International Baccalaureate:
Extended Essay

May 2022

Physics

Investigation of refraction of light depending on the concentration of the medium

Research Question: To what extent does the concentration of the medium affects the behavior of light

Word Count: 3541

Contents

1. Introduction

The behavior of light is a complex and difficult area of physics. Hence, I decided to work on that phenomenon. Besides used to wonder how the light behaves when I was a kid. Also, the propagation of light excites me a lot. Because of my interest in the behavior of light, I decided to investigate the refraction of light. This subject is under the title of "Waves" in the IB curriculum so while working on the light I will be working on the fundamentals of the waves. These reasons made me choose this investigation.

This essay attempts to answer the question, "To what extent does the concentration of sugar affect the refraction of light. The main aim of the essay is to make an additional model of the sugar detecting machine used in manufacturing. The machine which is used in manufacturing is based on prisms and reflection of light but mine is based on polarized light.

Firstly, the phenomenon of polarization should be investigated and explained. This is explained because polarized glasses are the main part of the essay, they are used to produce the polarized light and the project moves on with the polarized light. To explain the question "To what extent does the concentration of sugar affect the refraction of light" polarized light is used.

Secondly, to answer the question behavior of light should be investigated. Light is an example of a transverse wave, so oscillations are the electric and magnetic fields, which point at right angles to the ideal light rays that describe the direction of propagation.

Thirdly, after explaining the polarized light and behavior of light the model and usage of polarized glasses and sugar should be explained. Two polarized glasses are used which are put

with 90-degree angle difference so in perfect conditions any type of light could not pass these two glasses, but the usage of sugar makes the light pass through the polarized glasses.

After these steps, the effect of sugar on the refraction of light can be measured. The amount of sugar changes the refraction of light, and the purpose of the essay is to measure the difference between the different concentrations.

2. Background Information

2.1 Information of Light

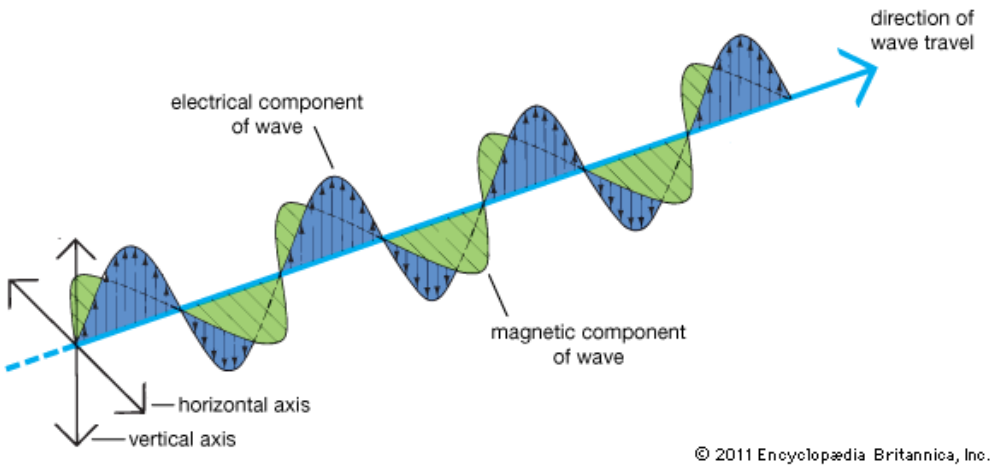


Figure1.

In figure number one light wave is shown. Light is composed of both particles and waves. This essay explores the wave part of the light. There are two types of waves. One of them is electromagnetic and the other one is mechanical. Light is a type of electromagnetic wave. It can travel through non-particular(vacuum) mediums. Light is an example of a transverse wave that

the motion of the particles in the wave is perpendicular to the movement of the wave. To create an electromagnetic wave there should be a change in the electric field, this change causes a change in the magnetic field, change in the magnetic field creates change in the electric field, and after these changes, the electromagnetic wave is produced.

The light used in this essay is produced by LEDs. LEDs produce light by using electricity. Simply when the electricity enters the LED. The electrical energy is emitted by the materials in LED they use this energy to excite the electrons these excited electrons emit the photons of light. Light is composed of electric field waves and magnetic field waves which are perpendicular to each other. This essay focuses on electric field waves of light. The light source used in this essay emits light in every direction so that there are multiple electric field waves in every direction. These electric field waves are not perpendicular to each other. The not-orientated electric field waves are called unpolarized light. Sun and light bulbs are an example of unpolarized light.

2.2 Phenomenon of Polarization

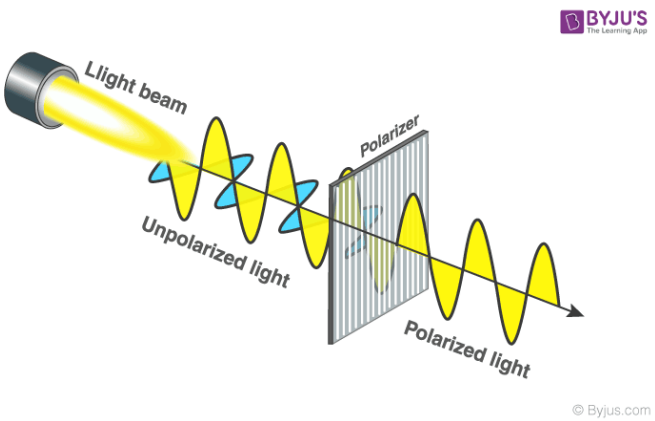


Figure2.

In figure number two the polarization is shown. A polarizer is made of plastic which has a molecular structure, only allows a particular orientation of electric field lines. The unpolarized light goes through the polarizer, the polarizer only allows the electric field waves which are in the same direction as the polarizer. Only electric fields waves that are parallel to the direction of the polarizer can pass through. After passing from the polarizer, electric field waves only have one direction which is as same as the polarizer they have passed. This is called polarization. An electromagnetic wave is said to be plane polarized if the electric field oscillates on the same plane. Polarized lights are named after the angle that they are made with the surface. If the polarizer was perpendicular to the surface the polarized light will be called vertically polarized light if it is horizontally placed to the surface polarized light will be called horizontally polarized light. Some of the daily life examples of polarizers are sunglasses, most monitors, and cameras.

2.3 Malus Law

Malus Law says that the intensity of light that passes through two polarizers depends on the angle difference between them. Polarizers let the light which is parallel to the direction of the polarizer pass through (refer to 2.2). If the directions of the polarizers are perpendicular to each other there will be no light passage to the other side of the polarizers. And Malus says that the intensity can be found with the use of formula. "$I = I_0 \cos^2(\theta)$"

I: intensity final

I_0: intensity initial

Θ: angle of difference between polarizers

3. Experiment Setup

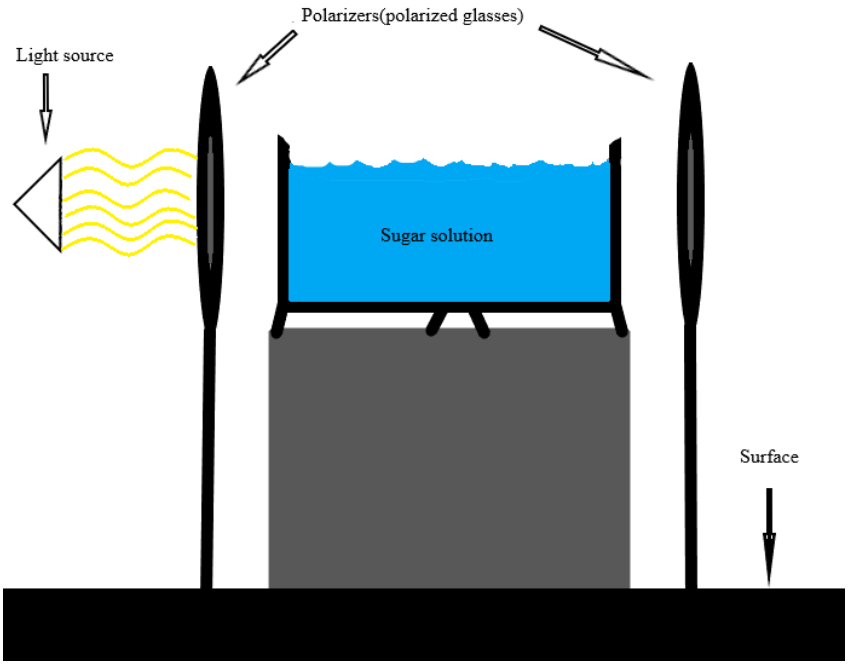


Figure3.

A container of sugar and water solution is placed between two polarizers and a light source is at the left of the model. Also, the center of the light source, the center of the polarizers, and the center of the solution are on the same line and that line is parallel to the surface. While making the setup it is important to place the light source perpendicular to the surface otherwise polarizers will not work properly and there will be a random error that affects the quality of the experiment. The experiment should start when the water stops fluctuating. Otherwise, light can be refracted in different ways which means light waves spread from each other and we could not get the result that we expected. One polarizer should be 90 degrees tilted than the other one. If not, the experiment cannot be done because the whole point of the experiment is to put the polarizers perpendicular to each other. Lux meter is placed at the right of the right polarizer. Also, the

center of the light meter is at the same line as the others. The distance between the light source from the left polarizer is 2 cm, the distance between the right polarizer and the lux meter is 2cm.

The solution is composed of 100 ml of distilled water and the amount of sugar always changed during the experiment. In 100 ml distilled water 40 grams of sugar can be solved so in every attempt mass of sugar is increased by 1 gram, at the first trial there was 1 gram of sugar so there were 40 trials. Also, make sure that sugar is solved into the water perfectly otherwise random errors can occur.

4. Experiment Procedure and Collection of Data

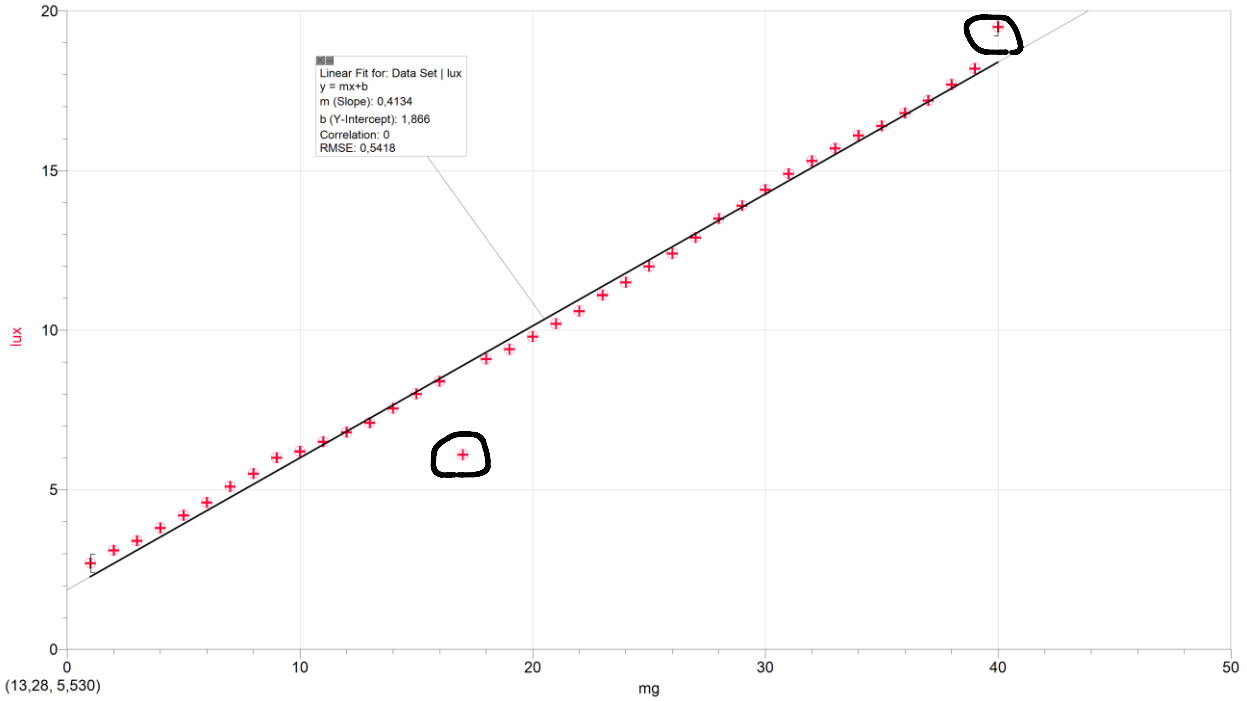
First, the lux of the light source is measured directly from the side then the lux is measured 14 cm away from the light source. After that, lux is measured while both polarizers are at the same degree (without the solution). After that, the lux is measured while one of the polarizers tilted 90 degrees. Then everything is stabilized with the tool stabilizers. After stabilizing every solution is measured carefully.

To avoid random errors experiment should be in a very dark place. There cannot be a place where light intensity is equal to zero because when the light intensity is equal to zero that means there is no light in that place. If there is no light anything cannot be seen. So, there will be an initial value of lux, for other results the rate of change of lux can be measured. Water must be very steady before the experiment. Care must be given to the degree of dissolution of sugar. If it seems not perfectly dissolved do not continue without dissolving perfectly. Dissolving perfectly means that, if it seems dissolved it is ready to continue because it cannot be 100% known that every sugar molecule dissolved in water. To reduce the random errors, stir the solution before the trials. I made two attempts for each amount of sugar. The average of those trials is written in the

box To be more accurate also to reduce the random error. Table 1 below shows the measured flux of all the eighty trials. The initial flux was ***2.7***. The lux measured of the light source from the side was ***762.0***. Lastly, the lux measured 14cm away from the light source was ***761.9***. All the units are lux.

Trials	*I/lux*	*Trials*	*I/lux*	*Trials*	*I/lux*	*Trials*	*I/lux*
1.	*2.7*	*11*	*6.5*	*21.*	*10.2*	*31*	*14.9*
2.	*3.1*	*12*	*6.8*	*22.*	*10.6*	*32*	*15.3*
3.	*3.4*	*13*	*7.1*	*23.*	*11.1*	*33*	*15.7*
4.	*3.8*	*14*	*7.55*	*24.*	*11.5*	*34*	*16.1*
5.	*4.2*	*15*	*8.0*	*25.*	*12.0*	*35*	*16.4*
6.	*4.6*	*16*	*8.4*	*26.*	*12.4*	*36*	*16.8*
7.	*5.1*	*17*	*6.1*	*27.*	*12.9*	*37*	*17.2*
8.	*5.5*	*18*	*9.1*	*28.*	*13.5*	*38*	*17.7*
9.	*6.0*	*19*	*9.4*	*29.*	*13.9*	*39*	*18.2*
10.	*6.2*	*20*	*9.8*	*30.*	*14.4*	*40*	*19.5*

Table 1. data gathered from the experiment



Graph1. Lux vs mass of sugar

Graph 1 shows the data collected from the experiment but unlike other data, there are two outliers. Those will not be taken into consideration. To make the calculation, the best-fit line has been withdrawn. Besides the outliers, all data are not on the same line they are slightly under or above the best-fit line. The reasons for not being on the same line are systematic errors and random errors.

5. Error Calculation

Before calculating error percentage sections that errors are made need to be found. While making the experiment water and sugar solution was not always as steady as it should be, the reason for outliers is water steadiness. Also, there is a systematic error which is caused by the flux meter. While scaling sugar there is a systematic error caused by scale. To reduce the random errors the outliers should be not involved in the equation. For systematic errors, errors should be

found and involved in the equation. Systematic error for weight is ±0.01. Systematic error for measured and lux is also ±0.01.

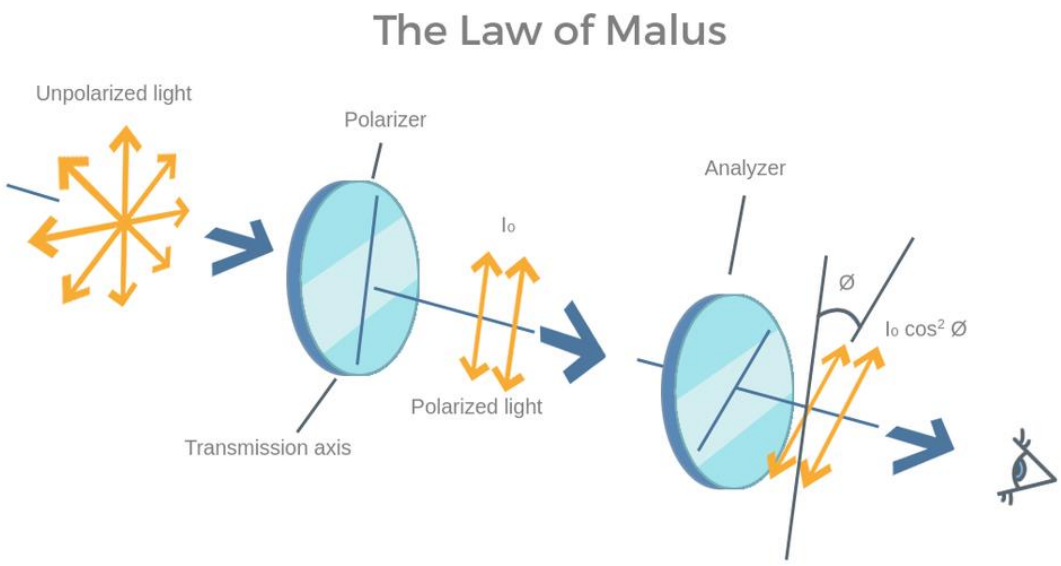
5.1 Scattering

Besides errors which are caused by electronic devices used and human mistakes, there is a reflection of light caused by water and sugar molecules. Scattering is not caused by water stability it is because of principles of reflection. When the polarized light waves enter the medium which is water, some of them got reflected because of the water. To measure the light which is reflected by water. The intensity is measured without water solution just two polarizers which were 762.0 then water was put between the polarizers then intensity is measured which was 761.3. From these calculations, 0.7± 0.01 lux went to the scattering. While measuring the scattering distilled water was used with a pH level of 7 to avoid the scattering caused by other molecules in water.

6. Correction of Law of Malus

The Law of Malus is used to calculate the intensity of light after passing two polarizers. (Refer to 2.3 background knowledge) Malus Law states that the final intensity of light passing through two polarizers depends on the angle difference between the two polarizers. So as the angle difference between polarizers increases the light passing through the second polarizer decreases. Malus Law is used to determine the angle difference, but the angles never change throughout the experiment so the angle difference found at the end means that if there were not

any solution, we should rotate the polarizer with that angle. Like the Malus Law, angle difference increases the concentration of sugar decreases.



$$I = I_0 \cos^2(\theta)$$

I: intensity of light at the end

I_0: intensity of light initially

Θ: Angle difference between the first polarizer and the second polarizer (the angle of obliquity)

After the first polarizer, polarized light passes through the analyzer (works as the second polarizer). The angle of obliquity increases the intensity of light decreases because

$$\mathbf{I \propto \cos^2(\theta)}$$

Because of this equation when both polarizers are perpendicular to each other the angle of obliquity is 90 degrees. When 90 degrees is put in the equation the resulting intensity of light equals zero.

$$\mathbf{I= 762x\ 0}$$

$$\mathbf{I=0}$$

When the light waves pass through the sugar solution then the angle of the light waves is changed by the solution. This change makes the light pass through the second polarizer. To find the change of the angle of the light wave the formula needs to be evaluated.

$$\mathbf{I/I_0 = \cos^2(\theta)}$$

After the formula, we take the square roots of both sides of the equation

$$\mathbf{\sqrt{\ } I/I_0 = \cos(\theta)}$$

Then, the square root of the value of Light intensity final/ light intensity initial is equal to α

$$\mathbf{\sqrt{\ } I/I_0 = \alpha}$$

After these arccos(α) is equal to θ

$$\mathbf{Arccos(\alpha) = \theta}$$

When all the calculations finish the value of the θ is equal to the value of the angle of obliquity.

Example of Calculation of **θ** (Trial 25)

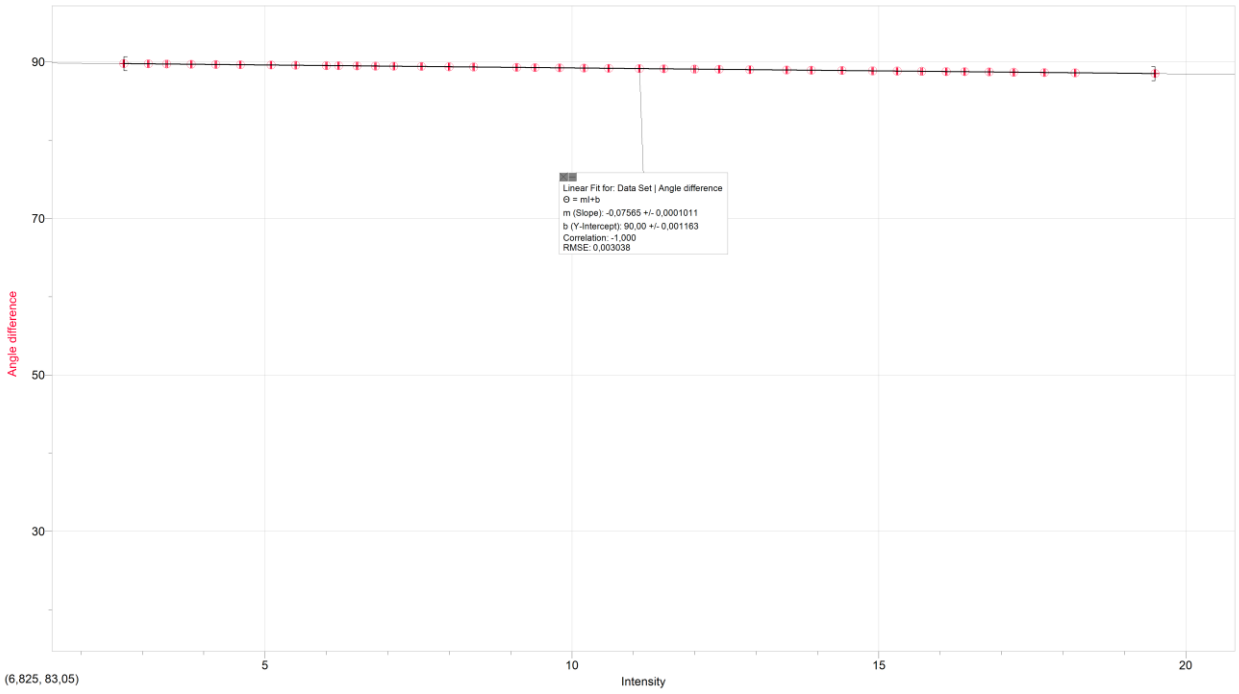
$\alpha = \sqrt{I/I_0}$

$\alpha = \sqrt{12/762} \approx 0.126$

$\text{Arccos}(\alpha) = \theta$

$\text{Arccos}(0.12549116102763) \approx 89.09$ degrees

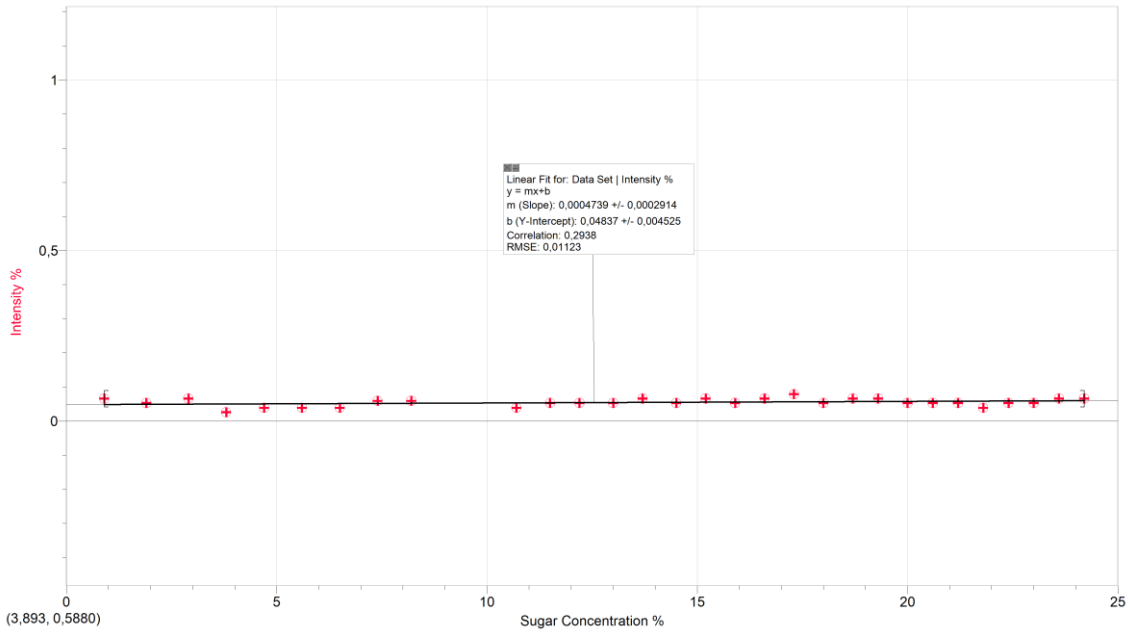
7. Relation Between θ and I



Graph 2. Angle difference vs Intensity

Graph two is a graph of intensity versus angle difference. Graph two shows how to rotate the polarizers to get the intensity. In the graph, it seemed to be parallel to the x-axis, but it is not it has a slope which is -0.75. Slope says that the intensity of light increases the angle difference decreases. The sugar effected very little due to graph 2. After the outliers are not taken into the consideration the data seem more accurate. Even so, the effect of the concentration of sugar cannot be seen perfectly, to see the effect of sugar concentration, a sugar concentration versus intensity graph should be sketched. Because θ was always the same during the experiment. The main goal of the experiment is to find the effect of sugar but θ is found at the end. Thus, to adjust the θ to sugar concentration, how much light is refracted because of the sugar had to be found. The formula is used in the essay is about the angle difference, but it is evaluated to find the sugar concentration. Graph two shows the angle to obtain the final intensity.

8. . Relation Between Concentration of Medium and I



Graph 3. Intensity vs sugar concentration

Graph 3 is sugar concentration versus %intensity graph. As stated before the angle needs to be changed into the sugar concentration. In graph three sugar concentration (as a percentage) with the errors also % intensity is given with errors. The main part of this essay is to calculate how much sugar can refract light. The slope of graph two gives the %intensity is refracted by 1 gram of sugar. As sugar concentration increases the % intensity which is reflected increases too. It can be seen every concentration of sugar refracts the same amount of light but that is the difference between the previous trial. So, the differences between trials are so close to each other slope is seen horizontal to the x-axis. Using the slope every gram of sugar can refract 0.047 percent of the light passing through the sugar. The light refracted is proportional to the concentration of sugar. So, the concentration of sugar increases the light refracted increases.

To calculate the sugar concentration by using this method the final and the initial intensity needs to be known also the amount of water needs to be known. Because 1 gram of sugar in, 100 ml water and 10 ml of water will respond differently. Besides this information, the final intensity without sugar water needs to be known. Before the calculations pH 7 water needs to be tested and light intensity data should be collected.

9. Conclusion and Evaluation

The process of investigating the concentration of the medium affecting the refraction of light and driving Malus Law to find the concentration of the medium has led to several interesting conclusions.

First, we observed that we can make light pass through the polarizers which are perpendicular to each other. The perpendicular polarizers are not supposed to let light pass through. Thus, sugar can refract light.

Secondly, we noticed that the concentration of medium and refraction of light is proportional to each other. This refraction and proportionality became more noticeable as the percentage of sugar in the water, percentage of refraction, and the number of trials increased. Also, the amount of percentage of refraction is slightly the same between the concentrations. With the use of *Graph 3*, we found that every gram of sugar refracts light the same. I am trying to say that with every gram of sugar increased in the solution the % intensity increases at the same rate. That is equal to the slope of *Graph 3* 0.047. 0.047 percent of light is refracted by the sugar in the medium.

Lastly, after making these investigations and experiments we created an alternative solution for finding the sugar concentration. After chemical ways for finding the concentration, we derive a solution for finding concentration. For finding the concentration the initial and final intensities of the solution need to be known also. The intensity without sugar concentration should be found. After that, we have known that the 1 gram of sugar refracts the 0.047 percent of the light that is coming.

Overall, we can deduce that we better understand the phenomenon of refraction of light. After all the observations made, we have produced a new model for analyzing sugar concentration for water if the necessary information is known. Also, we found that every gram of sugar molecule refracts light at the same rate. Besides these evaluations, some problems still need to be noted.

Part of the collection of data (4.) While gathering data from different solutions, the data are not going straight they are making an S shape. I realized that is just because the water was shaking and reflecting much light than it should be, but it is hard to see that the water is wavy in the dark. It was hard to make sure that all the sugar was dissolved in the water.

The uncertainties are because of the little waves and the dissolution of the sugar. In some of the trials, sugar was not dissolved perfectly and caused some uncertainties also the two outliers are because of the steadiness of the water, the sample was accidentally shaken. It is difficult to see the waves of the water in the dark. Another limitation was placing the light and the lux meter in the same direction, it was challenging to synchronize the centers of them. In some of the trials, the center of the light source and the lux meter was not in the same direction because the lux meter could not receive light. There were failed attempts like this one which is not considered in the essay and the data table.

Using the information of polarization phenomenon and the experiment I did. This solution can be used in some industrial areas. Deciding the concentration of sugar cannot be used anywhere because it is hard and the requirements of it are hard to complete and it is more expensive than the chemical ways. Besides that, the control of the light intensity can be used in farming. It can be used in greenhouses while planting crops sunlight can become harmful to the plants and the intensity of the light needs to be reduced. Instead of reducing some of the farmers use their own light source but it can be very expensive. To reduce light intensity, the mechanism that is used in this essay can be placed at the top of the greenhouses. Farmers can control the light intensity by changing the sugar concentration of the medium.

The aim of this investigation was to try and find the effect of the medium on the refraction of light. However, after the investigation results seemed to be interesting but the phenomenon of light was intricate and it was beyond my level to be completely done.

10.Extension

I believe that light can be tested in new circumstances. To understand the behavior of light other variables can be tested by using the polarization method. This essay aims to investigate the refraction of light. There are some other possible investigations to understand the behavior of light. A model can be created using one polarized monitor (nowadays most of the monitors are polarized) and one long cylindrical transparent container. Then the container with sugar solution is placed on the screen then if you twist the container the color of the solution will change. This research investigates the bending of light. There is one more research that can be done. In this research, there will be no polarizer. There will be sugar water, a polarized light resource which is a laser, and a mirror. The aim of this experiment is to see the bending of light. There will be a container like in this essay and a laser. The container will be filled with water then lots of sugar needs to be placed bottom of the container there will be lots of sugar that cannot dissolve in water. Lastly, the mirror is placed under the container. Also, the container must be transparent. Then the light of the laser is sent to the bottom of the container. The bend of light can be seen. These two ideas are made to investigate the behavior of light better.

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12.Appendix

The full table of Graph 3

Trials	Intensity	Angle difference
1	2.7	89.79
2	3.1	89.76
3	3.4	89.74
4	3.8	89.71
5	4.2	89.68
6	4.6	89.65
7	5.1	89.61
8	5.5	89.58
9	6.0	89.54
10	6.2	89.53
11	6.5	89.51
12	6.8	89.48
13	7.1	89.46
14	7.6	89.43
15	8.0	89.39
16	8.4	89.36
17	6.1	
18	9.1	89.31
19	9.4	89.29

20	9.8	89.26
21	10.2	89.23
22	10.6	89.20
23	11.1	89.16
24	11.5	89.13
25	12.0	89.09
26	12.4	89.06
27	12.9	89.02
28	13.5	88.98
29	13.9	88.95
30	14.4	88.91
31	14.9	88.87
32	15.3	88.84
33	15.7	88.81
34	16.1	88.78
35	16.4	88.76
36	16.8	88.73
37	17.2	88.69
38	17.7	88.65
39	18.2	88.62
40	19.5	88.52