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Effect of Sugar Concentration and Type on the Angle of Rotation of Polarized Light

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Abstract
The objective of this work is to compare the optical activity of brown and white sugar solution using polarimeter. Two type of sugar with different weights were used, it dissolved in the same amount of distilled water to make different concentrations. Xenon lamp was used as light source with two wavelengths (red & green) by using the proper filters.
Then sucrose solution was put on a cell with 10 cm length, the rotation angle was measured for different concentrations at the same temperature, and the specific rotation was calculated. We found the optical activity of the sucrose depends on the sugar type, concentration, light wavelength and it is biggest for green light than for red one. Beside that we noticed the brown sugar due to the additional component magnesium and potassium has more ability to rotate the polarized light than the white one.

Keywords: optical activity polarized light, concentration, sugar, rotation angle

1. Introduction

Optical isomers, or enantiomers, have the same sequence of atoms and bonds but are different in their 3D shape, also have no axis of symmetry, which means that there is no line that bisects the compound. Optical activity is the interaction of these enantiomers with plane-polarized light. Optical activity was first observed by the French physicist Jean-Baptiste Biot. He concluded that the change in direction of plane-polarized light when it passed through certain substances was actually a rotation of light, and that it had a molecular basis. His work was supported by the experimentation of Louis Pasteur. Pasteur observed the existence of two crystals that were mirror images in tartaric acid, an acid found in wine. Through meticulous experimentation, he found that one set of molecules rotated polarized light clockwise while the other rotated light counterclockwise to the same extent. He also observed that a mixture of both, a racemic mixture (or racemic modification), did not rotate light because the optical activity of one molecule canceled the effects of the other molecule. Pasteur was the first to show the existence of chiral molecules. An enantiomers that rotates plane-polarized light in the positive direction, or clockwise, is called dextrorotary [(+), or d], while the enantiomers that rotates the light in the negative direction, or counter clockwise, is called levorotary [(-), or l]. When both (d and l) isomers are present in equal amounts, the mixture is called a racemic mixture [1, 2].Optical activity is the ability of chiral molecule to rotate the plane polarized light [3], angle of rotation depends on the molecular structure, concentration of the dissolved substance, the path length of the light that passes through the solution, and the light wavelength [4, 5].
For polarized light research, detection of glucose and quantification of its concentration rely on the molecule's chirality that stems from its asymmetric molecular structure, resulting in a number of characteristic effects generically called optical activity [6, 7].
Optical rotation is the extent (measured in degrees) to which a solution of a molecule will rotate plane polarized light, as measured by a polarimeter Optical rotation (OR) at the sodium D line (D band in this spectrum is the result of the absorption by sodium atoms of light that has a wavelength of 589.6 nm) [8], ([α]D) is one of the most common experimental data that characterizes an optically active compound, and it can be correlated with the absolute configuration by reliable algorithms [9]. In recent years, there has been increasing interest in the calculation of the optical rotation at the sodium D line. Polavarapu [10] identified a "renaissance" in optical rotation. The first (ab) initio calculation of optical rotation was reported by Polavarapu and coworkers [11] in 1997 and subsequently more attention was paid to this calculation. In the beginning, most calculations were concentrated on small and rigid molecules for accuracy. Polavarapu and co-workers [12] calculated the optical rotation of small molecules: H_2O_2 and H_2S_2. With the development of computers and algorithms, more calculations were directed to large and flexible molecules or natural product molecules, even to the determination of the absolute configuration of molecules [13].
Moreover, the absolute configuration of more complex molecules can be determined combined with other calculations [14]. Many sugars have this property. Sugar, more commonly known as glucose, rotates the plane of polarized light to the right [clockwise, or (+)]. Dextrose is said to be dextrorotatory (from Latin dexter = right). Another molecule with this property is fructose, which sometimes goes by another name: laevulose, due to the fact that it rotates the plane of polarized light to the left [counterclockwise, or (–)]. Fructose is said to be levorotatory (from Latin laevus = left) [15]. In chemistry specific rotation ([α]) is a property of a chiral chemical compound [16]. It is defined as the change in orientation of

monochromatic plane-polarized light, per unit distance–concentration product, as the light passes through a sample of a compound in solution [17], or it is an angle measured at a path length of one decimeter and a concentration of 1g/mL. Values for specific rotation are reported in units of deg·mL·g^{-1}·dm^{-1}, which are typically shortened to just degrees, where in the other components of the unit are tacitly assumed [18].These values should always be accompanied by information about the temperature, solvent and wavelength of light used, as all of these variables can affect the specific rotation. There is a linear relationship between the observed rotation and the concentration of optically active compound in the sample. Specific rotation of a substance is usually reported at a specific temperature, wavelength, concentration, and path length. That is to say, the temperature can have an effect on how the substance interacts with the light [19]. The variance of specific rotation with wavelength—a phenomenon known as optical rotatory dispersion (ORD)—can be used to find the absolute configuration of a molecule [20, 21]. The concentration of bulk sugar solutions is sometimes determined by comparison of the observed optical rotation with the known specific rotation.

2. Theory

There is a nonlinear relationship between the observed rotation and the wavelength of light used. Specific rotation is calculated using either of two equations, depending on whether the sample is a pure chemical to be tested or that chemical dissolved in solution.

- **For Pure Liquids**

$$[\alpha]_T^\lambda = \frac{\phi}{.L.\rho} \quad (1)$$

Where ϕ represent the measured angle of rotation in degrees, L is is the path length in decimeters, and c is the concentration in g/mL.

For solutions

$$[\alpha]_T^\lambda = \frac{\phi}{.L.C} \quad (2)$$

Where ϕ the measured angle of rotation in degrees, L is is the path length in decimeters, and ρ is the density of the liquid in g/mL, T is the temperature in (degrees Celsius) and λ is the wavelength [22].

$$C = \frac{m}{V} \cdot \frac{1}{Mw} \quad (3)$$

Mw is Molecular weight, m is the mass dissolved in gram units, and V is the volume [23]. The molecular formula of sucrose sugar C_{12} H_{22} O_{11}, the molecular weight is (12*12+ 22*1+ 11*16= 342).

3. Equipments, Instruments and Method

a. Equipments and Instruments

The equipments used to complete this work are:

Polarimeter, ionized Water, two types of sugar, red filter and green filters, and sensitive microbalance.

b. Method

Sugar of weights (20g, 25g, and 30g) for white and brown were dissolved in ionized water (50 mL) to obtain different concentrations, and then the solution was placed in a cell (1 dm). Then the cell was placed in the polarimeter. As shown in experimental setup figure (1).

The first step the light pass through a polarizer, which only allows light with waves aligned in one direction to pass. This polarized light was then allowed to pass through the material to be studied, in our case a cell containing a solution of the sucrose. At the other end, a second polarizer was rotated, and the rotation angle of the sugar solution for the different concentrations using a red and a green filters were measured and then a relationship between the sugar type, concentration and the polarized light rotation angle was established between the dissolved and the calculated modification specific rotation angle.

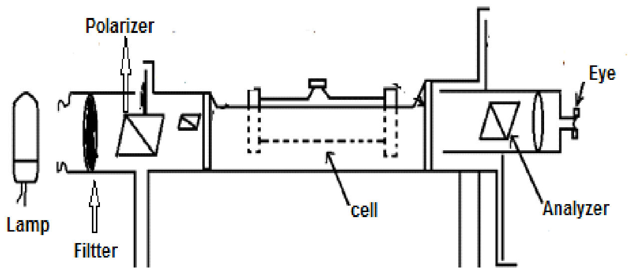

Fig 1: experiment setup

4. Result and Discussions

The results of rotation angle of the white sugar measured in degrees as function of the sugar concentration is recorded in table 1, for the two optical filters (red and green), one after another by inserting the filter and then detecting the rotation angle.

Table 1: Rotation angle for white sugar at different sugar concentrations

Wight of dissolve (g)	Concentration g/mL)(	Rotation angle (o) for red filter	Rotation angle (o) for green filter
20	0.835	25.03	25.01
25	0.975	50.45	56.85
30	1.096	66.01	75.96

The rotation of polarized light is a function of wavelength; it changes due to the change of color.

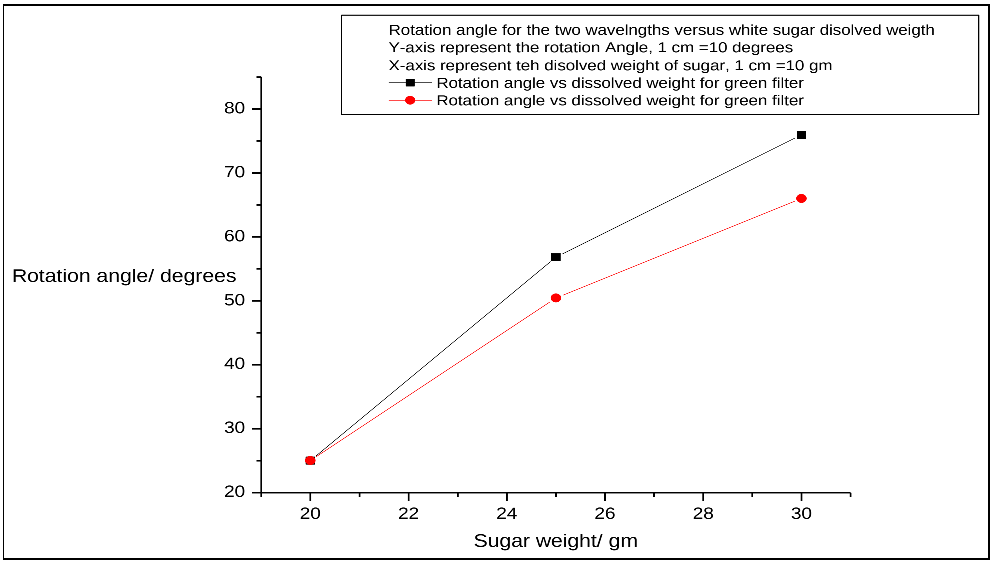

Fig 2: Rotation angle of white sugar for the two filters

Figure (2) showed that the rotation angle of the white sugar is affected by the sugar concentration; the result shown in figure (2) also showed that for the two optical filters used the behaviour of the rotation angle is similar and at the 10 gm weight of the dissolved sugar the rotation angle at the red and green wavelengths (filters).

The results of the angle of rotation of bright sugar for the two optical (red and green) filters as the concentration of the dissolved brown sugar is changed the obtained results are tabulated in table 2.

Table 2: Rotation angle for brown sugar at different sugar concentrations

Wight of dissolve (g)	Concentration g/mL)(	Rotation angle (o) for red filter	Rotation angle (o) for green filter
20	0.835	71.98	83.02
25	0.975	77.03	87.02
30	1.096	82.01	88.99

The rotation of polarized light is a function of wavelength; it changes due to the change of color**.** This result is plotted in figure 3.

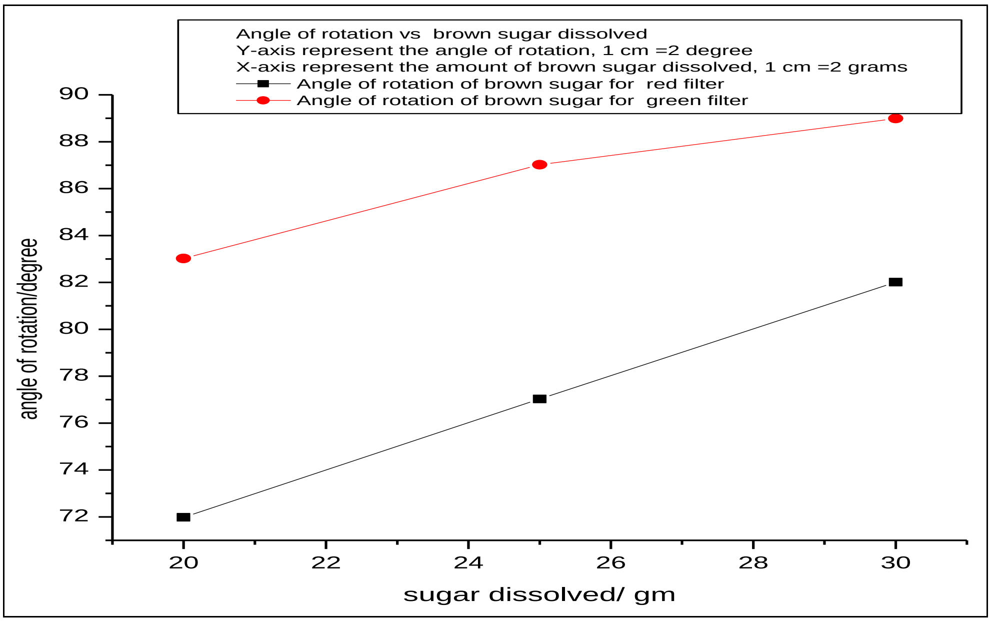

Fig 3: Rotation angle for brown sugar

The above tables and figures showed the optical activity for sugar. The results show the clockwise rotation for sugar and we notice that the angle of rotation change due to the dissolved mass and it is bigger for the green filter than the red filter because it has wavelength shorter than the red [4] small weight has the small rotation. The brown sugar show very large rotation angles according to the structure which contain potassium and magnesium.

Specific rotation for white sugar was measured using the two optical filters (red and green) for the dissolved sugar concentration and the obtained results were tabulated in table 3.

Table 3: Specific Rotation for white sugar

Wight of dissolve (g)	**20**	**25**	**30**
Specific Rotation deg·mL·g^{-1}·dm^{-1} (red filter)	29.98	51.74	60.23
Specific Rotation deg·mL·g^{-1}·dm^{-1} (green filter)	29.95	58.31	69.31

Specific rotation increase due to the increasing of weight of dissolve, figure (4) shows this increase.

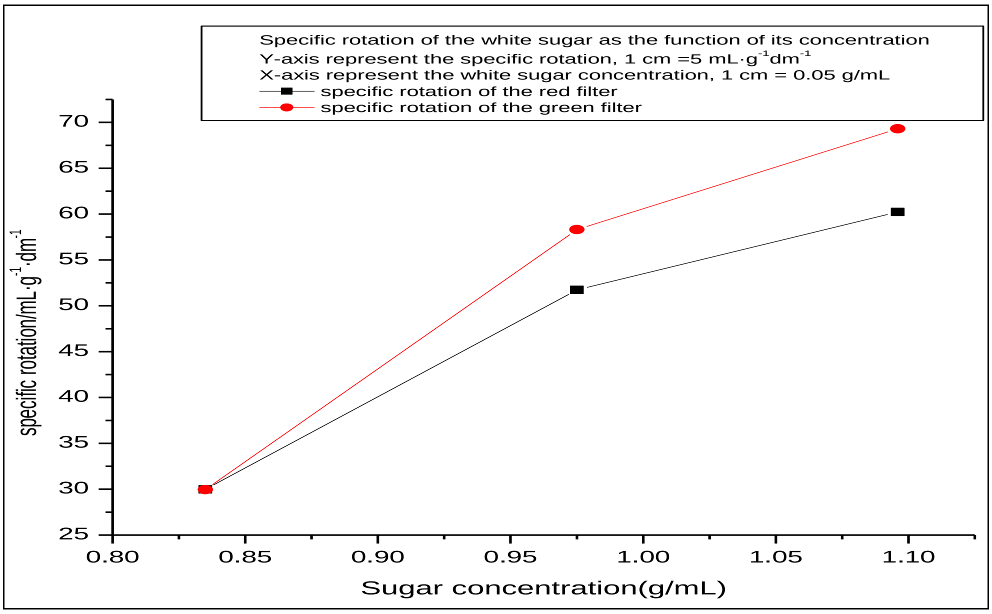

Fig 4: Specific rotation of White sugar

Figure (4) showed that the effect of wavelength on the optical activity is that the short wavelength leads to the increasing in the specific rotation [4, 17, and 19].But at the low concentration the two optical filters (red and green) has the same specific rotation. The specific rotation of the brown sugar at the same concentration for the two optical filters (red and green) is recorded in table (4) and is plotted figure (5).

Table 4: Specific rotation for brown sugar

Wight of dissolve (g)	**20**	**25**	**30**
Specific Rotation deg·mL·g^{-1}·dm^{-1} (red filter)	86.02	79.01	74.83
Specific Rotation deg·mL·g^{-1}·dm^{-1} (green filter)	99.43	89.25	81.10

Specific rotation is a function of concentration and structure. Results show the decrease on the specific rotation with the increase of the concentration of the brown sugar

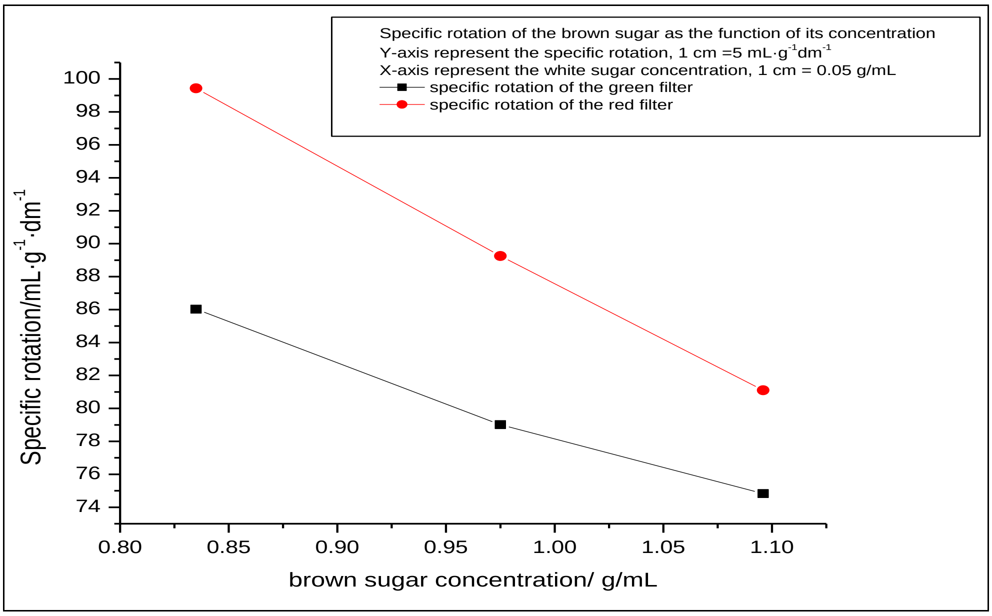

Fig 5: Specific Rotation for Brown sugar

Results showed that as with the concentration of the brown sugar is increased the specific rotation for the two optical filters (red and green) are decreased.

The specific rotation of white and brown sugar as a function of the sugar concentration is shown in figure 6.

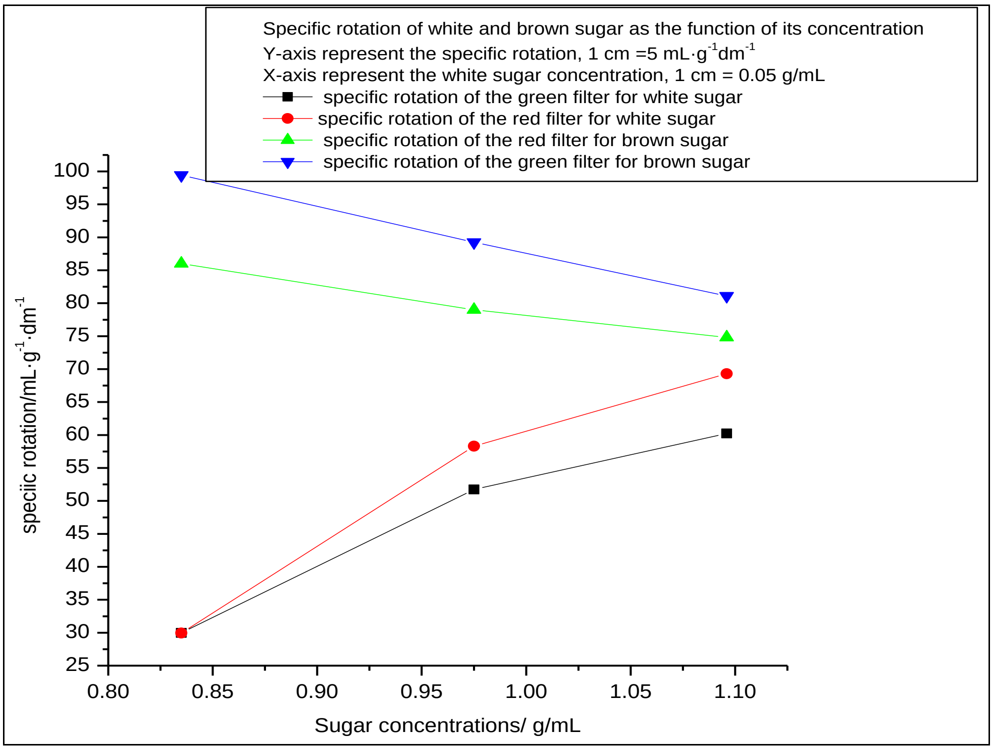

Fig 6: Specific Rotation of White and Brown sugar

At the end we noticed that the specific angle of rotation is a function of concentration and sugar types**.** For white sugar the specific rotation is increased as the sugar concentration is increased while for the brown sugar the specific rotation is decreased as the sugar concentration is increased for the two optical filters used.

5. Conclusions

From the above study we found the optical activity is change due to the sugar structure (type and concentration). Besides that, short wavelength has higher rotation. Concentrations and sugar type plays an important role in specific rotation.

White and brown sugar has different optical activity and the behavior of their specific rotation is totally the reciprocal for the two sugar type.

6. Recommendations

- Do more study for sucrose in different temperature to determine the effect of temperature on specific rotation
- More study on the effeteness of the optical activity to detect the sugar disease in human being.

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