International Baccalaureate

Extended Essay: Physics High Level

“The Effect of Concentration of the Chiral Compound Solution on the Angle of Rotation of Plane of Polarization”

Word Count: 3302

MAY, 2019

Content:

1. Introduction

Optical designs mostly focus on the wavelength and intensity of light. Another aspect of light that is very commonly used in technological advancements is the phenomenal prospect of light which is called polarization. Polarization is an important property of light that affects even those optical systems that do not explicitly measure it. Thus, understanding and manipulating the polarization of light is crucial for many optical applications.

One common application of polarized light is LCD screens, which is short for *Liquid Crystal Display*. In LCD Screens, optically active compounds are used in order to manipulate what parts of light passes by blocking the desired parts of the light flashed upon them, thus forming the image that we see on the screen. The physical and chemical prospects of these materials are between those of a liquid and those of a crystal, and this lets them influence the propagation of plane polarized light waves. The main content of these materials which makes them optical active is asymmetric long organic compounds they include, which is chirality. A similar substance which has chirality is honey. The sugar content of honey consists of long asymmetrical carbon compounds, which's chirality give honey optical activity. Briefly, this means that the sugar inside the honey makes it rotate polarized light.

In this experiment, the main goal is to form a more quantitative data on the relationship between the abundance of organic compounds inside the compound and the optical rotation occurring; and also discuss what effect changing the concentration of the sugar has on the angle of rotation.

2. Background Information and Literature

a) Light Waves

Light is a disturbance of electric and magnetic fields that travels in wave form. It consists of varying electric and magnetic fields that oscillate perpendicular to the direction of propagation. The primary properties of visible light are intensity, propagation direction, frequency or wavelength spectrum, and polarization. It moves with a speed of 299,792,458 meters per second[1]. When an unpolarized light is traversing through a medium, it oscillates in every direction as seen in Figure 2.1. The arrow represents a ray which depicts the direction of movement of unpolarized light. The bold arrows represent the direction of polarization of the individual waves composing the ray. Since the light is unpolarized, the arrows point in all directions.

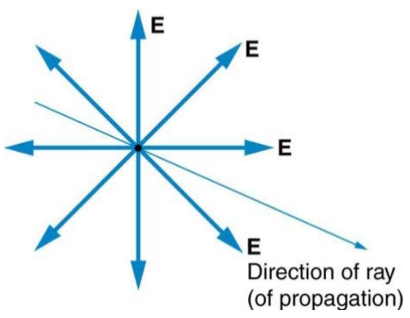

Figure 2.1: Unpolarized light propagating through a medium [2]

When the electric field vectors of a light wave are restricted to a single plane by filtration of the beam with specialized materials or tools such as polarizers, the propagation of the

[1] Tsokos, K. A. *Physics for the IB Diploma*. 6th ed., Cambridge University Press, 2014.
[2] «Introduction to Polarization.» 2001. *Edmund Optics Worldwide*.

electromagnetic vectors are fixated on a single plane (Figure 2.2). Then the light is referred to as plane or linearly polarized with respect to the direction of propagation, and all waves vibrating in a single plane are termed plane parallel or plane-polarized.

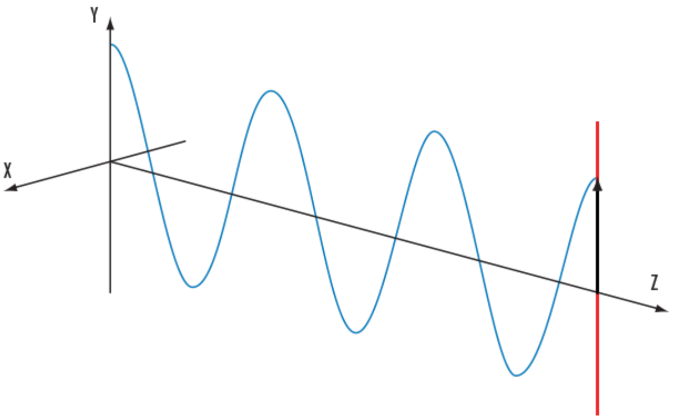

Figure 2.2: Polarized light propagating through a medium [2]

In order to polarize light, it is passed through a polarizer. A polarizer is a plate made up of opaque material which has a slit with an infinitesimal width in the middle.[3] Hence it is made up of non-transparent material, light rays can only pass through the slit in the middle. When this incident occurs, only light waves of a specific polarization are able to pass and other light waves with different plane of polarizations are blocked, thus the light is polarized (as seen in Figure 2.3).

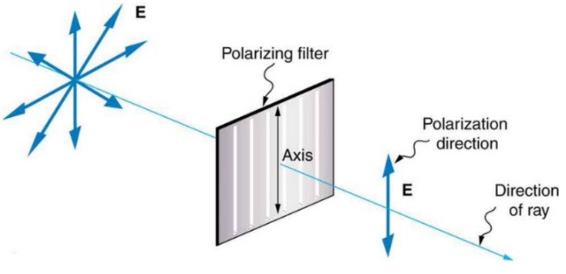

Figure 2.3: Polarization of an unpolarized light by a polarizer [4]

[3]«College Physics-Colors.» 13 January 2014. *Textbook Equity*.

b) Liquid Crystals and Chirality

Macroscopically, these substances are observed as and act like liquids but at the microscopic level they possess some order in the tradition of crystals. These kinds of materials have some very interesting optical properties, which differs from one to another. The optical property of the liquid crystals that is used in the experiment is its optical rotation. When a polarized light wave enters them, they start to rotate the plane of polarization of the polarized light (as seen in Figure 2.4). The feature of liquid crystals that enables this interaction is chirality.[4]

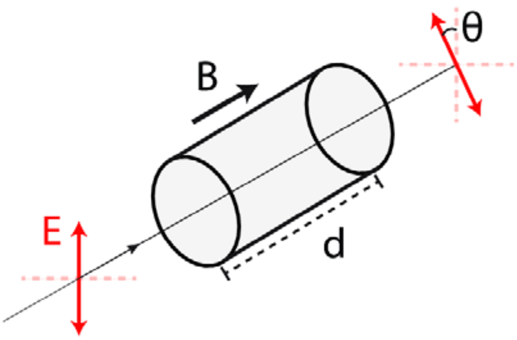

Figure 2.4: Polarized light being rotated by organic crystal [5]

Chirality is property of asymmetry that has many different applications in different branches of science and mathematics. An object is chiral when it and its mirror image cannot be superposed, or in other words when they can be distinguished from each other. The part in the crystals that are chiral are the long carbon chains. As polarized light passes through a chiral molecule, it will rotate clockwise or anti-clockwise. When this rotation occurs in clockwise, it is called dextrorotary, while it is called levorotary when it rotates anti-clockwise. Whether a carbon compound has these aspects or not can be distinguished by the fact that when a carbon

[4]«Introduction to Polarization.» 31 August 2015. *Photonics Online*,

compound has these traits, a prefix is put before the molecules IUPAC name, “d-” for dextrorotary and “l-” for levorotary.

Every carbon compound has a different amount of influence on the angle of rotation (shown by θ in Figure 2.4) which is a distinctive feature. It is called specific rotation, and is shown by $[\alpha]_{T}^{\lambda}$. The T and lambda are there because specific rotation is dependent on the heat of the surrounding and the wavelength of the light wave, despite being a constant[6]. The equation of this constant is as follows:

$$[\alpha]_{T}^{\lambda} = \frac{100 \times \alpha}{\ell \times c}$$ [5]

In this equation, α stands for the angle between the new plane and the old plane (before rotation and after rotation), ℓ stands for length of the container in decimeters and c stands for the concentration of the active compound. The constant coefficient 100 is there because the concentration is written in a format of g/100mL, which means gram per 100 milliliters, but hence in this experiment, concentration is written as g/mL, the equation becomes;

$$[\alpha]_{T}^{\lambda} = \frac{\alpha}{\ell \times c}$$

[5]«Chirality and Stereoisomers.» 23 February 2019. *Chemistry LibreTexts*.

3. Aim of the Experiment

The aim of this experiment is to find out the relationship between the rotation of plane of polarization and concentration of the carbon compound of the organically active solution. Also through this interaction of carbon compound and rotation amount, the sugar concentration of honey will be calculated.

4. Research Questions, Hypothesis, Variables

a. Research Question:

How much the concentration of the carbon compound in the optically active solution rotate the plane of polarization of the light wave while the light wave is traversing through equal amounts of the solution?

b. Hypothesis:

While a light wave is passing through an optically active solution, a rotation in plane of polarization occurs. The angle of rotation by plane of polarization is directly proportional with the concentration of the chiral compound present in the solution. Therefore, *it is expected that as the concentration increases, an increase in the angle of rotation would be observed.*

5. Variables

This experiment aims to grasp the interaction between the amounts of rotation of angle of plane of polarization with respect to the concentration amount of the chiral compound. Thus, the independent variable of this experiment is the carbon concentration in the medium, while the dependent variable is the angle of rotation. The methods used to control and observation for these variables are as stated below:

- Independent Variable: The concentration of chiral compound present in the solution

In order to change and control the concentration, d-sucrose type sugar is used. Since concentration of the solution is equal to gram of content present per mL, thus in order to increase the concentration, sugar is added to the solution and stirred so that all the sugar dissolves in the solution.

- Dependent Variable: The angular rotation of plane of polarization while the light wave is passing through the solution

As the sugar concentration of the solution increases, a change is expected to occur between the angle of the polarizer and analyzer when no light manages to pass through the slits.

- Controlled Variables: The controlled variables which have been remained the same throughout the experiment are the type of solvent (water), wavelength of the laser, distance of exposure of light wave to the optically active medium, which is equal to the length of the container, the specific rotation constant, which corresponds with the type of sugar and physical aspects of the container, the analyzer and the polarizer. The ways that they were kept constant are as listed in the next page.

1) Properties of the solvent:

Since different types of water might contain different ions that could change the outcome of the experiment, tap water from the same source was used throughout the experiment.

2) Wavelength of the laser:

The same laser with a wavelength of 650 nanometers, which is the standard wavelength of red lasers[6], in order to prevent any change in the angle of rotation caused by a difference in the wavelength, hence it is affected by the wavelength.

3) Length of the optically active medium:

Hence the light wave rotates as it goes through the optically active medium, the longer it travels through it, the more it rotates. In the equation, the amount of distance that the light wave goes through the solution is given by the letter "ℓ", which is equal to the length of the container. From the equation, we can deduce that angle of rotation and ℓ are directly proportional with each other. Because of this length of the container must be kept constant, so that no change caused by a variable that is different from the desired one is observed in the experiment. In order to be sure that the length is equal, same container, with a length of 50 cm is used throughout the experiment.

4) Specific rotation, and factors that affect this constant ($[\alpha]_T^\lambda$):

Specific rotation is orientation of plane of polarization per unit distance- concentration while the light wave is going through a sample of a dissolved chiral compound solution. Every type of chiral compound has a specific value for their specific rotation. This value depends on the temperature of the surrounding, the wavelength of the light wave that is passing through the

[6] "High Stability Red Laser." n.d. *Changchun New Industries Optoelectronics Technology Co., Ltd.* 12 November 2018.

solution and the type of the chiral compound.[7] In order to control all three of these factors, different methods were used. In order to fix the wavelength of the light wave, the same light source, which is a red laser with a wavelength of 650 nm, is used in each calculation. For temperature, the solvent (water) was heated to 25 ^{O}C before each calculation by a kettle. For the type of chiral compound, the type of compound present in honey and other such liquid crystals is d-sucrose, which is a type of sugar. For d-sucrose; $[\alpha]_{25}^{650} \cong +66.4^{o}$.[8] By fixing the type of sugar and the values of temperature of surroundings and the wavelength of light, the specific rotation is kept constant.

5) The physical properties of the tools and the accuracy of the measurement devices used in the experiment; the container, polarizer, analyzer, tools for measurement (ruler, goniometer and circular scale) and metal platforms:

In order to minimize any systematic error that would have been caused by the tools, the same tools were used for each of the trials.

6. Planning

In order to measure the angle of rotation of POP (Plane of Polarization) for the research question, a polarimeter would be sufficient, hence the function of polarimeter is calculating the change in the angle of POP. Automatic digital polarimeters are very expensive and hard to access, therefore a different method is used in order to fulfill the purpose of a polarizer, and a suitable setup is formed for this investigation. This setup mimics the working principles of Laurent's Half-Shade Polarimeter, since it is the easiest and most applicable to be recreated.

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[7] «Polarimetry - Optical Rotation Vs Specific Rotation Definition.» 14 October 2014. *Rudolph Research Analytical*.

[8] «D-Sucrose (Molecular Biology), Fisher BioReagents.» n d. *Fisher Scientific*.

Its working principal is that a polarizer and an analyzer are put to two opposite sides of the container. A circular scale is put behind the analyzer.

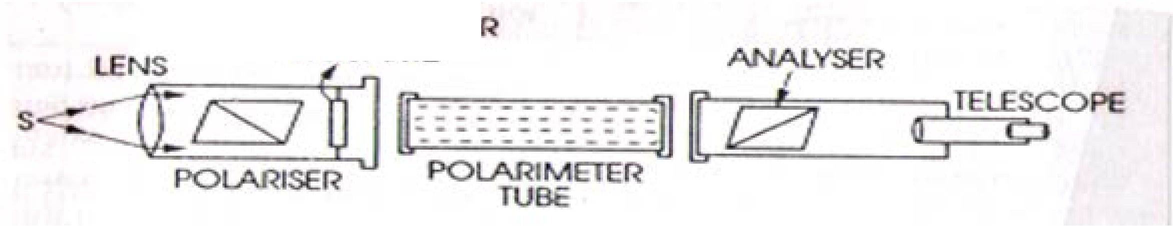


Figure 6.1: Laurent's Half-Shade Polarimeter

First the light wave is passed through the polarizer which than goes to the analyzer while the container between them is empty. The position of the analyzer is adjusted so that no light passes through it when container is empty, which means that the angle between the polarizer and analyzer is 90˚. The position of the analyzer is noted on a circular scale. After that the container is filled with the sugar solution. After it has been filled, the light wave is send again. The sugar solution rotates the POP of the light that had passed through the polarizer. Since the angle of polarization is now different, light starts passing through the analyzer. Now the analyzer is rotated again so that there is no light on the circular scale. Then the new position of the analyzer is noted again. The angular change of the first and second positions of the analyzer is equal to the rotation amount of POP. A detailed explanation of the procedure is given in the following titles.

7. Materials

In order to replicate the Laurent's Half-Shade Polarimeter, some tools were required, either for preparing the setup or calculating the results observed through the setup. These materials are as follows:

	Material Name	**Size**	**Quantity**
1	Transparent container	Height =15 cm Width =12 cm Length =50 cm	1
2	Red Laser	-	1
3	Water	-	2 L
4	Sugar	-	500 g
5	Circular Scale	r = 10 cm ± 0.5°	1
6	Goniometer	± 0.5°	1
7	Ruler	50 cm ± 0.5 cm	1
8	Metal Platforms	H = 10 cm	3
9	Polarizer/Analyzer	H = 2 cm W = 5 cm	2 (1 Polarizer and 1 Analyzer)
10	Tape	-	1

Table 7.1: Table of materials, their properties and their quantities

8. Method

a) Setting up the apparatus

1) 3 platforms with height of 10 cm are put on a table; one for the laser, one for the container and one for the scale. This is done in order to be sure that they are on equal level/height.
2) Polarizers are placed to the two sides of the container, one between the container and laser (the polarizer) and the other between the circular scale and the container (the analyzer).
3) The position of the analyzer is calibrated (as explained in the planning).

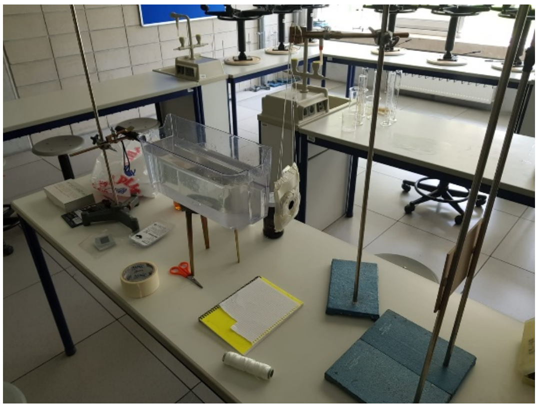


Figure 8.1: Image of the setup during the preparation.

b) Data Collection

1) First, 2 L's of water is heated to a specific temperature (25 ^{O}C). This is done in order to be sure that all the sugar dissolves in the water completely, since hotter water dissolves ionic compounds easier, and also to be sure that the temperature is kept constant through the span of the experiment, hence the specific rotation changes with different temperature.

2) 50 g’s of sugar is added to the water in the container. Then, the solution is stirred so that the sugar dissolves in the solution and thus it becomes optically active. The stirring is continued for a sufficient amount of time.
3) The laser is opened. The laser passes through the polarizer and passes through the solution. Since the angle of rotation is now changed, some amount of light manages to pass through the analyzer, despite the fact that the polarizer and the analyzer are perpendicular to each other.
4) The analyzer is realigned so that no light passes through it.
5) The new position is noted down on a notepad.
6) The angle between the noted location and the initial location of the analyzer is calculated by a goniometer.

This process is repeated by periodically adding 50 g’s of sugar and calculating the new change in the angle. All of these steps are repeated for 5 times, in order to form a more reliable conclusion.

9. Raw Data

Mass of sugar added to 2 L of water /g	Angular Rotation of Plane of Polarization / d / ± 0.5˚				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
50	28.5	28.0	27.5	29.0	28.5
100	86.5	86.0	87.5	86.5	87.0
150	158.0	157.5	156.5	157.0	156.5
200	229.0	230.5	229.5	229.5	230.0
250	316.5	317.5	317.0	316.5	318.0
300	404.0	404.5	404.0	403.5	405.0
350	477.5	477.0	478.5	478.0	478.0
400	560.0	560.0	559.5	558.5	559.0
450	636.0	637.0	636.5	636.5	635.5
500	726.5	728.0	727.0	726.5	727.5

Table 9.1: The angular rotation of plane of polarization while the light wave is passing through the sugar solution with different masses of sugar present

10. Data Analysis

	Mass of Sugar in the Solution (g)									
	50	100	150	200	250	300	350	400	450	500
Average Angle of Rotation ± 0.80	28.3	86.7	157.1	229.7	317.1	404.2	477.8	559.4	636,5	727.1

Table 10.1: Average angle of rotations for different masses of sugar

The arithmetic averages of the angles calculated between the polarizer and the plane of polarization (given in Table 8.1) are calculated. Also, their absolute uncertainties are calculated. All of the data calculated through this process is plotted in Table 9.1. An example calculation for 50 grams of sugar is given below;

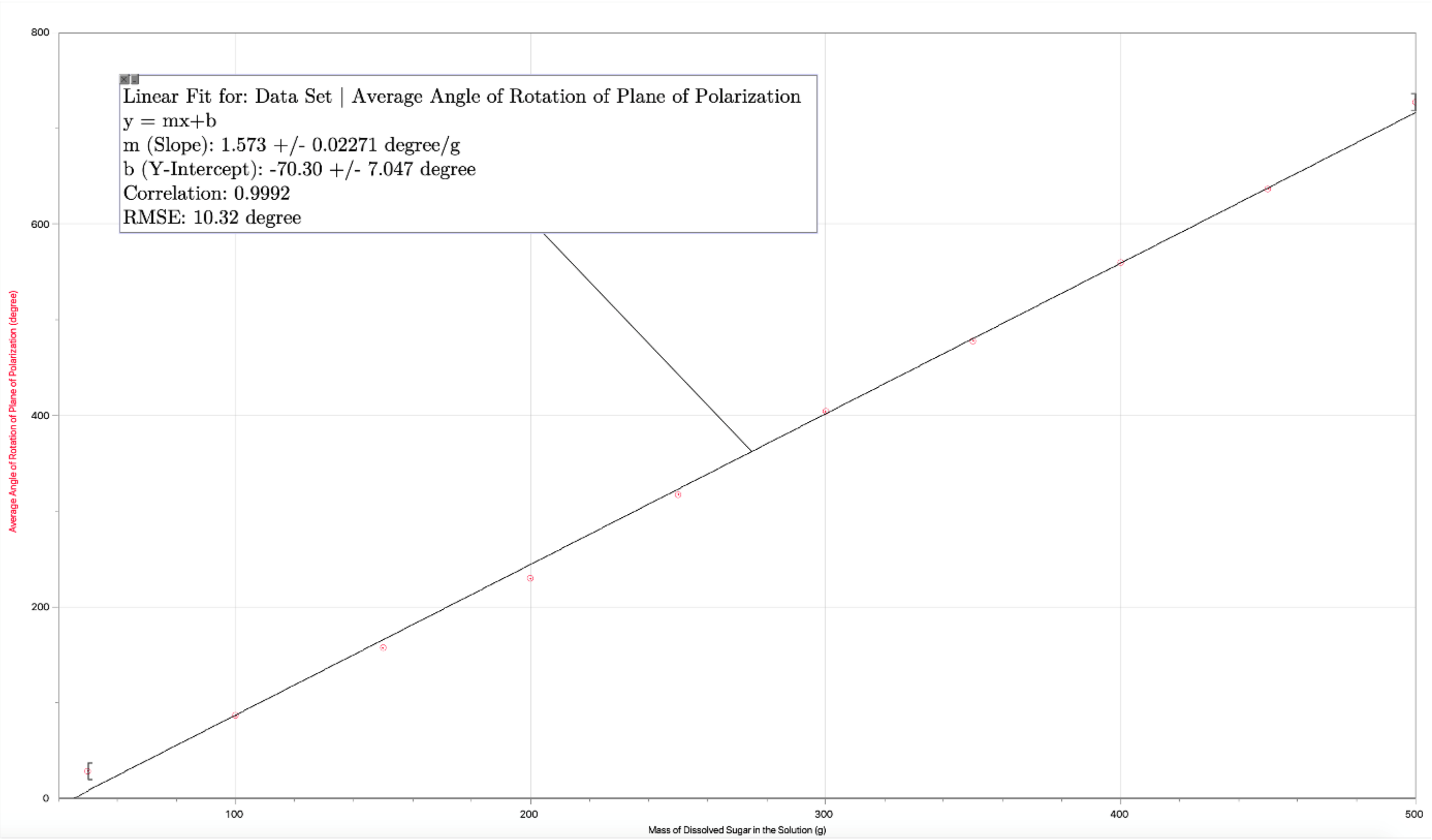
Example Calculation:

$$Arithmetic\ Average = \frac{28.5 + 28.0 + 27.5 + 29.0 + 28.5}{5} = 28.3^o$$

$$Absolute\ Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2} = \frac{29.0 - 27.5}{2} = 0.75 \approx 0.8^o$$

$$Result = 28.3 \pm 0.8^o$$

After this, the data listed in Table 9.1 was plotted using Logger Pro.



Graph 10.1: Average angle of rotation of plane of polarization for different masses of dissolved sugar

11. Error Analysis

The slope of the linear graph is 1.573°, with an absolute uncertainty of ±0.02271°. From these data, we can calculate that the percentage uncertainty is;

$$\frac{0.02271}{1.573} \times 100 \cong 1.444\%$$ (Rounded to 4 significant figures)

The minimal value of the percentage uncertainty shows that the collected data are very precise, however the fact that the best fit line is not passing through the origin shows that there was a significant systematic error present in the experiment.

12. Conclusion, Discussion and Evaluation

The purpose of this research was to explore the relationship between the concentrations of the chiral compound solution and how much it rotates the polarized light wave which is passing through it, thus having a better grasp on the topic of liquid crystals and other optically active compounds and their effects on plane-polarized light waves. In order to analyze this interaction, principles of Laurent's Half-Shade Polarimeter were replicated by a home-made setup. The main principal of Laurent's Polarimeter that was used in this experiment is that Half-Shade Polarimeter calculates the angular rotation of plane of polarization by calculating the change of angle between the polarizer and analyzer on the ends of the chiral compound. This enabled the experimenter to make calculations and obtain data in a more analogous way, thus enabling the experimenter to compare the results of the experiment.

The research was conducted in order to put a light on the addressed research question; which focused on whether a change in the concentration of the carbon compound present in the solution would cause a change on the angle of plane of polarization, and if it did, how much would the effect be. By calculating different angles of rotations for different concentrations of dissolved sugar, a correlation between the two variables was found.

When the data was plotted in Logger Pro as linear fit for the given data, a correlation of 0.9992 was found. In addition, the percentage uncertainty was calculated as 1.444%. The high correlation of data as linear fit showed that the angle of rotation is proportional with the concentration of chiral compound, which was also backed up by the equation given in the background information. On top of this, the low uncertainty values show that the data obtained were very precise, further strengthening the result and thus verifying the hypothesis of the experiment; “*it is expected the as the concentration increases, the angle of rotation would also increase.*”

However, the equation also stated that the variables were directly proportional with each other, but the best-fit line of the graph of average data didn’t go through the origin, rather passing through the y-axis in a spot lower than the origin. This occurrence on top of precise data concludes that there was systematic error present in the experiment, which was probably caused by the measurement tools.

The main limitation of this experiment was due to the difficulty in accessing different chiral compounds, all the data was collected by using d-sucrose as the source of chirality, which is a dextrorotary compound. Due to this, some other events that might have occur with different types of chiral compounds, such as levorotary compounds or are unable to be observed in this experiment.

A possible way to improve this experiment is to conducted more experiments while using a more diverse variety of chiral compounds while calculating the experiment while also using tools of higher quality. The higher quality of tools would benefit in eliminating the systematic error, while different types of compounds would allow us to have a more comprehensive data on the interaction of crystals with polarized light, thus achieving a more solid generalization.

13. Bibliography

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