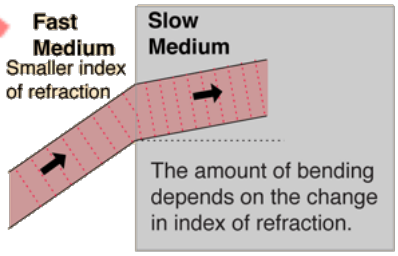
How does the density of a liquid affect its index of refraction?

IB Physics IA

Introduction

During my childhood, the phenomenon of refraction was impressive to me as I put a chopstick in a glass of water, and saw it bent. And in many books I read about this too, as in the form of being a magic trick of physics. During middle school, this phenomenon was again known in many test papers of its effect in determining distance of fish when observing in water, as its characteristic mentions the bending of light when enters another medium (Nave) .

Now, as I enters the study of IB physics, I have a better understanding of how light was refracted when it enters water, and also got a chance of learning another theory behinds it, that was the index of refraction. It defines the ability of liquid of bending lights, and it was just like density, since every liquid had their own index of refraction. It had the equation of $n = \frac{c}{v}$, where n stands for the index of refraction, c stands for the velocity of the light in vacuum, and v stands for velocity of light in the medium (Nave).



In the diagram shown above, which was from the website of hyperphysics, it can be seen that when light entered another medium that was slower, the lights will bend. That explained why chopsticks looked like being bent by water after putting itself in. Furthermore, it also had the equation of $\frac{\boldsymbol{n_1}}{\boldsymbol{n_2}} = \frac{\boldsymbol{\sin\theta_1}}{\boldsymbol{\sin\theta_2}}$, wherc $\boldsymbol{\theta_1}$ and $\boldsymbol{\theta_2}$ means the incident and refraction angle of the light in different medium, $\boldsymbol{n_1}$ and $\boldsymbol{n_2}$ stands for index of refraction.

However, as I finished this chapter, a question was raised in my mind. Is there anything that can change the index of refraction of liquid? Being motivated by this concern as a curious person, I listed some possible factors of change, and finally locked my point in the aspect of density and temperature, for them being iconic features that could use in physical experiments to help me find out the solutions as well as not too hard to conduct the experiment.

As a result, I decided to carry out an experiment to find out whether the density can change the index of refraction of the liquid.

Research Question

What relationship does density of the liquid and its index of refraction have?

Hypothesis

The greater the density of the liquid, the greater the index of refraction is.

Variables

In the experiment, I need to change the density of the liquid by changing the mass of its solute.

The independent variable in this investigation is the density of the liquid.

The dependent variable in this investigation is the angle of refraction.

The controlled variable in this investigation is the frequency of the laser and the temperature of water, they should be the same.

Materials

The following materials will be used to conduct this lab:

A large protractor and a small protractor

A laser beamer

A stand for the large protractor

A small transparent liquid holder (tank) with a magnet

Three beakers with readings on it

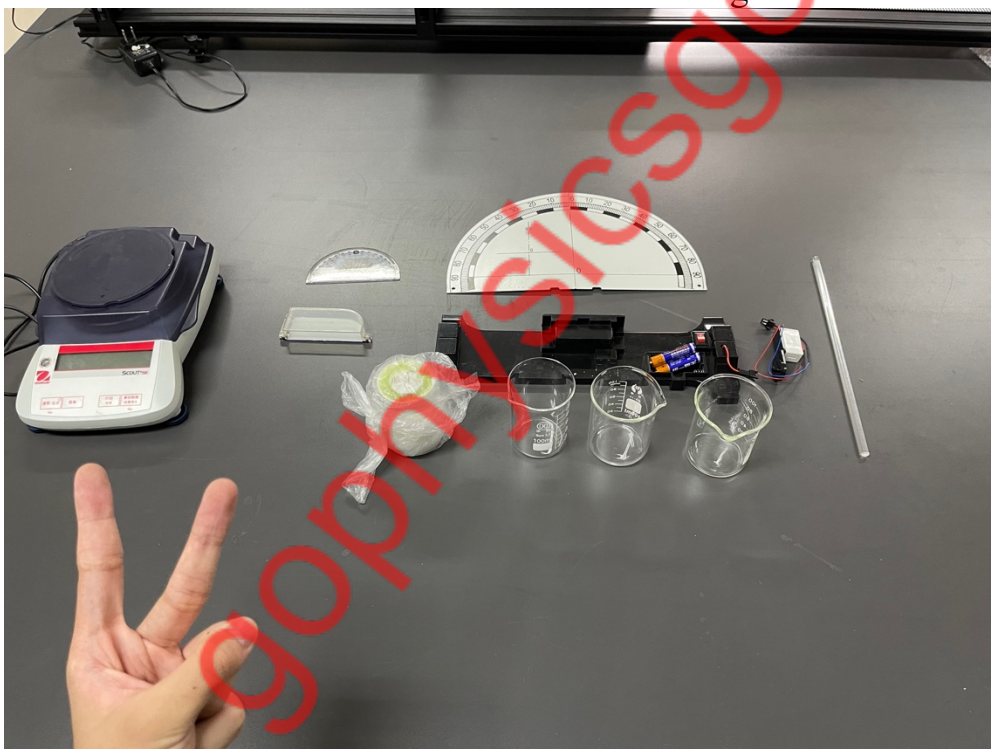
A thermometer

An electric weight

A bottle of salt

A glass rod

The materials used in this lab are shown in the figure below



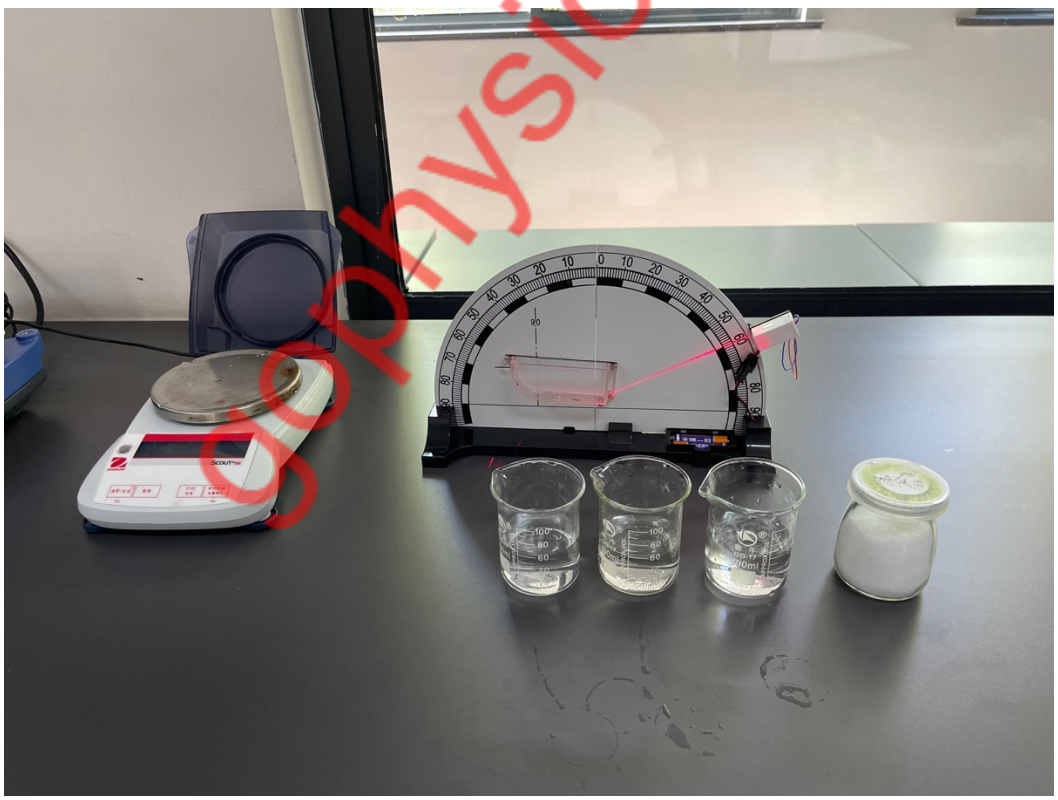
Procedure to Collecting Data

The following steps will be taken to conduct this lab:

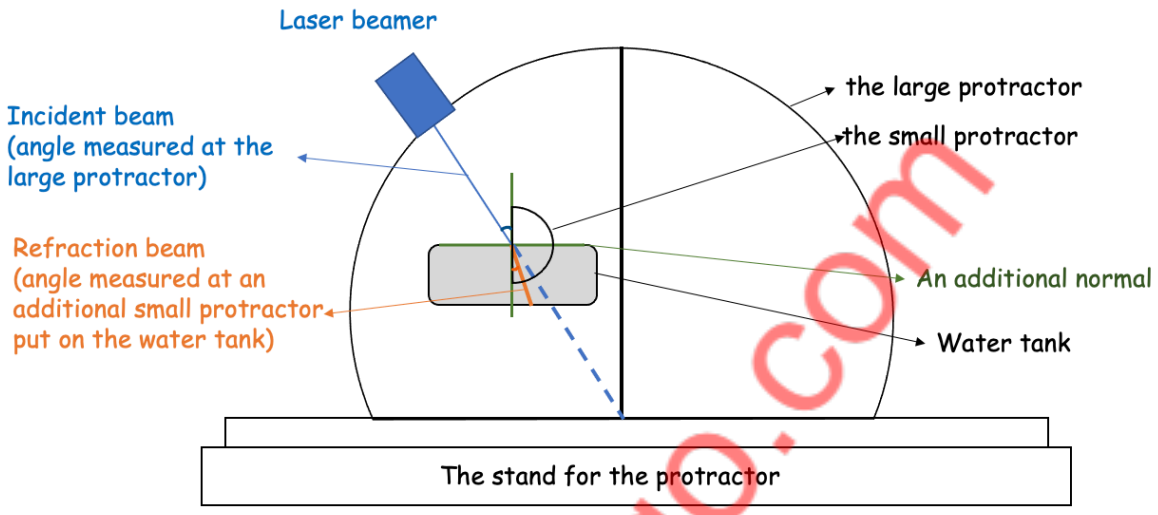
Before the trials:
Set up the laser equipment by assembling it, and attach the large protractor to its stand.
Turn on the electric weight
Make sure that all liquid was in the same temperature, here it will be room temperature (26 degrees by the time)

Here are the steps of the experiment:
Measure the mass of the salt on the weigh
Fill water inside the beakers with the same volume of 60ml, water could be filled from taps in the lab.
Put the different masses of salt inside the beakers and stir them with the glass rod
Fill the small container with one of the liquids.
Change the angle of the laser beam to make it into the liquid
Measure the incident angle and refraction angles
Repeat it five times by changing the thermometer on the heater.

The setup of the experiment is shown below



How the combined laser measurement tool works



The figure above shows how the combined equipment of laser and protractor works.

Ethical and Safety Concerns

I need to be careful from breaking some of the glass-made equipment including beakers.

When adding salt to the beaker, I should not pour the salt everywhere on the table, I should also not spill any kinds of liquid on the table or floor, otherwise it may be hard to clean.

Raw Data Results

Table 1 below shows the relationship of the density of the liquid and its refraction angle under different incident angles. Column 1 shows the volume of the water. Column 2 shows how much salt I add into the water. The remain columns shows the incident angle and the refraction angle

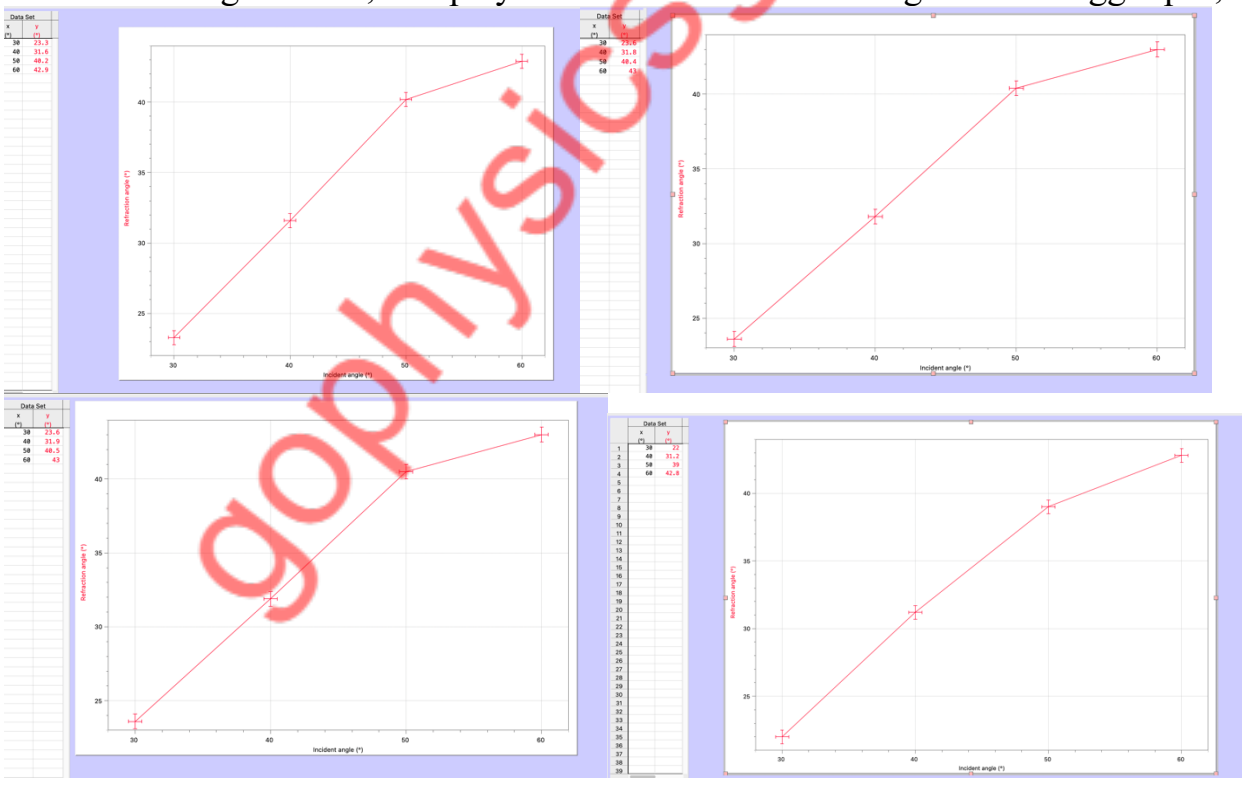
Table 1

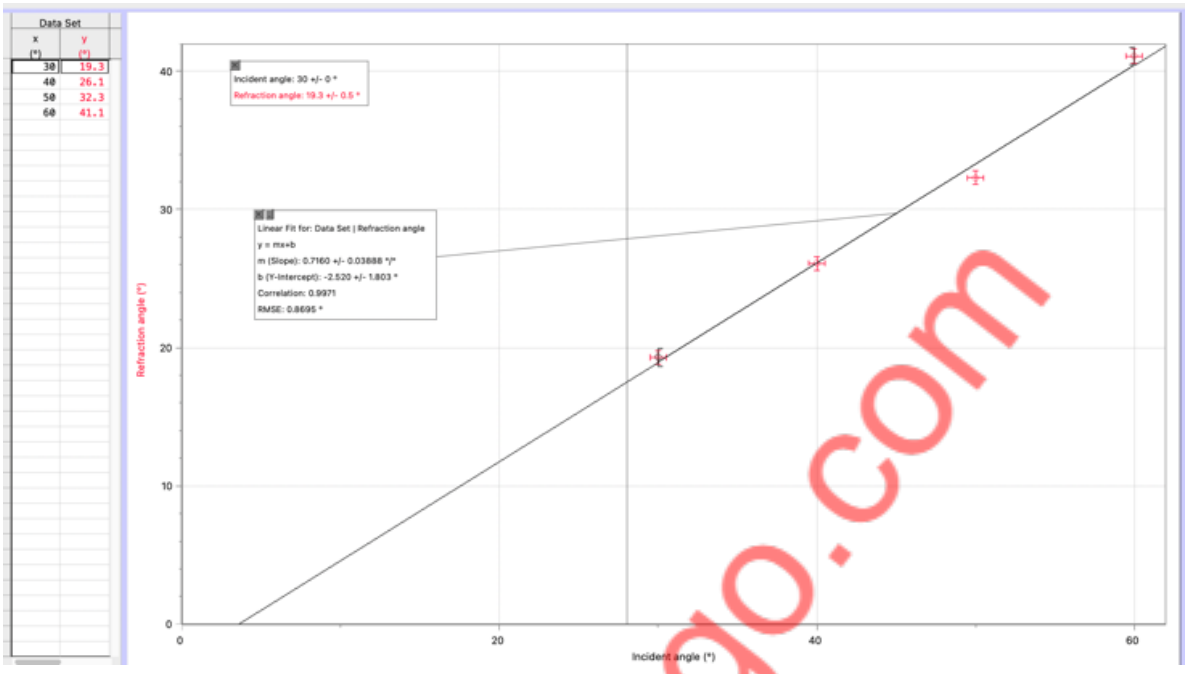
The volume of water	Mass of the salt ($\pm 0.1g$)	Incident angle($\pm 0.5°$)			
		30.0	40.0	50.0	60.0
		Refraction angle($\pm 0.5°$)			
60ml	5g	19.3	26.1	32.3	41.1
	10g	22.0	31.2	39.0	42.8
	$15g$	23.3	31.6	40.2	42.9
	20g	23.6	31.8	40.4	43.0
	25g	23.6	31.9	40.5	43.0

From the results above, I could observe a difference of the increasing of refraction angle as incident angle increased, and it is also affected by the mass of salt. However, I need to use logger pro and my calculator to find out to what extent did it increased, as well as find the index of refraction. Since I repeated the measurement for 5 times, the result should be more accurate.

Data Processing

After collecting the data, I displayed them in the form of diagrams via logger pro,





In these diagrams, Y axis shows the refraction angle of the light, while X axis showed the incident angle of the light. All of the five diagrams, which stood for each trial with different salt masses, revealed that the refraction angle increases as the incident angle increases, in both degrees of incident as well as the mass of salt being put increased. And they all followed a similar rate of increasing

However, my aim of the experiment is to obtain the value of index of refraction, that would be done after a series of calculation. In order to determine the index of refraction of the liquid, I can use the equation of $\frac{n_1}{n_2} = \frac{\sin\theta_1}{\sin\theta_2}$ to help me get the solution, that came from the physics handbook telling the relationship between the angle of refraction and the index of refraction of the liquid. My collected data can be used with this equation, and I should notice that the index of refraction of air is roughly 1.

For the experiment, I believe that the results are reliable, for I can change the density by changing the mass of salt put in the water. The data were shown in the chart1 below.

Chart 1

Type of liquid	Temperature	Index of refraction
Water, 60ml	5g	0.70
	10g	0.79
	$15g$	0.81
	20g	0.82
	25g	0.82

From the data above, I found that the index of refraction increases as the density of the liquid increases. In other words, they are proportional, which confirmed my thoughts in the beginning. However, I noticed that after putting 20g of salt in the liquid, the index of refraction didn't change significantly. In other words, the density wasn't changed after that rate.

Conclusion

After the experiment, I got the conclusion that the density of the liquid had a proportional relationship to the index of refraction of liquid.

Errors and Limitations of the Investigation

In the trial, I found that the density of the liquid didn't change after adding a certain amount of salt. That was because of the mass of the salt had reached the max capacity of Solubility, which means the maximum amount of a substance that will dissolve in a given amount of solvent at a specified temperature (Mittal). In other words, not all salt could melt inside the water after I stirred them, but I need to increase the temperature of the water or stir for a longer time to get them blended with water. However, I use the second method since increasing temperature is not the variable being changed in this trial. Although a small error happens in this part, it could still considered be a part of investigating of my experiment.

A limitation in the experiment is that, asides from the lab-provided tools, some of my equipment was brought from my kitchen, for they were easy to access, but the salt may not be pure from the salt used for lab. For my equipment of laser beams, I also brought an experiment kit online, that was used for measure the incident and refraction angles in the liquid. The reason of using this is because I found that the school lab lacked the specific type of laser beams that could be seen in the water,

while the one was available in my brought kit. Thus, in the kind of equipment, there was a limitation of lacking precision as well as costs an extra money.

Suggested Methods for Improvement

For the improvement, I think I can replace the small container attached on the equipment to a larger individual container, since the refraction angle was too small to observe. In order to maximize the precision, some lab tools can be used, such as the salt for Chemistry experiments to make the density of the salt water more precise. Furthermore, I also need to find a way to make the salts in the water to be melted in a more efficient way, maybe I could use a heater under the container to increase the temperature, thus made more salt being melted, only if I could figure out a way to make the combination of the equipment useable.

Bibliography

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