Investigation of the Effect of Density on the Speed of Light Travelling Through a Medium

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Abstract

The aim of this investigation is to reveal the relationship between speed of light and the density of the medium that the light is travelling through. This relationship was able to be found by directing a laser beam to a glass container bearing water, and then measuring the angle of refraction between the ray that is refracted after entering the medium and the normal axis. The speed of light travelling in vacuum(c) is a physical constant, so the change in the index of refraction of the medium would mean that the speed of light changed while travelling within the water. The basic procedure followed was to determine the refractory index of water under various values of densities, and to conclude the investigation by the data harvested during the investigation with the help of Snell's Law and the definition of the refractory index. As the index of refraction of a substance and the speed of light travelling through it are inversely proportional quantities, a relationship between the speed of light propagating through water and its density was able to be uncovered as can be infered from the graphs.

The investigation has indicated that the density of water and the speed of light travelling through it are inversely proportional quantities. Thus, this investigation was able to show that density is one of the factors that can affect the speed of light travelling in a particular environment. Although the index of refraction of a particular medium is essentially related with the temperature of the medium and the wavelength of the light directed at it, this experiment has showed that the density of the environment is also one of the variables capable of altering the speed of light.

Word Count: 280

Contents

1 Introduction

1.1 Background

One of the most important physical constants in Physics is the speed of light in a vacuum. This is the limiting speed for all material objects according to Einstein's theory of relativity. The speed of light in a vacuum, *c*, is what controls the laws of both the general and special relativity. If light is in a vacuum, its speed has the exact value of c regardless of the method of measurement. Speed of light is the ultimate limit of the universe even in a vacuumed box travelling away from Earth in a rocket. Anyone who measures the speed of light moving through that box will find exactly *c*, regardless of where he/she is in. However, we cannot say that nothing travels faster than light in other mediums; speed of light changes greatly outside vacuum. The speed of light is very diverse, as there exist various mediums in our world. Light scatters off of the molecules in different materials it is propagating through, and slows down. In mediums like water, the substance I based my investigation on, light slows more than other particles like electrons will. Index of refraction, or n, describes the amount by which light slows down in a particular material. It is defined by the speed of light in vacuum over the speed of light travelling through the medium, which can be denoted as $n = c/v$. From the formula, it can be seen that the index of refraction and the speed of light travelling through that medium show an inverse relationship, which is significant over the behaviour of light passing through a particular medium. When I encountered this subject, I wanted to investigate the behaviour of light under various concentrations of medium, since as density increases, the refractive index of a material also increases. I knew about the effects of temperature on the speed of light propagating through a medium from the previous studies, and I figured that I could explore the effects of altering the density of a particular medium directly rather than altering the temperature on the index of refraction of a medium. Thus, I was able to observe the change in the index of refraction of light by changing the salt concentration of water by means of adding and dissolving different amounts of salt, and therefore altering the density, as the change in the index of refraction of water changes the speed of light travelling through the medium.

1.2 Objective

The aim of this investigation is to find the relationship between the density of water and the speed of light travelling through that medium, which can be expressed as:

'How does the density of water affect the speed of light propagating through it under constant temperature and pressure, while the physical qualities of the container that is used to contain the water are kept constant?

2 Equipments and Setup

2.1 Brief Description of the Materials

The materials that are used in the experiment are briefly stated as below:

1. **A semicircular glass container** that is placed on the heater on a table, and connected to the electrical infrastructure to gain the necessary energy needed. The container is filled up with 100 mL of water. The concentration of water is altered by adding increasing amounts of salt, which consequently increases the density of water.

2. **A 405 nm blue laser pointer** that is fixed on a table to ensure that the glass container and the laser beam are aligned with an 80 degrees angle relative to the normal axis. The normal axis is perpendicular to the boundary between the air and the water.

3. **A transparent goniometer** (±0.5) that is utilized to measure the incident angle formed between the normal axis and the incident ray by the laser beam, and the refracted angles formed between the refracted ray and the normal axis after entering the water. A transparent goniometer is necessary to allow for better reading of the angles, and a goniometer is used to allow for delicate reading.

4. **A digital thermometer** (±0.5) that is placed within the water in the glass container so that the temperature of the medium would easily be able to controlled and monitored during the investigation, as the water is heated by the stove before dissolving the salt and cooled after. A digital thermometer is necessary to track the slight changes in the temperature since a normal one allows certain parallax errors and is not suitable for delicate reading.

5. **A gram measuring spoon** that is utilized to measure the mass of the salt added to the water.

2.2 Schematic Outline

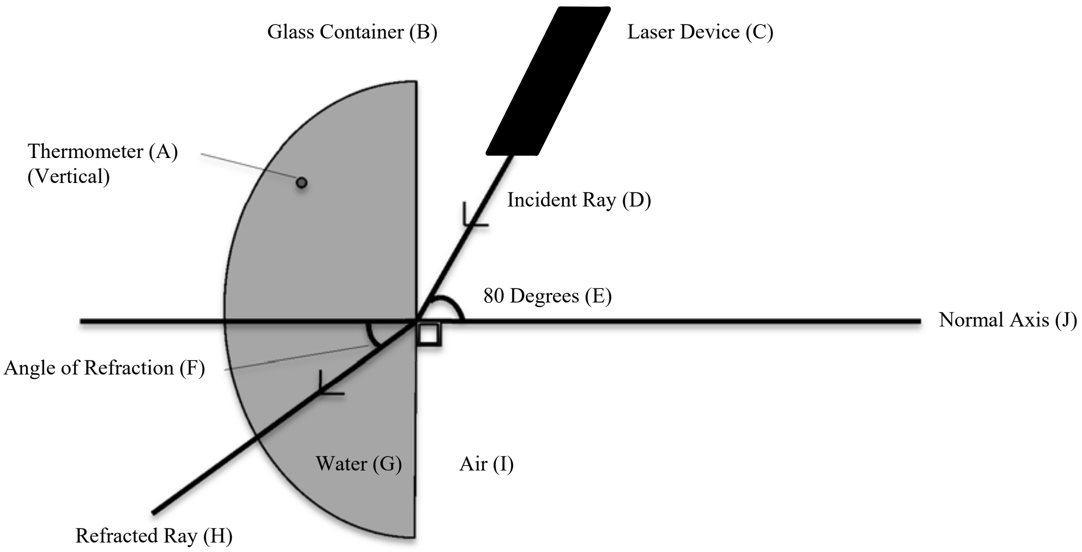

Figure 2.1: The bidimensional outline of the overall mechanism behind the experiment can be seen above. The mechanism is seen as looked from the top.

As can be seen below, the experiment is comprised of a 405 nanometers blue laser pointer (C), a semicircular glass container (B) with the water (G) it holds inside. There is an electrical oven right beneath the glass container that is used to heat the water, although it cannot be seen in this figure from the top. The thermometer (A) is placed inside the glass container vertically. The container receives the laser beam (D) with an angle of 80 degrees (E) that can also be called the angle of incidence, relative to the normal axis (J). As the refractive index of water (G) is larger than the refractive index of air (I), the angle (F) formed by the refracted laser ray (H) was smaller than the angle of incidence as it moves closer to the normal axis (J). The angle of incidence and the angle of refraction were able to be measured by the transparent goniometer.

3 Procedure

3.1 Preparations for the Experiment

After acquiring the materials, the apparatus is arranged to conduct the experiment as described in detail below.

3.1.1 Heater and Digital Thermometer

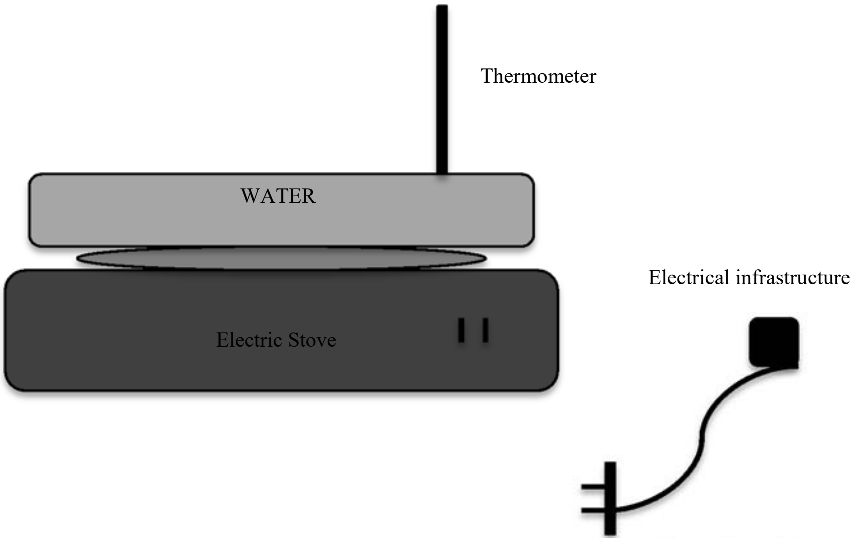

Figure 3.1: The sideview of the setup can be seen above in the figure. The electric stove is placed under the container that is full with water, and a thermometer is placed in the water so that its temperature can be tracked while heating, cooling and during the experiment.

Prior to the investigation, the electrical infrastructure was connected to the heater to gain the necessary energy to heat the water. After the rest of the apparatus is set up, the water in the container was heated up to 25 degrees celsius to allow for better dissolution. After the salt was dissolved, the water was cooled to room temperature and the experiment was conducted. The thermometer was used to track the temperature of the water, as the temperature must stay constant during the experiment since it can alter the results if there is a change in the temperature. It was also used to track the temperature of the water during heating and cooling.

3.1.2 Semicircular Glass Container

100 mL of pure water is measured with a beaker and used to fill the container up at the beginning of the experiment. The container was placed on top of the electric stove since it will be heated up later, and it was positioned to receive the laser ray from the straight side to allow the investigator read the angles of refraction more easily.

3.1.3 Laser Pointer

A 405 nanometers blue laser pointer was used, which was fixed to the table that all the apparatus rest. Protective goggles were used while using the laser pointer to protect the eyes of the investigator from any damage that the direct laser beam may create. The angle of incidence was fixed as 80 degrees by the use of goniometer so that the angle remained the same throughout the experiment.

3.1.4 Transparent Goniometer

A transparent goniometer was used to fix the incident angle formed by the laser beam as 80 degrees and to measure the refracted angles that are formed between the refracted rays and the normal axis. The data collected showing the refracted angles will function to determine the index of refraction of the water with different concentrations of salt.

3.1.5 Refractive Index of Air

The value of the refractive index of air was necessary to calculate the index of refraction of water by the use of Snell’s Law. After a throughout investigation conducted to determine the literature value for the refractive index of air, different values for the refractive index of air was suggested by various sources, and the range of the results was 0.000012. As this range is very small, the literature value for the refractive index of air was decided to be taken as 1.000293 regarding the latest investigation. It is important to state that this value is calculated under standart conditions regarding the pressure and temperature.

3.2 Carrying out the Experiment

After setting all the materials up, the water in the container was heated up to 25 degrees celsius by the electric stove, and the stove was turned off. 1 grams of salt was measured with the gram measuring spoon and dissolved in the water in the container by mixing for 3 minutes. After the salt is dissolved and the water returned to the room temperature, the blue laser was turned on to form an incident ray on the water with an angle of 80 degrees with the normal axis, which was fixed before the experiment. Later on, the angle formed between the refracted light and the normal axis was measured by the transparent goniometer. This entire procedure was repeated four more times, so that there are five trials in total. Consequently, the electric stove was turned on again to increase the temperature of the water in the container up to 25 degrees celsius and 1 more grams of salt was dissolved in the water by mixing for 3 minutes. After the water cooled off to the room temperature, another five trials were conducted. This method was ensued for 18 more times, adding 1 grams of salt after every 5 trials, so that 20 grams of salt was in the water in the container at last. The difference between the temperature of the water after it is cooled off to room temperature, which is 25°C, was found to be 0.1°C as read by the digital thermometer. Since the results of the trials were very adjacent, it was decided that the effect of the temperature change of water on the refracted angles was negligible.

After the data collection process, arithmetical averages of the angles of refraction for every 5 trials were computed and Snell's Law was used to calculate the refractive index of water (n_1) for each concentration of water, which states that:

$$\frac{\sin \theta incident}{\sin \theta refracted} = \frac{n1}{n2}$$

where n_1 is the refractive index of the water the refracted ray travels through and n_2 is the index of refraction of the air the incident ray travels through. As the index of refraction is equal to the ratio of the speed of light travelling in a vacuum to the speed of light propagating through the medium:

$$n = \frac{c}{\vartheta}$$

where n is the refractive index of water, the connection between the concentration of water and the speed of light travelling through the water can be found by using the formula with every trial. The raw data collected and the processed data are shown in the following chapter.

4 Data Collection and Processing

4.1 Data Collection

The data collected throughout the in the experiment is presented in the raw data table below.

Grams of salt added to the water (g, ±0.1)	Angle of Incidence (°, ±0.5)	Angles of Refraction (°, ±0.5)				
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1.0	80.0	47.5	47.6	47.6	47.6	47.5
2.0	80.0	47.5	47.5	47.5	47.5	47.5
3.0	80.0	47.4	47.4	47.4	47.4	47.4
4.0	80.0	47.4	47.4	47.3	47.3	47.3
5.0	80.0	47.2	47.2	47.2	47.2	47.2
6.0	80.0	47.2	47.2	47.1	47.1	47.2
7.0	80.0	47.1	47.1	47.1	47.1	47.1
8.0	80.0	47.0	47.0	47.0	47.0	47.0
9.0	80.0	46.9	46.9	46.9	46.9	46.9
10.0	80.0	46.8	46.8	46.8	46.8	46.8
11.0	80.0	46.9	46.9	46.8	46.8	46.8
12.0	80.0	46.7	46.7	46.7	46.7	46.7
13.0	80.0	46.6	46.6	46.6	46.6	46.6
14.0	80.0	46.5	46.6	46.5	46.5	46.5
15.0	80.0	46.4	46.4	46.4	46.4	46.4
16.0	80.0	46.4	46.4	46.4	46.4	46.4
17.0	80.0	46.3	46.3	46.3	46.4	46.3
18.0	80.0	46.2	46.2	46.3	46.2	46.3
19.0	80.0	46.1	46.1	46.1	46.1	46.1
20.0	80.0	46.0	46.0	46.0	46.1	46.0

Table 4.1: The raw data collected in the investigation can be seen in the table below. The angles are measured by the goniometer, while the grams of salt added to the water is measured by the gram measuring spoon. The structural and material qualities of the glass container is kept constant.

It can be seen that the angles of incidence, formed between the incident ray and the normal axis, stay the same during the investigation as the laser pointer was fixed to make a 80 degree angle with the flat side of the glass container to ease the calculations with the indices of refraction of water and to make the decreasing trend more visible. It can also be seen that the angles of refraction, formed between the refracted ray and the normal axis, decrease as more grams of salt are added to the water.

4.2 Processing

To calculate the index of refraction for varying grams of salt added to the water, arithmetical averages of the angles of refraction of each set of trials must be calculated, which are presented in the table below.

Grams of salt added to the water (g, ±0.1)	Angles of Refraction (°, ±0.5)					Arithmetical Averages of the Refracted Angles (°, ±0.5)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
1.0	47.5	47.6	47.6	47.6	47.5	47.6
2.0	47.5	47.5	47.5	47.5	47.5	47.5
3.0	47.4	47.4	47.4	47.4	47.4	47.4
4.0	47.4	47.4	47.3	47.3	47.3	47.3
5.0	47.2	47.2	47.2	47.2	47.2	47.2
6.0	47.2	47.2	47.1	47.1	47.2	47.2
7.0	47.1	47.1	47.1	47.1	47.1	47.1
8.0	47.0	47.0	47.0	47.0	47.0	47.0
9.0	46.9	46.9	46.9	46.9	46.9	46.9
10.0	46.8	46.8	46.8	46.8	46.8	46.8
11.0	46.9	46.9	46.8	46.8	46.8	46.8
12.0	46.7	46.7	46.7	46.7	46.7	46.7
13.0	46.6	46.6	46.6	46.6	46.6	46.6
14.0	46.5	46.6	46.5	46.5	46.5	46.5
15.0	46.4	46.4	46.4	46.4	46.4	46.4
16.0	46.4	46.4	46.4	46.4	46.4	46.4
17.0	46.3	46.3	46.3	46.4	46.3	46.3
18.0	46.2	46.2	46.3	46.2	46.3	46.2
19.0	46.1	46.1	46.1	46.1	46.1	46.1
20.0	46.0	46.0	46.0	46.1	46.0	46.0

Table 4.2: The arithmetical averages for each set of trials of the corresponding grams of salt added to the water can be seen in the table. Incident angles are constant, as the laser pointer is fixed to the table. The uncertainties of the arithmetical averages for the angles of refraction are the same with the uncertainties of the angles of refraction.

As the arithmetical averages are calculated, Snell's Law will be used next to calculate the index of refraction of water with increasing amounts of salt added to it. The calculation can be seen below:

$$\frac{\sin \theta incident}{\sin \theta refracted} = \frac{n1}{n2} \Rightarrow \frac{(\sin 80°) \times 1.000293}{sin\theta refracted} = n_{water}$$

The refractory indices of water for different grams of salt dissolved are calculated using the equation above.

The results of the calculation regarding the incident and refracted angles by the use of Snell's Law is presented in the table below.

Grams of salt added to the water (g, ±0.1)	Arithmetical Averages of the Refracted Angles (°, ±0.5)	Index of Refraction of Water (±0.014)
1.0	47.6	1.335
2.0	47.5	1.337
3.0	47.4	1.338
4.0	47.3	1.340
5.0	47.2	1.342
6.0	47.2	1.344
7.0	47.1	1.345
8.0	47.0	1.347
9.0	46.9	1.349
10.0	46.8	1.351
11.0	46.8	1.352
12.0	46.7	1.354
13.0	46.6	1.356
14.0	46.5	1.358
15.0	46.4	1.359
16.0	46.4	1.361
17.0	46.3	1.363
18.0	46.2	1.365
19.0	46.1	1.367
20.0	46.0	1.368

Table 4.3: The index of refraction of water for different salt concentrations, while the physical characteristics of the container used to contain the water are held fixed, can be seen in the table above.

The increasing trend of the index of refraction of water can be seen more clearly from Table 4.3. As the values of the refracted angles decrease with the increasing density of the medium, the index of refraction of water increases proportionally.

Upon calculating the refractive indices of water for different salt concentrations, the speeds of laser rays propagating through varying concentrations of water can also be calculated by using the relation below:

$$\vartheta = \frac{c}{nwater}$$

where ϑ represents the speed of light travelling through water, c the speed of light in vacuum equal to approximately 3×10^{8} ms^{-1}, and n the refractory index of water. The results of this calculation can be seen in Table 4.4, presented below.

Grams of salt added to the water (g, ±0.1)	Index of Refraction of Water (±0.014)	Speed of Light Propagating Through Water (ms^{-1})
1.0	1.335	224719101.1±2269662.9
2.0	1.337	224382946.9±2266267.8
3.0	1.338	224215246.6±2264574.0
4.0	1.340	223880597.0±2261194.0
5.0	1.342	223546944.9±2257824.1
6.0	1.344	223214285.7±2254464.3
7.0	1.345	223048327.1±2252788.1
8.0	1.347	222717149.2±2249443.2
9.0	1.349	222386953.3±2246108.2
10.0	1.351	222057735.0±2242783.1
11.0	1.352	221893491.1±2241124.3
12.0	1.354	221565731.2±2237813.9
13.0	1.356	221238938.1±2234513.3
14.0	1.358	220913107.5±2231222.4
15.0	1.359	220750551.9±2229580.6
16.0	1.361	220426157.2±2226304.2
17.0	1.363	220102714.6±2223037.4
18.0	1.365	219780219.8±2219780.2
19.0	1.367	219458668.6±2216532.6
20.0	1.368	219298245.6±2214912.3

Table 4.4: The effect of the increasing salt concentration of water on the speed of light propagating through it can be seen clearly. The physical characteristics of the container used to contain the water are kept fixed.

Since the refractive index of water increases with increasing density, the speed of light propagating through it decreases. It can be seen that while density and index of refraction are linearly proportional, the density and speed of light is inversely proportional.

In order to find the relationship between the salt concentration of water and the speed of light travelling through it, salt concentrations must be calculated by using the data regarding the grams of salt added to the water.

Salt concentrations, or densities, will be calculated in the form of grams per mL by the formula:

$$\frac{m_{total}}{V_{water}}$$

where m_{total} indicates the total mass of the salt and water, and V_{water} indicates the volume of the water in the container. The calculations are presented below:

$m_{total} = m_{salt} + m_{water}$
$= \text{(grams of salt added)} + 100\ g$

$$\frac{\text{(grams of salt added)} + 100\ g}{100\ mL} = \text{density}$$

Using these calculations for each 20 values, the salt concentration, or density, of water can be calculated. The results can be seen in Table 4.5.

Salt concentration of the water (g/mL, ±0.01)	Index of Refraction of Water (±0.014)	Speed of Light Propagating Through Water (ms^{-1})
1.01	1.335	224719101.1±2269662.9
1.02	1.337	224382946.9±2266267.8
1.03	1.338	224215246.6±2264574.0
1.04	1.340	223880597.0±2261194.0
1.05	1.342	223546944.9±2257824.1
1.06	1.344	223214285.7±2254464.3
1.07	1.345	223048327.1±2252788.1
1.08	1.347	222717149.2±2249443.2
1.09	1.349	222386953.3±2246108.2
1.10	1.351	222057735.0±2242783.1
1.11	1.352	221893491.1±2241124.3
1.12	1.354	221565731.2±2237813.9
1.13	1.356	221238938.1±2234513.3
1.14	1.358	220913107.5±2231222.4
1.15	1.359	220750551.9±2229580.6
1.16	1.361	220426157.2±2226304.2
1.17	1.363	220102714.6±2223037.4
1.18	1.365	219780219.8±2219780.2
1.19	1.367	219458668.6±2216532.6
1.20	1.368	219298245.6±2214912.3

Table 4.5: The salt concentration of the water and the corresponding speed of light travelling through the water are illustrated below. The density also shows an increasing trend.

The uncertainties calculated that are presented in Table 4.3, 4.4 and 4.5 are shown in Appendix A. The absolute uncertainties of the means of refracted angles that are converted to percentage uncertainties are also included.

5 Presentation and Analysis

5.1 Presentation

The collected and processed data showing the effect of increasing salt concentration, or density, of water on the speed of light propagating through it are presented below.

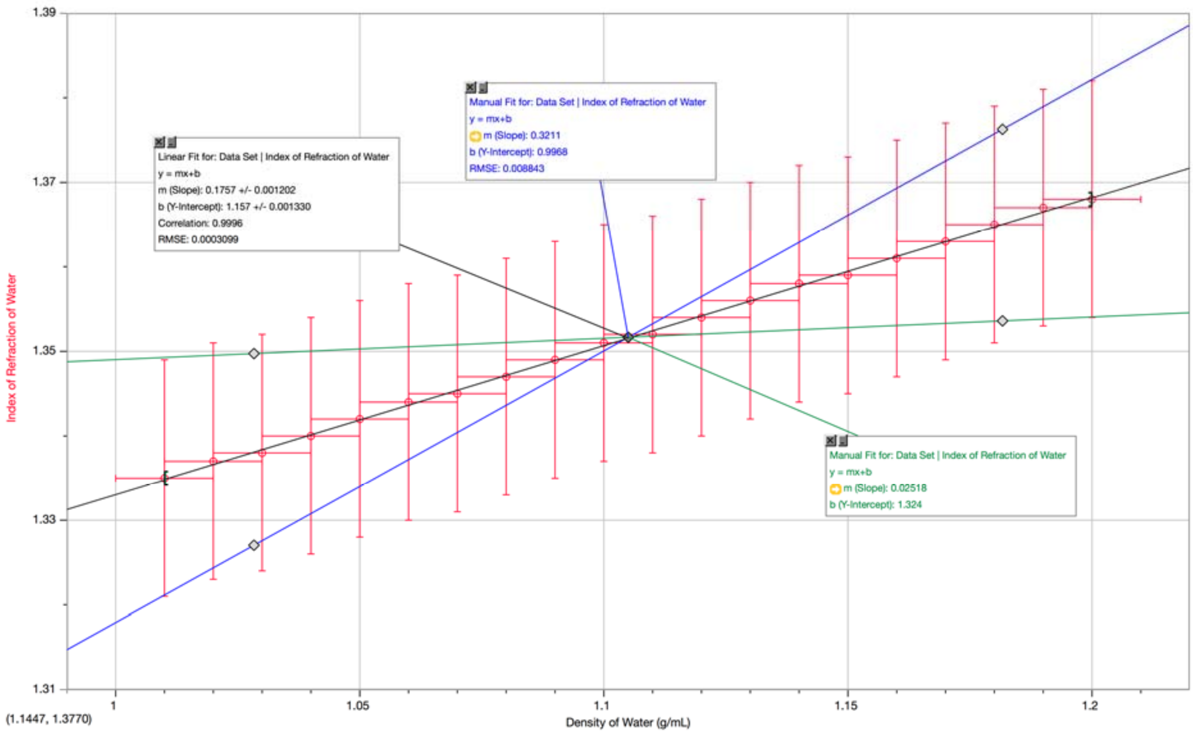

Figure 5.1: The correlation between the density of water and the index of refraction of water can be clearly seen in the figure, as the index of refraction increases proportionally with increasing density of water. Best and worst fit lines are also constructed, which also conform with the best fit line and the data gathered.

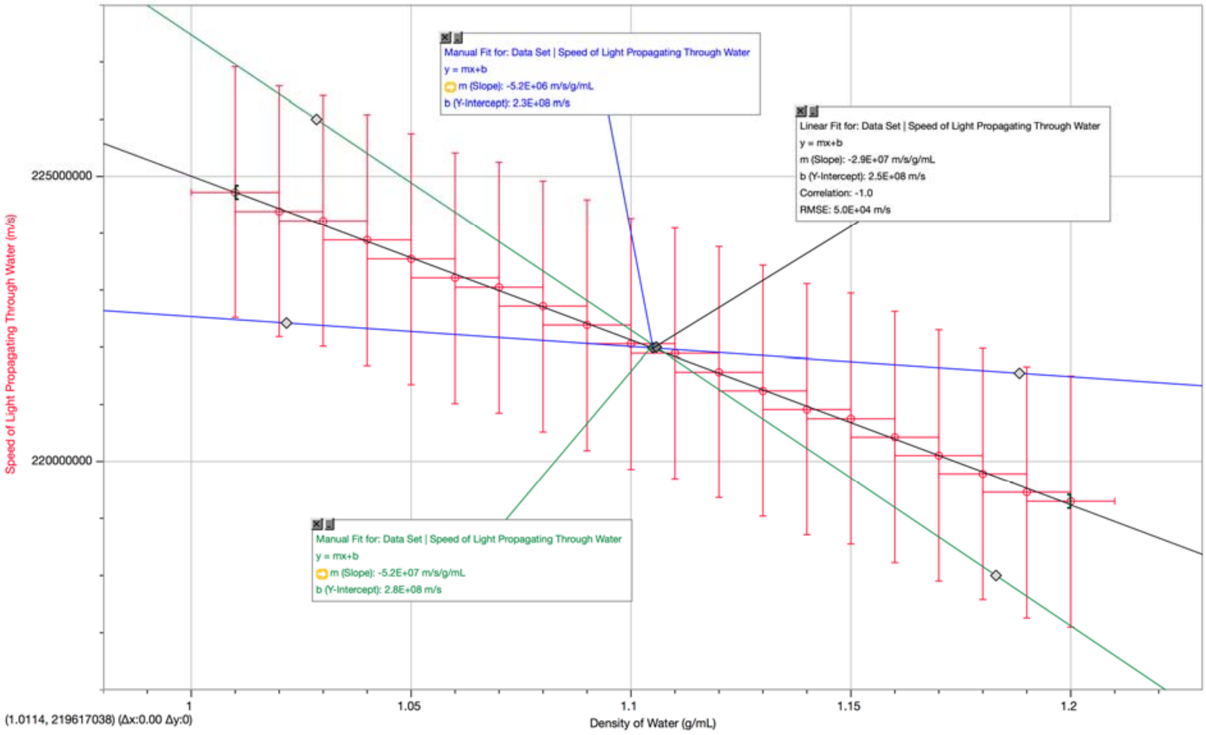

Figure 5.2: The correlation between the density of water and the speed of light travelling through the water can be clearly seen in the figure. As the density of water increases, the speed of light propagating through the water decreases proportionally. Best and worst fit lines are also constructed, which also conform with the best fit line and the data gathered.

5.2 Analysis

The relationship between the density of water altered by the addition of salt and the refractory index of the water are linearly proportional as can be seen by Figure 5.1. It can be seen that the index of refraction of water gradually increases as the concentration of the water is increased. However, the magnitude of the vertical(y) error bars suggests that the data harvested throughout the investigation may reflect the relationship between the density and the refractory index of a medium erroneously because of the errors present. Moreover, the overall change in the index of refraction of water as more salt is dissolved in it, resulting in 20 grams of salt dissolved at the end of the experiment, is 0.033. This value is smaller than the initial refractory index of water, 1.335, which is measured when 1 grams of salt is dissolved in the water. This little fluctuation in the index of refraction measured by the elementary and relatively insensitive equipment suggests that the experiment might easily have been disrupted by the environmental conditions and human factors.

The data could be arranged to a line of best fit in Figure 5.1, although there is not a formulated relationship between the refractive index and the density. The best fit line shows that the relationship between the variables can be formulated with a linear function, in the form y=mx+n, where m corresponds to slope and n corresponds to an interception point of the line with the y-axis. The slope of the line is 0.321, based on the line of best fit.

Since Figure 5.1 suggested that the density and the index of refraction are proportional properties, the relationship can be represented as :

$$n \alpha d$$

in which 'n' is the index of refraction and 'd' is the density. The linear function in Figure 5.1 supports the relationship between these variables. The data collected and processed therefore fit the theoretical predictions.

The graph in Figure 5.2 that represents the relationship between speed of light and density, is formed by dividing the speed of light in vacuum(c) to the individual refractive indices of water. That is why it can also be said that this graph also conforms with the theoretical expectations like the graph in Figure 5.1. This graph also shows a linear relationship between the density of water and the speed of light propagating through it. Since the slope of the line is negative in magnitude, as the angle between the line of best fit and the x-axis is less than 90 degrees, the relationship between the two variables can be said to be inversely proportional.

A formula for the relationship between the density of the medium and the speed of light propagating through water can be derived using the form $y=mx+n$, in which 'm' represents the slope of the best-fit line and 'n' represents the point of intersection between the best fit line with the y-axis.

The intersection point between the best-fit line and the y-axis is indicated as 2.3×10^5, while the slope is represented as -2.9×10^5; so the formula can be generated as:

$$\vartheta_{light} = |-2.9\times10^5|d + (2.3\times10^5)$$

6 Conclusion and Evaluation

Through this investigation, I proved that an increase in the salt concentration of water by the addition of salt leads to an increase in the refractive index of water, which decreases the speed of light propagating through that water. The increase in the salt concentration of water leads to a higher density since:

$$d = \frac{m}{V}$$

where 'd' indicates the density of the water, 'm' indicates the overall mass of the setup and 'V' indicates the volume of the water. The dissolved salt increased the total mass while the volume of the water remained the same, thereby the density increased with the addition of salt. As indicated by Figure 4.3 and the graph in Figure 5.1, the increase in density by the addition of salt increased the index of refraction of water. The refractive index was defined as the speed of light in a vacuum(c) divided to the speed of light propagating through that medium(ϑ); so the speed of light decreased dependently as the index of refraction increased.

It can be concluded that density of a medium is also a factor capable of changing the index of refraction of that medium, since Figure 5.1 demonstrated a linearly proportional relationship between index of refraction and density, while Figure 5.2 demonstrated an inversely proportional relationship between density and the speed of light travelling through water. If it is assumed that the uncertainties in the experiment did not have a considerable effect on the results, it can be said that a linear relationship exists between the density of water and the speed of light propagating within it. That is why a formulated relationship can be generated between these two variables as:

$$\vartheta_{light} = |-2.9\times10^5|d + (2.3\times10^5)$$

The large magnitude of the uncertainties in the experiment that can be seen in the graphs suggests that the result of the investigation may have been affected by certain sources of error, which can be discussed as below:

1. **Measurement of the Angles**: The refracted angles were measured with a goniometer that involves an uncertainty of ±0.5 in the measurements. This relatively simple equipment was not sufficient to provide precise results since the angles were very small and did not allow great uncertainties. The angles must be measured by more advanced apparatus to reach an accurate conclusion since the angles of refraction have only altered by 1.6 degrees with an addition of 20 grams of salt in

total. A possible alternative could be to use a professional refractometer to directly measure the indices of refraction.

2. **Increasing the Temperature**: The temperature of water is increased by 5 degrees to make the temperature of water 25 degrees prior each trial to allow the salt to dissolve better. However, this may have caused some of the water to evaporate, thereby causing a loss of volume and an increase in density. A possible solution may be to close the top of the container with a lid to prevent the water particles rising into the air.

3. **Addition of Salt**: The addition of salt was kept constant at 1 grams after each 5 trials throughout the investigation. Even though this provided to acquire a hundred trials by wasting less salt, it made an overall difference of 1.6 degrees in the angle of refraction, which is small in magnitude. This may have decreased the precision and the quality of the results. A possible solution may be to increase the amount of salt added, such as 3 grams at each trial.

4. **Dissolving the Salt:** Although the temperature was elevated and the water was stirred for 2 minutes after each addition of salt, there may have been some particles left that may have been missed. An improvement could be to use sugar instead of salt to allow for better dissolution, since sugar dissolves better than salt at the same temperature. The temperature could also be increased by 2 more degrees to increase the rate of dissolution.

Other areas similar to the aim of this experiment that can be investigated are:

- Performing the investigation with other transparent materials such as gelatin, glass, olive oil, etc.
- Conducting the experiment with increasing the temperature of water to fing the relationship between temperature and speed of light.
- Conducting the experiment with different colors of laser pointer to find the relationship between wavelength and speed of light.
- Conducting the experiment by using a medium with a higher index of refraction and a laser with a lower wavelength.

Appendix A

Uncertainty Calculations

The index of refraction of water for a single density is calculated by Snell's Law, which is represented in the equation at chapter 4.1. Since the uncertainties of the averages of angles of refraction is ±0.5 degrees, the absolute uncertainty for $\sin\theta_{\text{refracted}}$ can be calculated by subtracting the orginial value derived for an angle θ from the value produced by the sum of the angle and the uncertainty, which would be $(\theta + 0.5)$. For example, the uncertainty of $\sin\theta_{\text{refracted}}$ for θ=47.0 degrees is calculated as below:

$$\begin{aligned}\sin(\theta_{\text{refracted}}+0.5) - \sin\theta_{\text{refracted}} &= \sin(47.5) - \sin(47.0)\\ &\approx 0.7373 - 0.7314\\ &= 0.0059 \approx 5.9\times10^{-3}\end{aligned}$$

This result can be converted to a percentage uncertainty since it will be used in multiplications and divisions later. The percentage uncertainty is calculated by dividing the absolute uncertainty value to the actual value and multiplying the result by 100.

$$\%\text{uncertainty} = \frac{5.9\times10^{-3}}{\sin(47.0)} \text{x}100 = 0.81\%$$

The percentage uncertainty for sin(47.0) is found as 0.81%. If the same calculations are applied for θ= 80 degrees, the percentage uncertainty of sin(80) can be found approximately as 0.15%. To come up with the overall absolute uncertainty for the refractory index of water with a density of 1.08 g/mL, these two uncertainty values were summed up and then multiplied with the respective refractive index of water as indicated below:

$$\frac{0.81+0.15}{100} \text{ x } 1.347 = 0.01369 \approx 0.014 = 1.4\text{x}10^{-2}$$

Therefore, the uncertainty value for the index of refraction of water when 8 grams of salt is dissolved can be calculated as an approximate ±0.014. The uncertainties of the rest of the indices of refractions for other values of θ were also approximately 0.014, hence the absolute uncertainty values for all refractive indices of water was taken as 0.014.

The uncertainties in Table 4.4 were also computed similarly by multiplying the absolute uncertainty of the refractory index of water with individual values of speed of light travelling through the medium.

For example, the uncertainty of 224719101.1 was found as below:

$$224719101.1ms^{-1} \text{ x } \frac{1.01}{100} = \pm 2269662.9ms^{-1}$$

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