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Optical characterisation of polarised light beam under different aqueous concentrations

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ABSTRACT

In this study, the optical activity of salt, brown and white sugar solutions of different concentrations is determined. The optical rotation angle as a function of wavelength was studied using different optical color filters. Sodium-D light and laser source of light were used. The optical activity was found to depend on the type of sugar, sugar concentration and the wavelength of the light used. The study revealed that the optical activity was linearly dependent on the concentration of the sugar solution (both white and brown). Cyan light recorded the highest angle of rotation while red light recorded the lowest. It also found that brown sugar has a greater ability to rotate polarized light than white sugar due to the presence of potassium and magnesium components. It is worth noting that the salt solution is optically inactive because it lacks microscopic mirror symmetry. Finally, the findings provide an understanding of the characteristics of polarized light under different solution concentrations and can serve as a guide for conducting further research on high-efficiency polarizers.

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1. INTRODUCTION

Sugar is primarily one of the basic classes of optically active carbohydrates [1]. Sugar is an important part of our daily diet and has unique effects on the performance of the human body. A diet too high in sugar can lead to serious health concerns such as diabetes, hypertension, and obesity [2-4]. Determination of sugar content and sugar concentration in beverages, juices, and other sugar-containing products is an essential parameter for quality control according to standards. Several prescribed analytical techniques have been used including Ultraviolet-Visible absorption spectroscopy (UV-vis) [5, 6], Thin-Layer Chromatography (TLC) [7], Infrared (IR), and Fourier Transform Spectroscopy (FTS) [8, 9], and Raman Spectroscopy [10-12]. Nevertheless, optical methods such as polarimetry[13, 14], and interferometry [15, 16] are widely used for the qualitative determination of sugar and its concentration because their analysis is rapid and non-destructive.

On the other hand, the mechanism of polarisation can also be applied in the determination of sugar content in substances. Polarisation is a property of waves that explains the orientation of their oscillations in the plane perpendicular to the direction of propagation of the wave. Unpolarised light or ordinary light rays happen to be light waves oscillating in more than one plane. It is possible to convert unpolarised light into polarised light by using polarising filters. Planar polarised light can be explained as light waves that oscillate in only one direction [17-19]. Polarisation phenomena are of significance in the fields of physics, chemistry, biology, and engineering [20]. Generally, in the treatment of polarisation, the electric field is always considered and the magnetic component is disregarded. This is done because the magnetic field component is perpendicular to the electric field and directly proportional to it. The electric field vector from Maxwell's equations can be arbitrarily divided into three components, namely *x*, *y*, and *z*.

A great deal of research has been done to measure optical activity [21-24]. The key factors affecting the specific rotation angle were studied by Hasanuzzaman et al. [25]. These factors include the molecular structure, concentration and temperature of the solution, and wavelength of the light. The characterisation and quantification of the optical rotation of a chiral solution using white light were studied by Anderson et al. [26]. The results provided the behavior of polarized light in different media with different refractive indices and their potential applications in several engineering fields. Quantitative analysis of different concentrations of sucrose, glucose, and fructose solutions was performed by Islam et al. [7]. Till now, no work has been done on the use of laser light and different types of optical filters, except for blue and red light. Therefore, this present study optically characterizes the polarised light beam under different aqueous concentrations. The optical activity of different concentrations of salt, brown and white solutions was studied using a laser lamp and four different optical filters. The specific rotation angle for salt, white, and brown sugar solutions using different optical filters and a laser lamp was calculated for the first time.

2. GOVERNING EQUATIONS

Research shows that the concentration of a sugar solution can be quantified using polarisation theory. When the solution is placed in a clean and transparent vessel and polarised light is focused on it, the solution rotates in the direction of polarisation. The amount of rotation depends on the depth of the solution. The angle of rotation is also related to the depth and concentration of the solution [27]. The higher the concentration of the solution, the greater the angle of rotation. In addition, the angle of rotation depends on the wavelength or colour of the light used. Light with a shorter wavelength has a larger angle of rotation and vice versa.

The physical origin of optical rotation is the differential response of a chiral medium to oppositely circularly polarised light rays [26]. The specific rotation of an optically active solution is defined as the angle through which the plane of polarisation of monochromatic light is rotated [28]. This can be expressed mathematically using the Biot law.

$$[\alpha]_{\lambda}^{T} = \frac{\alpha}{L.C} \qquad [1]$$

where α is the, measured optical rotation angle, C is the concentration of the solution, T is the temperature of the solution, λ represents the wavelength of the light source used and L represents the optical path length. Furthermore, the concentration, C of the solution is given as:

$$C = \frac{m}{V} \qquad [2]$$

Where m is the mass measured in grams (g) of the sugar and V is the volume of distilled water measured in milliliters (mL).

3. MATERIALS METHODS

To study the rotation angle using different wavelengths of light, the solution of salt, white and brown sugar of different concentrations was prepared at room temperature. Salt, white and brown sugars with various concentrations (0.2, 0.25, 0.3, 0.35, 0.4 g/ml) were prepared by dissolving known masses of 20 g, 25 g, 30 g, 35 g, and 40 g respectively in 100 ml of distilled water. The solution was placed in an Erlenmeyer flask as shown in the experimental setup in Figure 1.

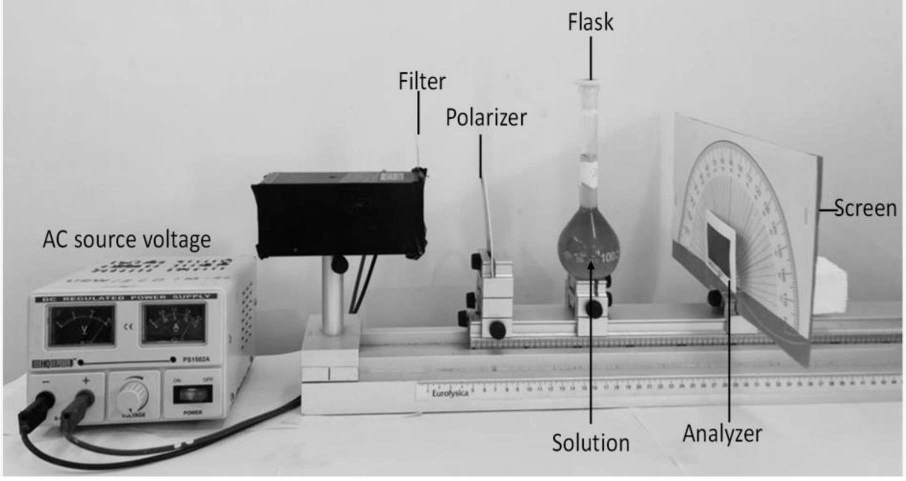


Figure 1. Experimental set-up for determination of the angle of rotation for different sugar solutions

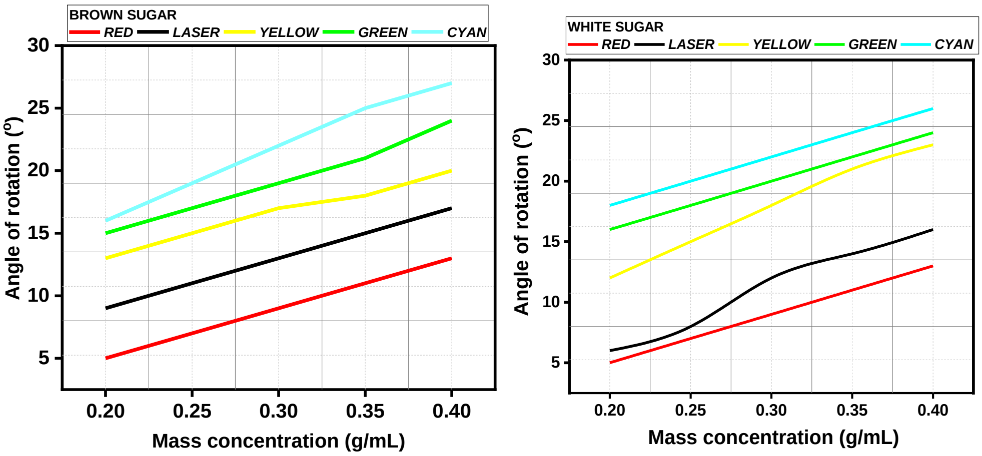
A sodium D-lamp and laser light were used as the light source for this experiment. The sodium D-lamp acquired from Europhysica Limited (122148) was made to travel through the polariser, which transmits the light waves aligned in one direction. The polarised light was then passed through the sugar solution with different concentrations. Then, a second polariser was inverted and the rotation angle of the solution of different concentrations was determined. In addition, the sodium-D light was replaced by laser light. To obtain different wavelengths, different optical filters from Philips Harris Ltd (the colour investigation kits Q594005) were placed in front of the sodium-D light source. The optical path length was set to 2.5 dm. Red, green, yellow, and cyan optical filters and laser light were employed in this work. In this experiment, the filters were used in turns and the corresponding optical rotation angle was determined. The optical rotation angles were measured in degrees.

4. RESULTS AND DISCUSSIONS

The relationship between the salt, type of sugar, concentration, and polarised rotation angle was established. This information was also used to calculate the specific rotation angle. The salt solution was not optically active for all salt concentrations. This effect can be attributed to the lack of microscopic mirror symmetry.

4.1. Relationship between optical rotation and sugar concentration

Figure 2(a) shows the rotation angle of the brown sugar for different wavelengths of light. It was found that the optical rotation angle of the sugar is affected by the sugar concentration and types of sugar involved.



(a) (b)

Figure 2. Optical rotation angle versus concentration (different wavelengths) for (a) brown sugar and (b) white sugar

The concentration of both white and brown sugar is directly proportional to the mass concentration of sugar. From Figure 2(a), it can be seen that the cyan filter has the highest value of angle of rotation, followed by green, yellow, laser, and red. This can be explained by the fact that the cyan filter has the lowest wavelength, about 500 nm, followed by green with a wavelength of 550 nm. The laser lamp is between red and yellow with a wavelength of 630 nm, which is larger than that of red light (smaller than that of the yellow light).

Figure 2(b) shows the clockwise optical rotation angle of white light as a function of concentration. The graph also shows that the concentration of the solution increases with increasing optical rotation angle. The optical rotation angle is higher for cyan optical followed by the green filter, yellow, and red filters are the least. This is because cyan has the lowest wavelength among the other selected optical filters (light), about 500 nm, while the red optical filter has a wavelength of 700 nm and the green filter has a wavelength of 550 nm. Again, it can be observed that the laser light source is between the red and yellow light. This is because the wavelength of the laser light at 630 nm is lower than the red light and higher than the yellow light with a wavelength of 580 nm. When comparing the white and brown sugars, it was found that brown sugar has a large difference in the rotation angles compared to white sugar. This can be explained by the chiral properties of these two sugar molecules. The fact that brown sugar, unlike white sugar, contains potassium and magnesium [25, 29, 30] can also be attributed to the differences.

4.2. Relationship between specific optical angle and sugar concentration

Figures 3 (a) and (b) show the graph of specific rotation angle versus concentration of brown and white sugar, respectively.

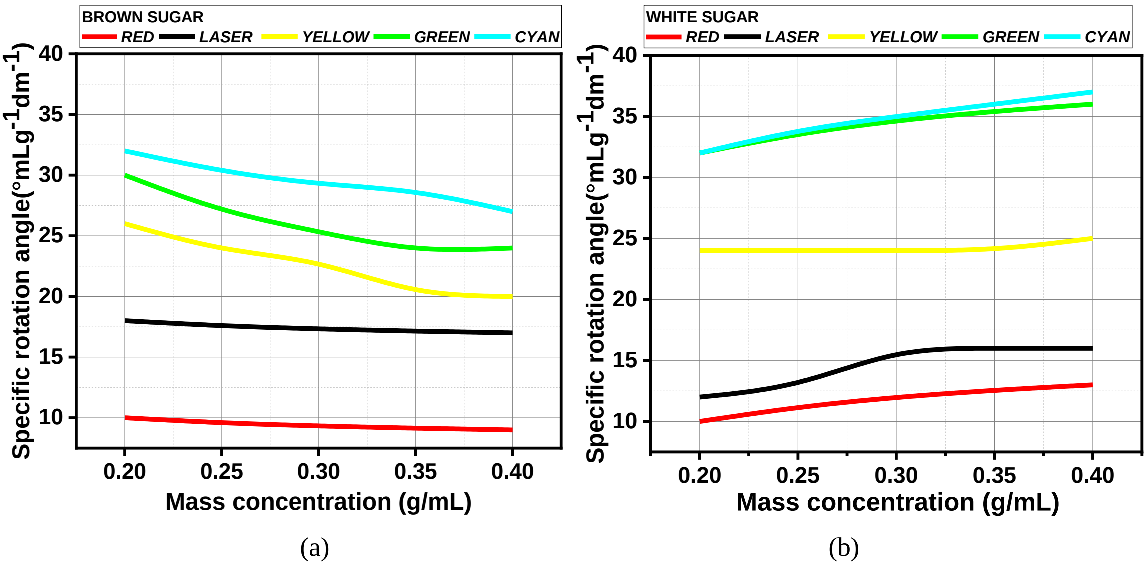


Figure 3. A graph of specific optical rotation angle versus concentration (different wavelengths) for (a) brown sugar and (b) white sugar

The specific rotation angle was measured for both brown and white sugar using four different light sources (optical filters) and a laser lamp. For white sugar, the specific rotation angle increases with increasing solute concentration. This could be explained by the wavelength of the optical filters. It was also observed that the short wavelength leads to an increase in the specific rotation angle, which is consistent with the work of [18, 31, 32]. At low concentrations, the red optical filter and the laser light have almost the same value for the specific rotation angle.

Although the specific rotation angle is a function of concentration and structure, the graph in Figure 3(a) shows a decrease in the specific rotation angle with an increase in the concentration of brown sugar. For the red light and the laser light, the specific rotation angle slightly changes. The specific angle of rotation depends on the concentration and the types of sugar involved.

5. CONCLUSION

In summary, the optical activity of white and brown sugar with different light (*optical filters*) and laser light was studied. The change in optical activity is caused by the chiral properties of the sugar and the type of sugar. White and brown sugars have different optical activities and the specific rotation angle is determined as the reciprocal of each other. The present study can be used as a guide to determine sugar concentrations in food beverages and syrups which can be useful in the management of diabetics and other related diseases.

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