 532nm -wavelength was used as a light source. The schematic description of the configuration of the apparatus is shown in Figure earlier.
- Initially, with no fluid in the prism, the collimated laser beam passes through the prism and the direction is registered.
- Then 5ml of water was measured using a measuring cylinder and poured into the prism.
- Once the prism has been filled with the fluid, one surface of the prism is exposed with a collimated or parallel ray of the laser.
- Next, the prism is rotated. The place where the broken beam shifts its direction shows the angle of minimum divergence. This could be determined by changing the position.
- Next, 2 grams of sugar is first weighed using a digital weighing balance and then is crushed into smaller particles, so that the sugar dissolves easily in the water.
- Then the water is poured into the container in which the sugar was crushed into, and is stirred thoroughly.
- The solution is then poured into the prism and the laser light is turned on.

Performing the Experiment –

- The point at which the beam shows up on the screen is marked using a marker.
- The same steps are repeated till 10g of sugar is added into the prism, and the points are all marked and labeled on the paper.
- Once the points are marked, the value of Angle of Minimum Deviation (As indicated in Fig.3) using a protractor. This was done while the prism was occupied with distilled water. This is how the Angle of Deviation was calculated.
- The Angle of Prism (A) was measured using a protractor (As mentioned in Fig.3)
- Repeat these for each of the concentrations. Additionally, the whole experiment were replicated for a total of four times, to help me get the more accurate sets of data.

Safety Precaution –

- ✓ I wore a Facemask, a pair of gloves and maintained social distancing which were mandatory requirements to follow, during the COVID-19 Pandemic
- ✓ I handled the equipment made of glass like the prism, glass sledge and beakers very carefully to avoid any damages on them.
- ✓ I wore glasses to help prevent damage to the eyes while viewing the laser light point on the screen

5. Raw Data (*Quantitative Data)*

Raw Data Table: Effect of Concentration of Sugar on Refractive Index of the solution									
Concentration of Sugar (g)	Angle Value of Prism (±0.5°)	Dmin Angle Value **Trial 1**	Refractive Index **Trial 1**	Dmin Angle Value **Trial 2**	Refractive Index **Trial 2**	Dmin Angle Value **Trial 3**	Refractive Index **Trial 3**	Dmin Angle Value **Trial 4**	Refractive Index **Trial 4**
0 g	57.0°	21.8	1.330	21.5	1.325	21.3	1.323	21.6	1.327
2 g	57.0°	22.0	1.333	21.7	1.328	21.5	1.326	21.8	1.330
4 g	57.0°	22.2	1.335	21.9	1.332	21.7	1.329	22.0	1.334
6 g	57.0°	22.3	1.338	22.3	1.338	21.9	1.332	22.2	1.336
8 g	57.0°	22.6	1.342	22.5	1.340	22.1	1.335	22.4	1.339
10 g	57.0°	22.9	1.345	22.7	1.344	22.3	1.337	22.7	1.343

Qualitative Data- Presented by the data sets above, we can clearly make out that as concentration of sugar by mass increases, the Deviation (Dmin) value that represents the reading of change in angle also increases. We can note that the changes between the (Dmin) value doesn't have a large difference in it is because the concentration intervals are relatively less, therefore a small but significant result is displayed.

- **Average Angle (D_{min}) Value for 0 grams of sugar**

$$\frac{Trial\ 1 + Trial\ 2 + Trial\ 3 + Trial\ 4}{4}$$

$$\frac{21.8 + 21.5 + 21.3 + 21.6}{4} = 21.55$$

$\therefore$ **D_{min} for 0 grams $\bar{x}$ = 21.55**

- **Refractive index averaged values (n) for 0 grams of sugar**

$$\frac{Trial\ 1 + Trial\ 2 + Trial\ 3 + Trial\ 4}{4}$$

$$\frac{1.330 + 1.325 + 1.323 + 1.327}{4} = 1.326$$

$\therefore$ **n_{avg} $\bar{x}$ = 1.326**

Determining the refractive index of 0 grams for Trial 1

$$\therefore n = \frac{\frac{\sin(A + Dm)}{2}}{\sin\left(\frac{A}{2}\right)}$$

$$= \frac{\frac{\sin(57+21.8)}{2}}{\sin\left(\frac{A}{2}\right)} = 1.330$$

$$\therefore \boldsymbol{n} = \mathbf{1.330}$$

Standard Deviation of Dmin Value for 0 grams

$$= \frac{\sqrt{(\Sigma X_{trials} - \bar{x})}}{4}$$

$$= \frac{\sqrt{(21.8 - 21.55)^2 + (21.5 - 21.55)^2 + (21.3 - 21.55)^2 + (21.6 - 21.55)^2}}{4}$$

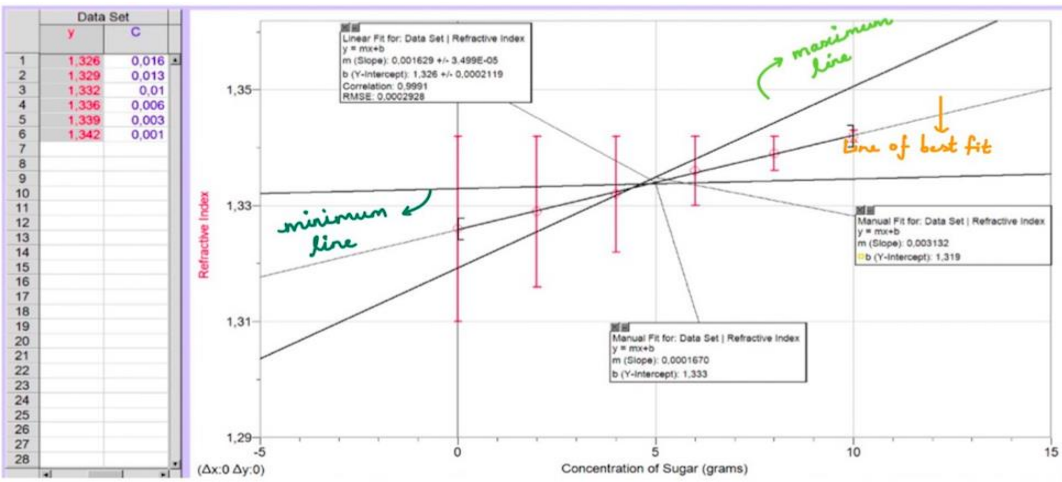
$$= \frac{\sqrt{(0.1089) + (0.0025) + (0.0625) + (0.0025)}}{4} = 0.105$$

$\therefore$ Standard Deviation for Dmin Value for 0 grams of Sugar is ± **0.105**

6.2 Processed Quantitative Data (Averaged Values)

Concentration % (By Mass) [g]	**Angle of Prism Value** (±0.5°)	**Average Deviation Angle Value**	**Change in Deviation Angle (ΔD)** $(\frac{max - min}{2})$	**Standard Deviation for Average Deviation Angle**	**Refractive Index**	**Standard Deviation for Refractive Index**
0 g	57.0°	21.6	0.3	± 0.1	1.326	± 0.005
2 g	57.0°	21.8	0.2	± 0.3	1.329	± 0.004
4 g	57.0°	22.0	0.2	± 0.2	1.332	± 0.003
6 g	57.0°	22.2	0.2	± 0.7	1.336	± 0.005
8 g	57.0°	22.5	0.3	± 0.9	1.339	± 0.013
10 g	57.0°	22.7	0.3	± 1.1	1.342	± 0.016

Graphical Representation of Effects of Concentration of Sugar on Refractive Index of the solution



7. Data Analysis- The**e** association is observed is that the sugar concentration in water increases, thus resulting in the solution's refractive index to increase as well. We can prove it from the graph. The graph equation $y = mx + b$, shows us that this is a linear line. The *m* value helps show us the slope, which is positive in this case. The angle between the graph and the x-axis are also positive. A line of best fit displayed through the origin is drawn within the *X* axis and *Y* axis error bars of the graph, which helps show a directly proportional regression or a R^2 value of 0.99. This shows a positive co-relation between the solution's refractive index and the changes in sugar concentration. This implies that the equation and the graph have a positive and increasing linear equation. If the concentration of sugar present in the water solution increases, the refractive index of the solution increases as well, just how it was mentioned in the hypothesis framed earlier in the report. Although apparently small, this difference is significant given the number of trials obtained for it, 4, and the accuracy of the angle measurement with an average value of $\pm 5.5 \times 10^{-1}$ degrees. Moreover, the high *Y* error bar especially for the 0% concentration that is the highest for the collected data. Since the absolute values of both gradients which are for the distance above the overlooked anomaly and distance below the overlooked anomaly should be identical, the anomaly could be ignored. An average gradient can be used as a reference point for the percentage error of the carried out experiment, which is basically the abnormality from the gradient formed experimentally and the gradient formed hypothetically. This would provide assurance whether the hypothesis would be accepted and correct or not.

8. Conclusion- The effects of the sugar solution on the solution's refractive index is discussed and reflected elaborately in this thesis. To illustrate the effects, I carried out multiple tests and measurements, which helped me determined the relationship between the concentration of sugar in water and the refractive index of the solution. I had hypothesized that the association between sugar concentration and the refractive was a direct correlation. After completing the experiment and the measurements required, I observed that my claim was precise and the link between them is straightforward. So the motive of the experiment was achieved, and the correlation was achieved. The average absolute value of the experimentally obtained gradient was $16.29 \times 10^{-4} \pm 3.49 \times 10^{-5}$, having a random error of around 29%. The percentage error an indicator of the accuracy of this experimentally obtained gradient, being within its random error of 29% and less than 1.0% away from the hypothesized gradient, helps the hypothesis to stand accepted. Moreover, the hypothesis is further validated by the direct proportionality obtained with high regression value of 0.99 However, the random error of 29% suggests that the main reasons to the error of the experiment were the random errors

9. Evaluation- In my theory, I proposed that the association between the sugar concentration of the solution and its refractive index had a direct connection. After the investigation I carried out a, I found that my proposed theory was right and that there was a clear connection between them. The objective of the experiment is thus accomplished, and the correlations were measured. Though the experiment went smoothly, it can never be such that it is always a 100% accurate. There were some weaknesses to it and there were errors I faced as well, while carrying out the experiment.

<u>**Random Error**</u> **Significance**	**Improvement**
Stability of Table The water in the prism must be stable in order to detect the refraction. If not, several different refractions can occur, which will make it difficult to observe continuous, stable refractions. In the case of my experiment, due to the conditions of the experiment, the table on which I performed the experiment is nearly stable. It shakes sometimes as it's touched. I wanted to stop this and stopped a little longer to make the water steady, but this may also have an effect on the outcome of my experiment as the sugar might have just settled at the bottom of the prism and not dissolved evenly.	To fix this problem I could have used a more stable surface where there may not be much movement involved, due to external forces applied.
Point plotting I placed a point on the path of the laser light, using a permanent marker, the laser light's radius is so large that it stopped me from constructing precise markings. The mark I drew on to the path can differ in the direction of the laser light. This can alter the angles that are being calculated.	I could have used a more professional board to accurately mark the points, thus helping me in calculating the most accurate angles.

Systematic Error Significance	Improvement
Dissolving of Sugar The amount sugar that I add in the distilled water must be combined consistently. In order to do this, I stir them with a special mixer to make it easier. But as it got denser, I found that some of the sugar crystals are still present and become un-dissolvable.	To fix the problem of uneven dissolving, I could have used powdered sugar as it would have been easier to evenly distribute it in the solution. So these were few ways in which my experiment must may have been affected.

Strengths:

Although there were several weaknesses, there were several strengths as well to the experiment.

Firstly, I could get a linear graph with the points marked as I increased the concentration / weight of sugar poured into the prism. The linear representation showed that I had been successful in conducting the experiment and that as concentration increased, the solution's refractive index had also increased. The result that we needed to obtain was successful in the end.
Another strength that I can say about my experiment was the fact that the hollow prism I had constructed on my own turned out to work because it had reached a point where the characteristics of self made hollow prism matched the commercially sold one accurately. The angle of the prism in my case was 57 degrees, whereas the readymade ones you get come around 55 to 60 degrees as well.
Scientific wise it was a successful experiment, but it has also taught me several values that are far beyond this report. The fact that I could come up with a solution to the unavailability of the prism, taught me that every problem does in fact have a solution if given enough thought and patience to. Also I learnt that everything would not always go your way, I had to go through a lot of trial and error, as well as repeat the experiment several times to finally land on the accurate measurements. This is something I also consider as my strengths too. Overall this was a great learning experience for me

Extension: The investigation was mainly focused on the effect of varying Concentrations of Sugar on the Refractive Index of the solution. Upon further research, I found out that there are several other aspects or parameters that can affect a refractive index of a solution or material. Therefore, factors such as the prism's measurements, temperature, density of a solution etc. could have been investigated as well, if I would have been given more time. This could possibly aid in determining different reasoning's as to how and why does a refractive index of a solution or material can be affected. Alternatively, the investigation could have possibly been extended by comparing the different parameters and finding out which one would give the most difference in results, out of all the conditions.

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