

**UNIVERSITY OF ZIMBABWE**



**Application of optical methods to determine the  
concentration of sugar solutions**

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**This thesis is submitted in partial fulfilment for the requirements of Master of  
Science degree in Applied Physics.**

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**July 2008**

## **ABSTRACT**

Two optical methods were used to determine the concentration of sugar (sucrose) solution. The first employed a hollow perspex prism, a prism spectrometer and a monochromatic light source. The angles of minimum deviation for different sugar samples were determined, whose values were used to compute the refractive indices of these samples. The relationship between the refractive indices and the sugar concentrations of the samples was found to be linear. The effect of temperature on the refractive index of the solutions was also investigated and it was found that the relationship is linear with a negative gradient. The temperature coefficient of refractive index was determined and was found to be in agreement with the expected result.

The second method employed the use of a half-shade polarimeter to determine the optical rotation of different sugar samples. The relationship between the angle of optical rotation and the concentration of the solutions was found to be linear. The optical rotatory power of sugar solution was also determined and found to be in agreement with the expected result and with results from other researchers. The two methods were also used to determine the sugar concentrations in raw sugar, orange and apple juices. It was found that the concentration of sugar in these fluids was almost the same.

The two methods were therefore found to be reliable.

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## **DEDICATION**

This thesis is dedicated to Tanyaradzwa and Tanatswa Dhliwayo, the boys that I love so much and who love me too. It is also dedicated to my late parents. May their souls rest in peace.

## **ACKNOWLEDGEMENTS**

I would like to give my sincere acknowledgements to my supervisor, Professor A.C. Selden for the support he gave me during the course of this project. I would also want to thank Mr A Makotore for helping me in the construction of the hollow prism. My sincere gratitude to the technicians in the Chemistry department for helping me with chloroform for bonding together my perspex prism joints. I would also want to thank the technicians in the Physics department for helping me with the necessary equipment needed during the course of the project.

Mr Chitabwa from the Zimbabwe Sugar Refinery was very helpful in explaining how the concentration of sugar solutions is determined in industry. Mrs Hama helped in the operation of the polarimeter. I would like to thank them very much.

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Introduction**

Sugar is a vital ingredient in our everyday diet. It is a very sweet substance but has many side effects. There are a number of people who suffer from diabetes and would need to feed on fluids with the correct concentration of sugar. They also need to take fruit juices that have a small amount of sugar which does not affect the sugar in their blood. The amount of sugar in fluids taken by sick people, especially children may need to be controlled so that they live a near normal life. Therefore there is need to find a method which is cheap but can be used to accurately determine the concentration of sugar in solutions and fluids. This method is also intended for use by small commercial sugar cane farmers who would want to establish some small sugar refineries.

### **1.2 Background Information**

Concentration of sugar solutions is mainly determined using refractometry. Refractometry is used to determine the concentration of a solution by determining its optical refractive index. A refractometer is an industrially made instrument used to determine the optical refractive index of a solution with precision. It is very expensive to buy especially in developing countries.

### **1.3 Aims and Objectives**

The objectives of this project are:

- To determine the refractive indices of different sugar solutions.
- To determine the sugar concentration of a solution from its refractive index data.
- To determine the concentration of a sugar solution using polarimetry.

### **1.4 Justification**

Application of refractive index data and optical rotation data are simple methods of determining the concentration of a solution in a basic laboratory where expensive equipment like the refractometer cannot be found. The research involves the construction of a hollow prism that is much cheaper than buying refractometers. Other equipment like the light source can also be sourced at cheaper rates. If monochromatic sources cannot be found, white light can be used instead.

### **1.5 Benefits**

The intended benefits of this project are:

1. Determination of sugar concentration of solutions used by diabetic patients.
2. Determination of sugar concentration in salt and sugar solutions.
3. Determination of sugar concentration in fruit juices for medical purposes.

## **1.6 Organisation of the thesis**

This chapter discussed the background to the study, aims and objectives of the study, justification and the benefits of the study. The next chapter will discuss the theory behind the study

## CHAPTER 2

### THEORY

#### 2.1 Introduction

A number of theories are used to determine the refractive index of solutions and optical rotation of solutions. This chapter is going to discuss about Snell's law and polarisation to determine the refractive index and optical rotation of solutions respectively. It will also discuss the use of refractive indices and optical rotation to determine the concentrations of solutions.

#### 2.2 Snell's law

Snell's law (also known as Descartes' law or the law of refraction), provides a formula used to describe the relationship between the angles of incidence and refraction, for light or electromagnetic waves, passing through a boundary between two different isotropic media, such as air and glass. The derivation of Snell's law is shown in Appendix 4.

Snell's law states that the ratio of the sines of the angles of incidence and of refraction is a constant that depends on the properties of the media.<sup>5</sup>

When a ray of light is incident on a prism at an angle  $\theta_i$  it is refracted either towards or away from the normal depending on the optical densities of the media as shown in figure 2.1.

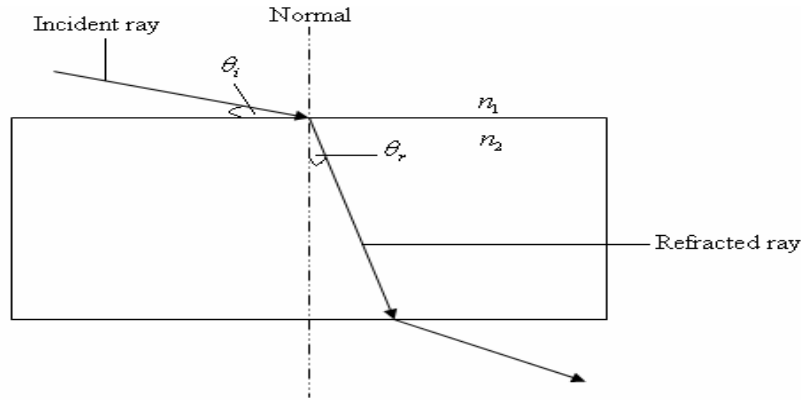


Figure 2.1 Illustration of Snell's law

$$n_1 \sin \theta_i = n_2 \sin \theta_r \quad (2.1)$$

Where  $n_1$  and  $n_2$  are refractive indices of materials 1 and 2 respectively.

$\theta_i$  and  $\theta_r$  are angles of incidence and angle of refraction respectively.

$$n = \frac{n_2}{n_1} = \frac{\sin \theta_i}{\sin \theta_r} \quad (2.2)$$

Where  $n$  is the relative refractive index.

The greater the relative index of refraction, the more the light bends. Index of refraction of a liquid depends on the density of the liquid.

Snell's law is used to determine the direction of light rays through refractive media with varying indices of refraction. The indices of refraction of the media, labeled  $n_1$  and  $n_2$ , are used to represent the factor by which light is "slowed down" within a refractive medium, such as glass or water, compared to its velocity in a vacuum.

As light passes the border between media, depending upon the relative refractive indices of the two media, the light will either be refracted to a lesser angle, or a greater one. These angles are measured with respect to the normal line, represented perpendicular to the boundary. Refraction between two surfaces is also referred to as reversible because if all conditions were identical, the angles would be the same for light propagating in the opposite direction.

### 2.3 Angle of minimum deviation

Figure 2.2 shows the set up to determine the angle of minimum deviation using a prism.

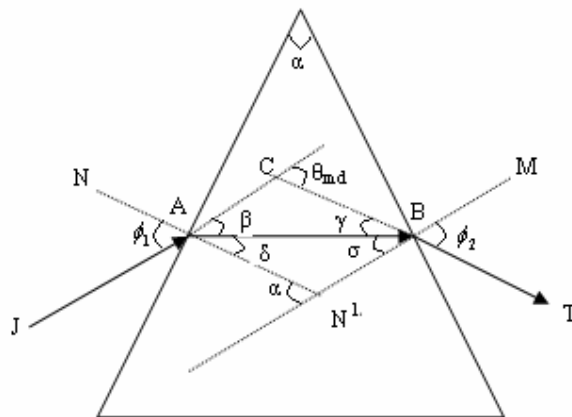


Figure 2.2 The geometry of a light ray passing through a prism.  $\alpha$  is the apex angle,  $\phi_1$  is the angle of incidence on surface A,  $\phi_2$  is the angle of refraction on surface B,  $\gamma$  is the angle of incidence on surface B,  $\delta$  is the angle of refraction on surface A and  $\theta_{md}$  is the angle of deviation.

A light ray (solid line) is incident on the first surface of the prism at an angle of  $\phi_1$ .

The refraction at both surfaces obeys Snell's law.<sup>7</sup>

$$\frac{\sin \phi_1}{\sin \delta} = \frac{n_g}{n_a} = \frac{\sin \phi_2}{\sin \sigma} \quad (2.3)$$

where  $n_g$  and  $n_a$  are refractive indices of the glass and air respectively.

The angle of deviation produced by the first surface is:

$$\beta = \phi_1 - \delta \quad (2.4)$$

The angle of deviation produced by the second surface is:

$$\gamma = \phi_2 - \sigma \quad (2.5)$$

The total angle of deviation is given by:

$$\theta_{md} = \beta + \gamma$$

$$\theta_{md} = \phi_1 + \phi_2 - (\delta + \sigma) \quad (2.6)$$

But  $\delta + \sigma = \alpha$

Therefore equation (2.6) becomes:

$$\theta_{md} = \phi_1 + \phi_2 - \alpha \quad (2.7)$$

### 2.3.1 Condition for minimum deviation

The minimum deviation occurs at a particular angle of incidence where the refracted ray inside the prism makes equal angles with the two prism faces. This occurs when the path of the light inside the prism is parallel to the base of the prism.

Therefore it means that in Figure 2.2  $\phi_1 = \phi_2$ ,  $\delta = \sigma$  and  $\beta = \gamma$ .

Equation (2.7) becomes:

$$\phi_1 = \frac{1}{2}(\alpha + \theta_{md}) \text{ and } \delta = \frac{1}{2}\alpha \quad (2.8)$$

### 2.3.2 Using a hollow prism to determine concentration of a solution

Figure 2.3 shows a set up to determine the refractive index of a solution using a hollow prism.

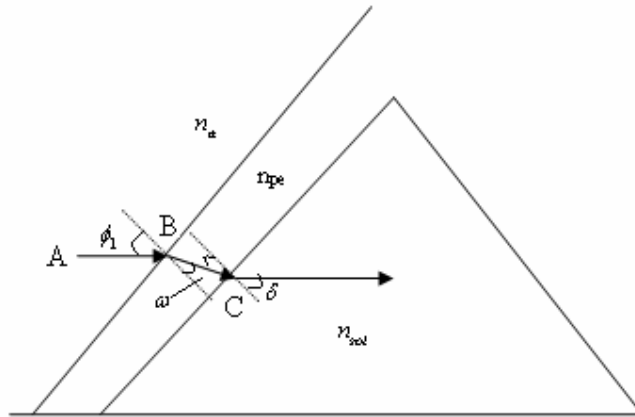


Figure 2.3 The geometry of a light ray passing through a hollow prism

From A to B, light is travelling in air. It is refracted at B and travels in the perspex up to C. At C it is refracted again and we assume it travels parallel to the base of the prism to achieve minimum deviation.

Applying Snell's law at B:

$$n_{air} \sin \phi_1 = n_{pe} \sin \omega \quad (2.9)$$

Where  $n_{air}$  and  $n_{pe}$  are refractive indices of air and Perspex respectively.

The only unknown parameter in equation (2.9) is the angle of refraction,  $\omega$ .

Rearranging Equation (2.9) gives:

$$\sin \omega = \frac{n_{air}}{n_{pe}} \sin \phi_1 \quad (2.10)$$

Applying Snell's law at C:

$$n_{pe} \sin \omega = n_{sol} \sin \delta$$

$$\sin \omega = \frac{n_{sol}}{n_{pe}} \sin \delta \quad (2.11)$$

Equating equations (2.10) and (2.11)

$$\frac{n_{air}}{n_{pe}} \sin \phi_1 = \frac{n_{sol}}{n_{pe}} \sin \delta$$

Therefore

$$n_{air} \sin \phi_1 = n_{sol} \sin \delta \quad (2.12)$$

Substituting equation (2.8) into (2.12):

$$n_{air} \sin \frac{1}{2}(\alpha + \theta_{md}) = n_{sol} \sin \left(\frac{1}{2}\alpha\right) \quad (2.13)$$

Therefore the passage of the ray through the perspex material has no effect on the angle of minimum deviation. It is assumed that there is no absorption and scattering of light through the perspex.

### **2.3.3 Applications of refractive index to determine the concentration of sugar solutions**

When a laser light is incident on an empty hollow prism, the light will pass through to the screen. When the prism is filled with water, the light is refracted. When sugar is added to the water, its optical density changes and the light is refracted more. The angle of deviation  $\theta_{md}$  will be minimum when light passing through the prism is parallel to the base of the prism.

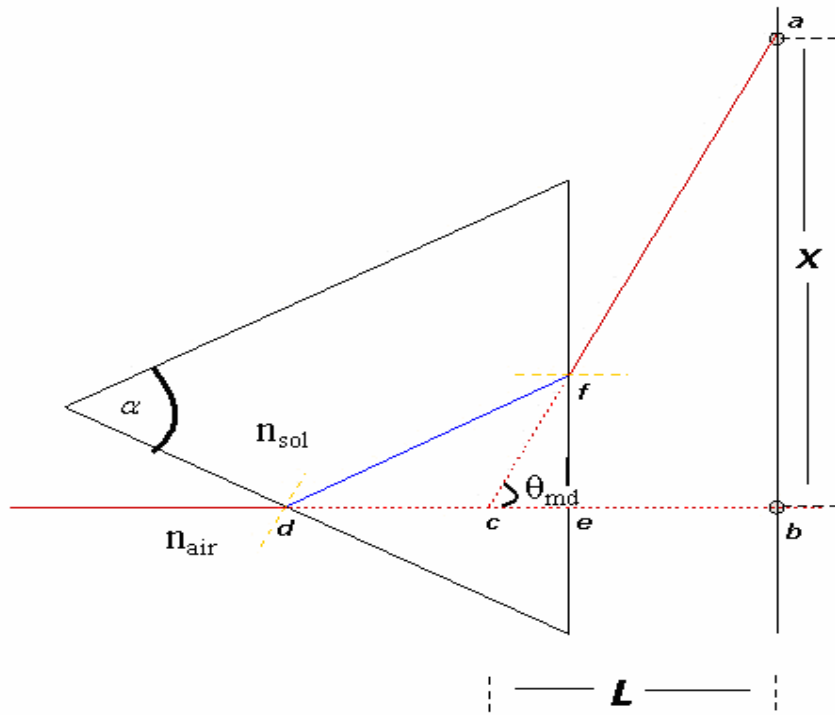


Figure 2.4 Set up showing how to measure angle of minimum deviation of a 60°

Laser beam is monochromatic, coherent and highly directional. These properties of laser enable the whole beam to travel from the source to the prism with minimum dispersion, which is negligible. The laser beam is also very bright and therefore it can be traced up to the screen with greater precision.

Using Figure 2.4 it can be found that:

$$n_{sol} \sin\left(\frac{1}{2}(\alpha)\right) = n_{air} \sin\left(\frac{1}{2}(\theta_{md} + \alpha)\right) \quad (2.14)$$

Where  $n_{sol}$  and  $n_{air}$  are refractive indices of the solution and air respectively.

$\alpha$  and  $\theta_{md}$  are the apex angle of prism and angle of minimum deviation respectively.

Since the apex angle,  $\alpha$  is 60°,

$$n_{sol} \sin\left(\frac{1}{2}(60^\circ)\right) = n_{air} \sin\left(\frac{1}{2}(\theta_{md} + 60^\circ)\right) \quad (2.15)$$

But  $n_{air}$  is 1 and  $\sin 30^\circ = 0.5$  therefore,

$$n_{sol} = 2 \sin\left(\frac{1}{2}\theta_{md} + 30^\circ\right) \quad (2.16)$$

$\theta_{md}$  can be found experimentally using a prism spectrometer.

Substituting the value of  $\theta_{md}$  into equation (2.16) would give the value of the refractive index of the solution.

Changing the concentration of the solution would also give different values of the refractive indices. Now given a solution of unknown concentration, the refractive index can be determined. Also from the values of the other refractive indices, the concentration of the unknown solution can then be determined. All this should be done at a constant temperature, preferably at room temperature.

The effects of the medium on the passage of light are discussed in Appendix 5.

## 2.4 Polarisation

### 2.4.1 Polarisation of light

Polarisation is a property of transverse waves which describes the orientation of the oscillations in the plane perpendicular to the wave's direction of travel.

Conventionally, when considering polarization, the electric field vector is described and the magnetic field is ignored since it is perpendicular to the electric field and proportional to it. The electric field vector may be arbitrarily divided into two perpendicular components labeled  $x$  and  $y$  (with  $z$  indicating the direction of travel).

For a simple harmonic wave, where the amplitude of the electric vector varies in a sinusoidal manner, the two components have exactly the same frequency. However, these components have two other defining characteristics that can differ. First, the two components may not have the same amplitude. Second, the two components may not have the same phase that is they may not reach their maxima and minima at the same time. Figure 2.5 shows how light is polarised.

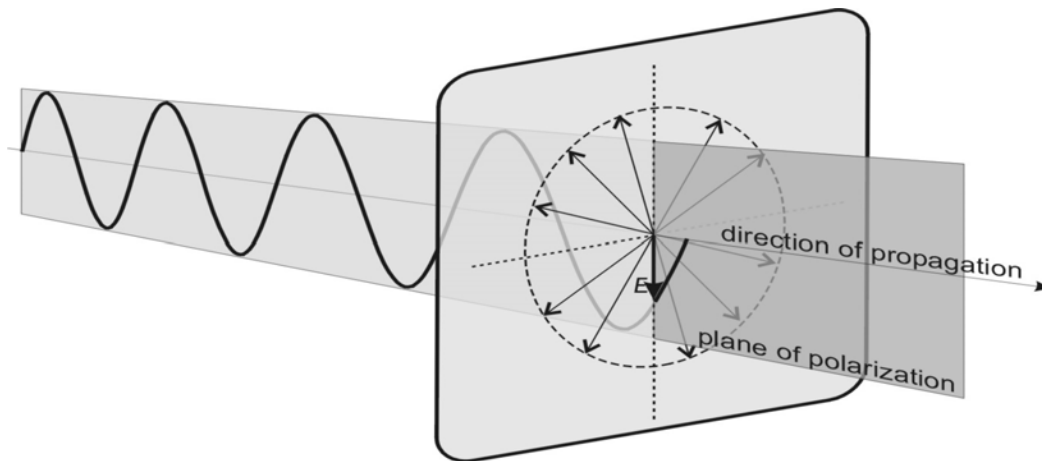


Figure 2.5 A diagram which shows the plane polarisation of light

The double ended arrows inside the dashed line circle represent several directions of the electric field vector oscillation in case of unpolarised light.

## 2.4.2 Types of polarisation

### 2.4.2.1 Linear polarisation

If the electric field vector,  $\mathbf{E}$ , the magnetic field vector,  $\mathbf{H}$  and the wave vector  $\mathbf{k}$  form a triad of mutually perpendicular vectors, this is called a linearly polarised wave.

Vectors  $\mathbf{E}$  and  $\mathbf{k}$  define a plane called a plane of polarisation.

$$E = E_o \exp[i(k.r - \omega t)] \quad (2.17)$$

$$H = H_o \exp[i(k.r - \omega t)] \quad (2.18)$$

The energy flow  $\Pi$  is parallel to the wave vector and is given by:

$$\Pi = E \times H \quad (2.19)$$

This takes place when there are two orthogonal components which are in phase.

In this case the ratio of the strengths of the two components is constant, so the direction of the electric vector (the vector sum of these two components) is constant.

Since the tip of the vector traces out a single line in the plane, this special case is called linear polarization. The direction of this line depends on the relative amplitudes of the two components.

#### **2.4.2.2 Circular polarisation**

This occurs when the two orthogonal components of a wave have exactly the same amplitude and are exactly ninety degrees out of phase. In this case one component is zero when the other component is at maximum or minimum amplitude. There are two possible phase relationships that satisfy this requirement: the  $x$  component can be ninety degrees ahead of the  $y$  component or it can be ninety degrees behind the  $y$  component. In this special case the electric vector traces out a circle in the plane, called circular polarization. The direction the field rotates in depends on which of the two phase relationships exists. These cases are called right-hand circular polarization and left-hand circular polarization, depending on which way the electric vector rotates.

### 2.4.2.3 Elliptical polarisation

All other cases, that is where the two components are not in phase and either do not have the same amplitude and/or are not ninety degrees out of phase are called elliptical polarization because the electric vector traces out an ellipse in the plane.

## 2.4.3 Methods of polarisation

It is possible to transform unpolarised light into polarized light. Polarized light waves are light waves in which the vibrations occur in a single plane. The process of transforming unpolarised light into polarized light is known as polarization. There are a variety of methods of polarizing light.

### 2.4.3.1 Polarisation by transmission

This involves the use of a polaroid filter. Polaroid filters are made of a special material, which is capable of blocking one of the two planes of vibration of an electromagnetic wave. In this sense, a polaroid serves as a device that filters out one-half of the vibrations upon transmission of the light through the filter. When unpolarised light is transmitted through a polaroid filter, it emerges with one-half the intensity and with vibrations in a single plane; it emerges as polarized light.

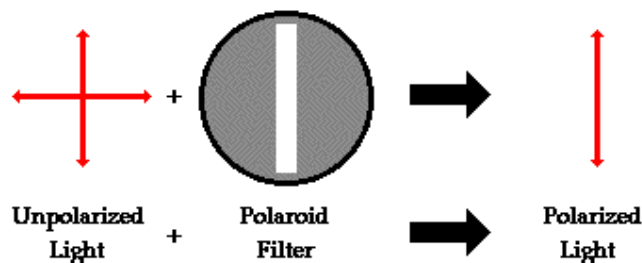


Figure 2.6 Illustration of polarisation using a Polaroid filter

A polaroid filter is able to polarise light because of the chemical composition of the filter material. The filter can be thought of as having long-chain molecules that are aligned within the filter in the same direction. During the fabrication of the filter, the long-chain molecules are stretched across the filter so that each molecule is aligned in say the vertical direction. As unpolarised light strikes the filter, the portion of the waves vibrating in the vertical direction are absorbed by the filter. The general rule is that the electromagnetic vibrations, which are in a direction parallel to the alignment of the molecules, are absorbed.

The alignment of these molecules gives the filter a polarisation axis. This polarisation axis extends across the length of the filter and only allows vibrations of the electromagnetic wave that are parallel to the axis to pass through. The filter blocks any vibrations, which are perpendicular to the polarisation axis. Thus, a polaroid filter with its long-chain molecules aligned horizontally will have a polarisation axis aligned vertically. Such a filter will block all horizontal vibrations and allow the vertical vibrations to be transmitted. On the other hand, a polaroid filter with its long-chain molecules aligned vertically will have a polarisation axis aligned horizontally; this filter will block all vertical vibrations and allow the horizontal vibrations to be transmitted.



Figure 2.7 Orientation of Long chain molecule and polarisation axis

Figure 2.7 (a) shows that when molecules in the filter are aligned vertically, the polarisation axis is horizontal. Figure 2.7 (b) shows that when molecules in the filter are aligned horizontally, the polarisation axis is vertical.

#### 2.4.3.2 Polarisation by Reflection

Unpolarised light can also undergo polarization by reflection off non-metallic surfaces. The extent to which polarisation occurs is dependent upon the angle at which the light approaches the surface and upon the material which the surface is made of. Metallic surfaces reflect light with a variety of vibrational directions; such reflected light is unpolarised. However, non-metallic surfaces such as asphalt roadways, snowfields and water reflect light such that there is a large concentration of vibrations in a plane parallel to the reflecting surface. A person viewing objects by means of light reflected off of non-metallic surfaces will often perceive a glare if the extent of polarisation is large.

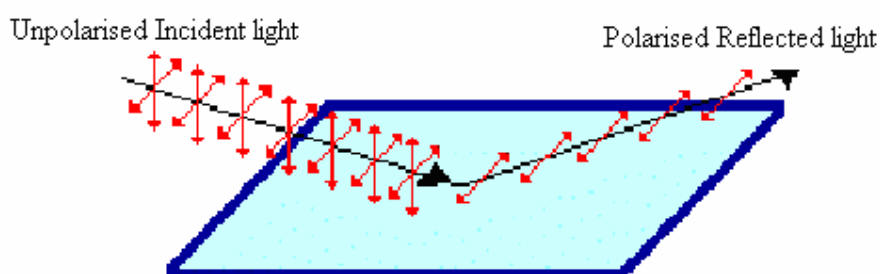


Figure 2.8 Illustration of polarisation by reflection

Figure 2.8 shows reflection of light off non-metallic surfaces and this results in some degree of polarisation parallel to the surface.

#### 2.4.3.3 Polarisation by Refraction

Polarisation can also occur by the refraction of light. Refraction occurs when a beam of light passes from one material into another material. At the surface of the two materials, the path of the beam changes its direction. The refracted beam acquires some degree of polarisation. Most often, the polarisation occurs in a plane perpendicular to the surface. Figure 2.9 shows two refracted rays passing through an Iceland Spar crystal and are polarised with perpendicular orientations.

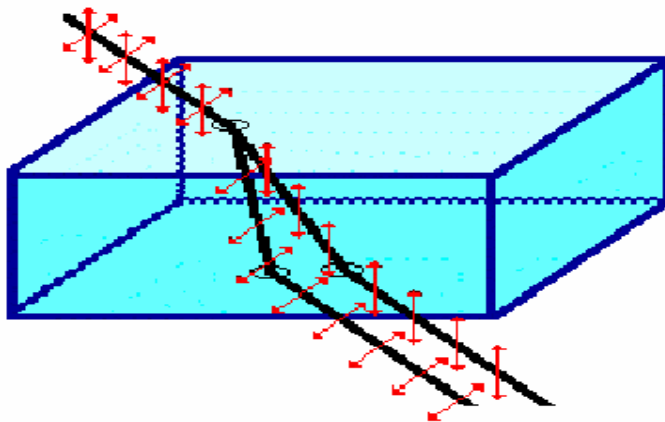


Figure 2.9 Illustration of polarisation by refraction

#### 2.4.3.4 Polarisation by Scattering

Polarisation also occurs when light is scattered while travelling through a medium. When light strikes the atoms of a material, it will often set the electrons of those atoms into vibration. The vibrating electrons then produce their own electromagnetic wave, which is radiated outward in all directions. This newly generated wave strikes neighbouring atoms, forcing their electrons into vibrations at the same original

frequency. These vibrating electrons produce another electromagnetic wave, which is once more radiated outward in all directions. This absorption and reemission of light waves causes the light to be scattered about the medium. This scattered light is partially polarized.

#### 2.4.4 Applications of polarisation in the sugar industry

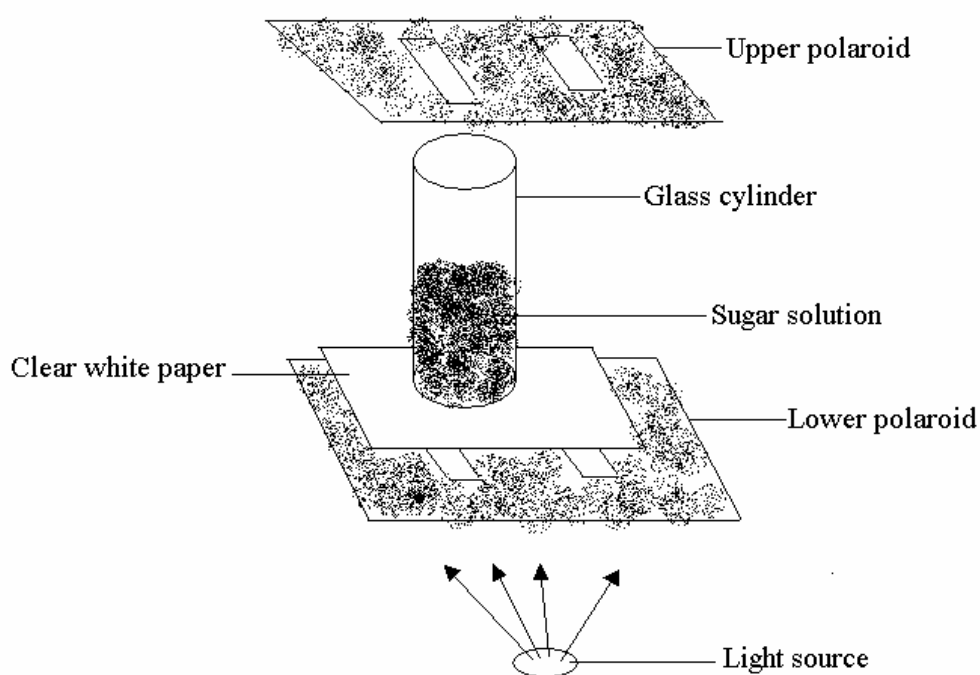


Figure 2.10 Set up to determine concentration using polarising filters

The concentration of sugar solution can be determined using the concept of polarisation. When a sugar solution is poured into a transparent glass container and polarised light is shone through it, the solution rotates the direction of polarisation. The light emerging from the light source at the bottom of the glass cylinder is

unpolarised. That means that this light vibrates in all directions perpendicular to the direction of motion. The polarizing filter under the sugar solution causes this light to vibrate in only one direction.

When polarised light passes through the sugar solution, the direction of its polarisation is rotated. The amount of rotation depends on the depth of the solution. The angle of rotation is proportional to the depth. It is also proportional to the concentration of the solution. The more concentrated the solution, the greater the rotation. Finally, the angle of rotation depends on the wavelength or colour of the light. Blue light, with its shorter wavelength, rotates more than the longer-wavelength red light as shown in the equation below.

$$\alpha = \frac{\pi}{\lambda} (n_l - n_r) \quad (2.20)$$

When a substance is capable of rotating the plane of polarisation of light, it is said to have optical rotatory power or to be optically active. The ability to rotate the plane of polarisation is influenced by the form of either right handed or left handed spiral. It is also due to the asymmetry of the substance itself. In optically active media, it is known that the two circularly polarised rays have different velocities in the direction of the beam of light. The result is that the components now meet on a line, which is inclined to the original, and hence the plane of polarisation is rotated through a definite angle.

### 2.4.5 Reflection symmetry

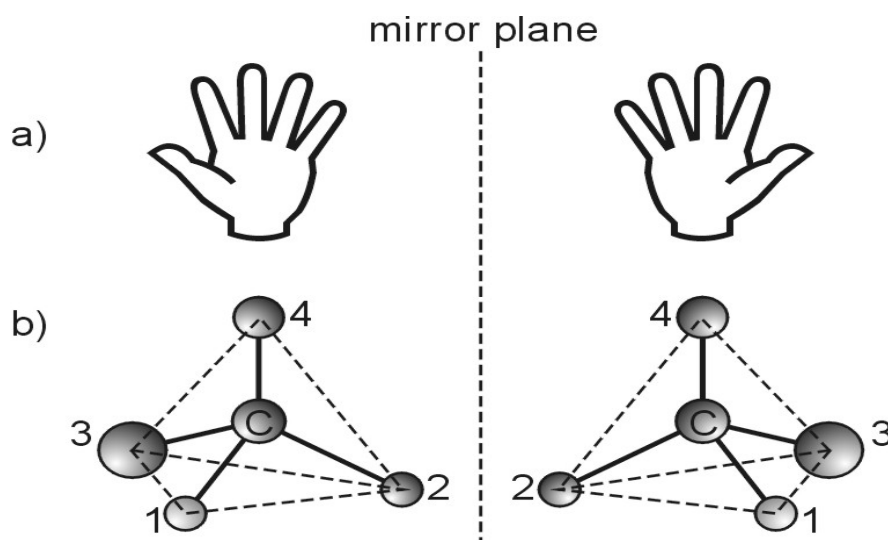


Figure 2.11 A diagram showing examples of optical isomers.

Certain sugars like glucose may exist in two forms, just like two palms (fig. 2.11a), which are mirror images of themselves (fig. 2.11b). Such molecules possess neither a center nor a plane of symmetry and exhibit optical activity – i.e. their solutions rotate the plane of polarization of passing light.

The refractive index of a given medium is related to the velocity of light in it and it appears that optical rotation may be regarded as due to differences in the refraction of right and left circularly polarised light.<sup>4</sup>

$$\alpha = \frac{\pi}{\lambda} (n_l - n_r) \quad (2.20)$$

Where  $\alpha$  is the angle of rotation,  $\lambda$  is the wavelength of light,  $n_l$  and  $n_r$  are left and right refractive indices of the substance respectively.

If  $n_l$  exceeds  $n_r$ , the angle of polarisation is in one direction, but if it is smaller then the angle of polarisation will be in another direction.

## 2.4.6 Specific rotation

The specific rotation or optical rotatory power  $[\alpha]_{\lambda}^T$ , of optically active solutions is defined as the angle through which the plane of polarisation of a ray of a monochromatic light would be rotated by a column of solution 100 mm in length,  $l$ , containing 1 g of substance per  $\text{cm}^3$  at  $20^\circ\text{C}$ .  $\lambda$  represents the wavelength of the light used and  $T$  represents the temperature of the solution was during the experiment.

It is generally expressed in terms of its specific rotation or specific rotatory power defined by the equation.<sup>4</sup>

$$[\alpha]_{\lambda}^T = \frac{\alpha}{lc} \quad (2.21)$$

Where  $\alpha$  is the angle of optical rotation,  $l$  is the path length (length of the tube) and  $c$  is the concentration of the liquid. It is measured in  $\text{degrees.m}^2\text{kg}^{-1}$ .

Equation (2.21) is known as the Biot's law.

But  $l$  is measured in dm, and is equal to unity since the tube is 10 cm long.

Equation (2.21) becomes:

$$[\alpha]_{\lambda}^T = \frac{\alpha}{c} \quad (2.22)$$

For a pure liquid, the density,  $\rho$  replaces the concentration.

$$[\alpha]_{\lambda}^T = \frac{\alpha}{\rho l} \quad (2.23)$$

The angle through which the plane of polarisation of light is rotated by a substance depends to some extent on the temperature and particularly on the wavelength of the light.

If during the optical rotation, the temperature of the solution deviates from T, then a correction needs to be done.

For sugar solution the correction is worked as:<sup>6</sup>

$$[\alpha]_{\lambda}^T = \frac{[\alpha]_{\lambda}^{T_1}}{1 - 0.00037(T_1 - T)} \quad (2.24)$$

Where  $T_1$  is the final temperature observed in the polarimeter after the experiment.

The above-mentioned dependence of the optical rotation on wavelength is applied in the technique called the optical rotatory dispersion (ORD). It is helpful in determining the spatial arrangement of molecules. This technique makes it possible to study the influence of some physical factors such as pH or temperature on molecular conformation.

Measurements of specific rotation also enable one to carry out the analysis of optical purity (enantiomeric excess) of a compound. The optical purity is determined as the percentage ratio of the specific rotation of a mixture  $[\alpha]_{mixture}$  and the specific rotation of pure component  $[\alpha]_{pure\ component}$  and is expressed as follows:

$$Optical\ purity = \frac{[\alpha]_{mixture}}{[\alpha]_{pure\ component}} \times 100\% \quad (2.25)$$

When white light emerges from a sugar solution, each colour in the light has its own direction of polarization. When viewed without a polarizing filter, this light still appears white, since our unaided eyes cannot detect the direction of polarization of light. However, when you look through a second polarizing filter, you see only the light that is vibrating in a direction that can pass through the filter. Only certain

wavelengths or colours of light have the appropriate polarization. The intensity of the other colours in the light, which have different directions of vibration, is diminished. If a certain colour of light has its polarization perpendicular to the axis of the polarizing filter, it is blocked out completely. As the filter is rotated, each orientation of the rotated filter produces a different dominant colour, as does each different concentration of sugar solution.

#### **2.4.7 Sources of optical activity**

The chromophores responsible for optical rotation are the furanose and pyranose ring oxygen atoms and the hydroxyl and methoxyl groups. The absorption maxima for the ring oxygen atom and the methoxyl groups are about 180 nm while that for the hydroxyl oxygen atoms is in the region of 150 nm.<sup>[4]</sup>

#### **2.4.8 Effects of sugar on polarisation**

Glucose is an example of an optically active substance. All organically produced glucose rotates the direction of polarisation of light clockwise. This type of sugar is called d-glucose (dextrose) or dextrorotatory. There is another type of sugar, which rotates the plane of polarisation anticlockwise. This is called l-glucose (levulose) or levorotatory. It is made by inorganic chemical synthesis. Both the d-glucose and the l-glucose have the same chemical formula and both have the same sweetness. However, the atoms in each of these isomers are arranged in a different pattern. The l-glucose cannot be used by humans as an energy source, it can produce sweetness but without energy.

## 2.5 Polarimetry

Polarimetry is the measurement and interpretation of the polarization of transverse waves, most notably electromagnetic waves, such as radio waves and light. Typically polarimetry is done on electromagnetic waves that have traveled through or reflected, refracted, or diffracted from some material or object in order to characterize that object.

A polarimeter is the basic scientific instrument used to make these measurements.

It comprises a light source, polariser, sample cell and analyser as shown in figure 2.12. The polariser is to plane polarise the light. The analyser is to determine the plane of polarisation after light has traversed the substance under investigation. Usually both the polariser and analyser contain a Nicol prism. This is a calcite crystal, which produces two refracted rays, which are plane polarised in directions that are mutually perpendicular. The crystal is cut such that only one of these beams emerges, the other being returned by total internal reflection in the direction of the light source. Thus the light emerging from Nicol prism is plane polarised.

Rotating the analyser until a position of maximum or minimum light transmission is observed makes the measurement. The two prisms are then angled to each other by an extent  $\alpha$  or  $\alpha + 90^\circ$ .

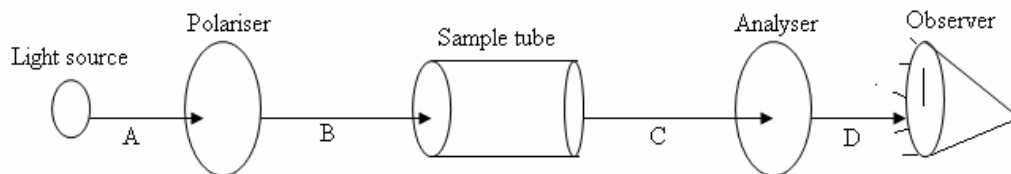


Figure 2.12 A block diagram showing the polarimeter.

The light source produce waves of normal unpolarised light vibrating in all directions at right angles to the direction of travel. Usually monochromatic light from a sodium vapour lamp is used. The polariser will allow light vibrating only in a single plane to pass through it, producing plane-polarised light. Light at point B is plane polarised.

If an optically active compound is placed in the sample tube, the sample rotates the plane-polarised light. Light at point C has its plane rotated by some angle  $\alpha$  .

The analyser is a second polariser. It is viewed and rotated until maximum light is seen. The direction and size of rotation are measured.

The observer measures the degree of rotation,  $\alpha$  and notes the direction as clockwise or anticlockwise.

## **2.6 Conclusion**

This chapter was talking about the theory behind the project. It was talking about the use of Snell's law and optical rotation to determine the concentration of solutions. The next chapter will talk about the methodology used in order to achieve the objectives of the project.

## CHAPTER 3 METHODOLOGY

### 3.1 Introduction

This chapter is going to describe the construction of the hollow prism, the measurement of angle of minimum deviation and the determination of optical angle of rotation.

### 3.2 Construction of the hollow prism

A hollow prism was constructed using perspex material. A strip of 8 cm by 3 cm was cut from a perspex sheet 2 mm thick.

Three smaller strips of 2.5 cm by 2.5 cm were further cut from the main strip.

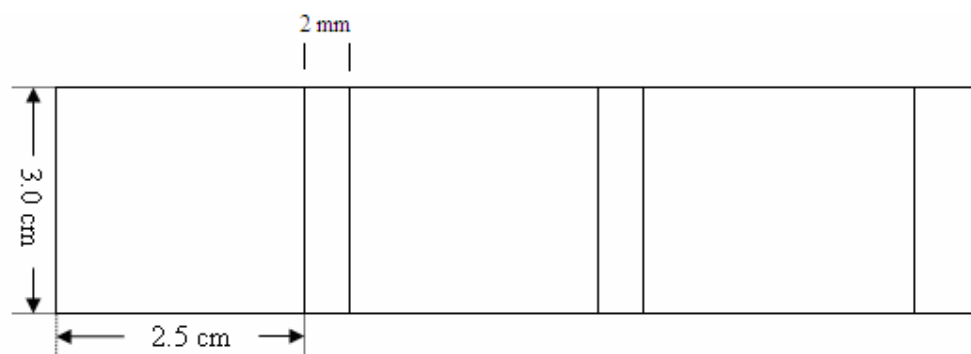


Figure 3.1 Smaller perspex strips cut from the larger perspex sheet.

The strips were cut using a guillotine and the edges were filed using a stone grinder. The three pieces were held together and attached to each other using an adhesive tape.

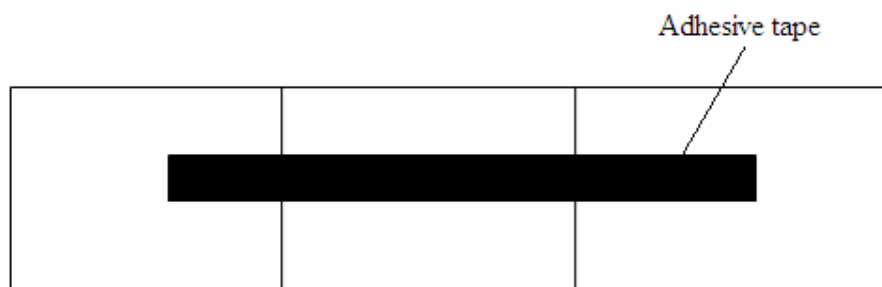


Figure 3.2 Pieces of Perspex attached together using an adhesive tape.

The Pieces were then joined to form a prism.

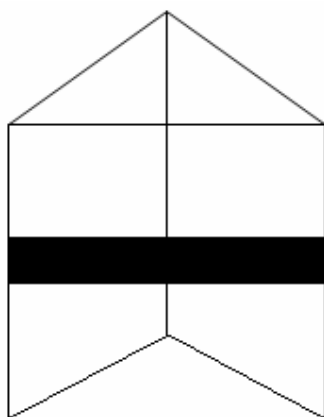


Figure 3.3 The three perspex pieces forming a prism.

The joints of the perspex pieces were joined together permanently using a bonding solution made of perspex and chloroform. Chloroform liquid and perspex swaff were mixed to form a high viscosity mixture that was then spread along the joints. When the mixture dried, a watertight joint was formed.

A rectangular prism base was similarly attached as shown in figure 3.3. The adhesive tape was then removed after the prism bond was strong and dry.

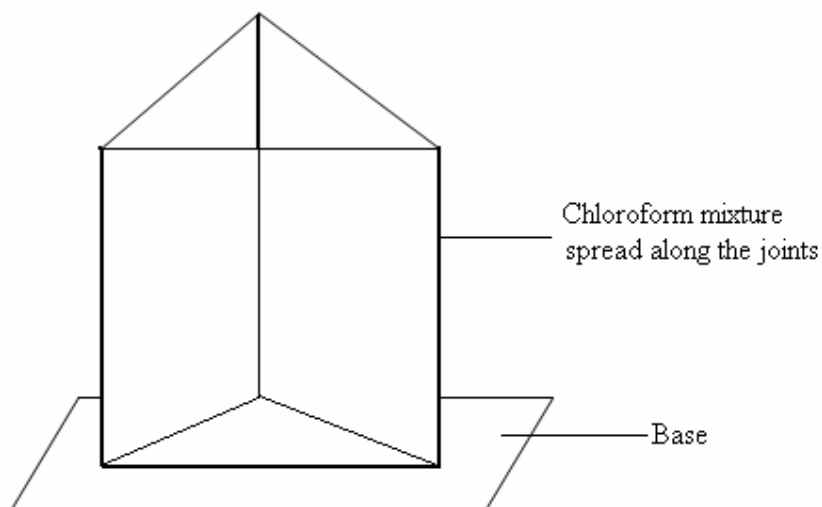


Figure 3.4 A complete hollow prism made of Perspex.

### 3.3 Measurement of angle of minimum deviation

The next step was to measure the angle of minimum deviation. The apparatus consists of a hollow prism, an optical spectrometer, a sodium lamp, a mercury vapour lamp, electronic mass balance, measuring cylinder, sugar and water.

#### 3.3.2 Preparation of sugar solution

A sugar solution had to be prepared. A  $100 \text{ cm}^3$  graduated measuring cylinder was used to measure the volume of de-ionised water. An electronic balance was used to measure the mass of sugar. Two types of sugar were used, white sugar and brown sugar. The same concentrations were determined for each type of sugar. Considering that the density of de-ionised is  $1 \text{ gm}^{-3}$ ,  $1 \text{ cm}^3$  of water would be equal to 1 g of water. The concentrations were determined as shown in table 3.1.

Table 3.1 Determination of concentration of sugar

| Concentration of sugar (%) | Volume of water (cm <sup>3</sup> ) | Mass of water (g) | Mass of sugar (g) |
|----------------------------|------------------------------------|-------------------|-------------------|
| 0                          | 100                                | 100               | 0                 |
| 10                         | 90                                 | 90                | 10                |
| 20                         | 80                                 | 80                | 20                |
| 30                         | 70                                 | 70                | 30                |
| 40                         | 60                                 | 60                | 40                |
| 50                         | 50                                 | 50                | 50                |
| 60                         | 40                                 | 40                | 60                |
| 70                         | 30                                 | 30                | 70                |
| 80                         | 20                                 | 20                | 80                |

### 3.3.3 Experimental set up

Figure 3.5 shows the set up to determine the angle of minimum deviation.

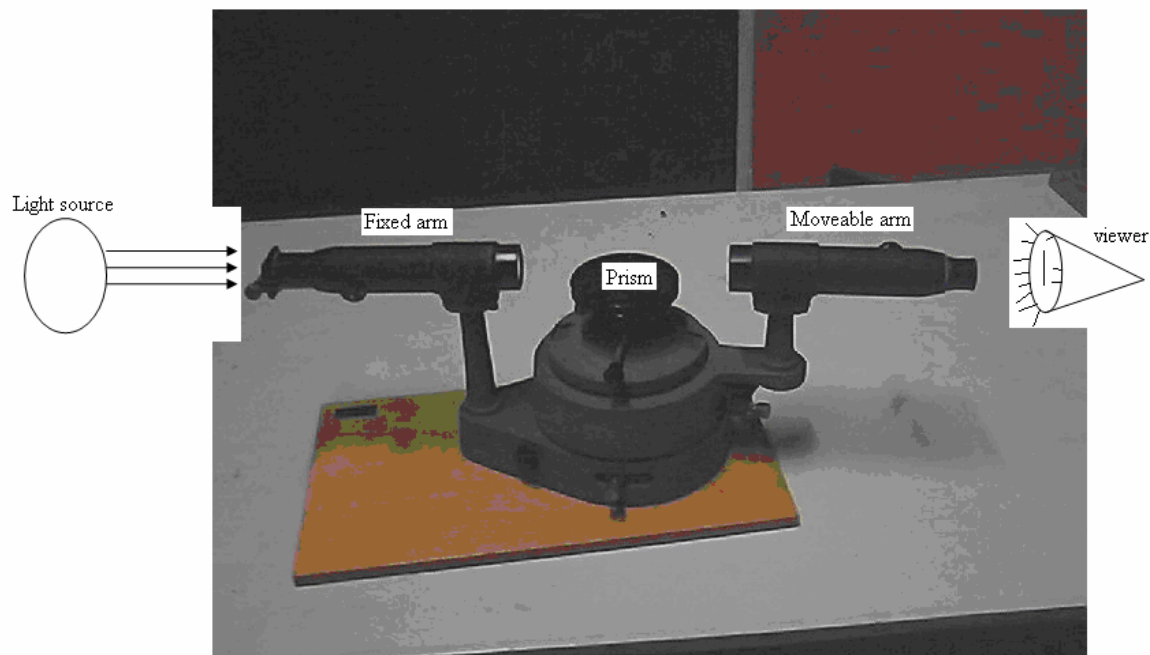


Figure 3.5 Arrangement to determine angle of minimum deviation

The apparatus was set up as shown in Figure 3.5. The hollow prism was centrally positioned on the spectrometer and the sugar solution of known concentration was poured into the prism. A sodium lamp was used and a collimated beam of light was allowed to fall on one face of the prism. The angle of minimum deviation was determined for yellow light. This was done for all concentrations of sugar solutions. Three values of the angle were determined for each concentration value. The same procedure was done for both white and brown sugar. This was also done for juices from raw sugar cane, orange and apple fruits.

### 3.4 Determination of angle of rotation

The diagram below shows how the angle of rotation was determined

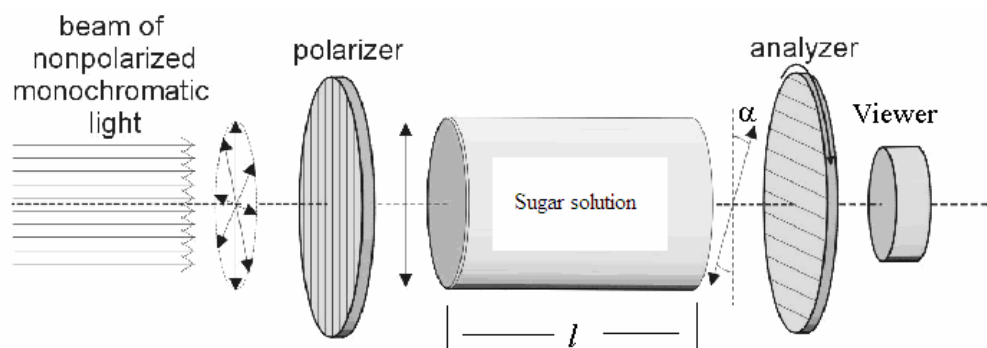


Figure 3.6 Schematic diagram of a polarimeter

The sample tube was first washed and dried. The solution was then poured into the sample tube. Non-polarised monochromatic light from the sodium lamp ( $\lambda = 589nm$ ) was passed through the polariser and then into the tube containing the sugar solution. Looking through the viewing point, an orange circle divided into two halves was observed. The other half was darker than the other. The angle of rotation was set at zero. The analyser was then rotated clockwise and the in intensity of the colour of the darker half was noted. The analyser was then rotated anticlockwise and the change in colour of the darker half was again noted.

The analyser was then rotated in the direction where the intensity of the colour of the darker half improves. This was done until the intensity in both halves was the same.

When the intensity of light in both halves was the same, the angle of rotation was noted. The angle of rotation of the solution was then determined. The same procedure was repeated for different concentrations of sugar solution. This was done for each samples of the solution. This was also done for juices from raw sugar cane, orange and apple fruits.

### **3.5 Conclusion**

This chapter was describing the methodology of the study. It described how the hollow prism was constructed, the determination of angle of minimum deviation and optical angle of rotation. The next chapter talks about the presentation and analysis of results.

## CHAPTER 4 RESULTS AND ANALYSIS

### 4.1 Introduction

This chapter is going to discuss about presentation and analysis of results.

### 4.2 Experimental data

The following tables represent the presentation of results.

#### 4.2.1 Tables of results

Table 4.1 Results of minimum deviation angle for white sugar solutions using a sodium lamp as light source.

| Concentration (%) | Angle of minimum deviation (°) |       |       |         | Refractive index |
|-------------------|--------------------------------|-------|-------|---------|------------------|
|                   | 1                              | 2     | 3     | Average |                  |
| Empty prism       | 0                              | 0     | 0     | 0       | 0                |
| 0                 | 23.20                          | 23.17 | 23.19 | 23.19   | 1.33             |
| 10                | 24.59                          | 24.57 | 24.59 | 24.58   | 1.35             |
| 20                | 25.89                          | 25.92 | 25.89 | 25.90   | 1.36             |
| 30                | 28.05                          | 28.06 | 28.06 | 28.06   | 1.39             |
| 40                | 29.66                          | 29.65 | 29.64 | 29.65   | 1.41             |
| 50                | 30.45                          | 30.44 | 30.44 | 30.44   | 1.42             |
| 60                | 32.59                          | 32.57 | 32.57 | 32.58   | 1.45             |
| 70                | 34.59                          | 34.57 | 34.60 | 34.59   | 1.47             |
| 80                | 36.34                          | 36.35 | 36.34 | 36.34   | 1.49             |

Table 4.2 Results of minimum deviation angle for brown sugar solutions using a sodium lamp as light source.

| Concentration (%) | Angle of minimum deviation (°)                                                              |       |       |         | Refractive index |
|-------------------|---------------------------------------------------------------------------------------------|-------|-------|---------|------------------|
|                   | 1                                                                                           | 2     | 3     | Average |                  |
| Empty prism       | 0                                                                                           | 0     | 0     | 0       | 0                |
| 0                 | 23.20                                                                                       | 23.17 | 23.19 | 23.19   | 1.33             |
| 10                | 23.74                                                                                       | 23.75 | 23.75 | 23.75   | 1.34             |
| 20                | 24.89                                                                                       | 24.91 | 24.91 | 24.91   | 1.35             |
| 30                | 26.46                                                                                       | 26.45 | 26.46 | 26.46   | 1.37             |
| 40                | 27.41                                                                                       | 27.39 | 27.41 | 27.40   | 1.38             |
| 50                | 28.85                                                                                       | 28.85 | 28.86 | 28.85   | 1.40             |
| 60                | 30.39                                                                                       | 30.40 | 30.40 | 30.40   | 1.42             |
| 70                | These were difficult to observe. The yellow line was obscured by the brown colour of sugar. |       |       |         |                  |
| 80                |                                                                                             |       |       |         |                  |

Table 4.3      Results of minimum deviation angle for white sugar solutions using  
Mercury lamp and a green filter as light source.

| Concentration (%) | Angle of minimum deviation (°) |       |       |         | Refractive index |
|-------------------|--------------------------------|-------|-------|---------|------------------|
|                   | 1                              | 2     | 3     | Average |                  |
| Empty prism       | 0                              | 0     | 0     | 0       | 0                |
| 0                 | 23.24                          | 23.25 | 23.25 | 23.25   | 1.33             |
| 10                | 24.63                          | 24.64 | 24.65 | 24.64   | 1.35             |
| 20                | 25.89                          | 25.90 | 25.89 | 25.89   | 1.36             |
| 30                | 27.03                          | 27.04 | 27.04 | 27.04   | 1.38             |
| 40                | 28.56                          | 28.55 | 28.55 | 28.55   | 1.40             |
| 50                | 30.49                          | 30.48 | 30.49 | 30.49   | 1.42             |
| 60                | 32.63                          | 32.64 | 32.65 | 32.64   | 1.45             |
| 70                | 34.61                          | 34.62 | 34.62 | 34.62   | 1.47             |
| 80                | 36.31                          | 36.32 | 36.33 | 36.32   | 1.49             |

Table 4.4 Results of Temperature, concentration and angle of minimum deviation for white sugar solutions using sodium lamp as light source.

| Temperature (°C) | Angle of minimum deviation (°) |       |       |       |       |       |       |       |
|------------------|--------------------------------|-------|-------|-------|-------|-------|-------|-------|
|                  | 0 %                            | 10 %  | 20 %  | 30 %  | 40 %  | 50 %  | 60 %  | 70 %  |
| 65               | 22.22                          | 23.85 | 24.88 | 26.35 | 27.84 | 29.03 | 30.98 | 32.01 |
| 60               | 22.29                          | 23.92 | 24.95 | 26.42 | 27.91 | 29.10 | 31.04 | 32.08 |
| 55               | 22.36                          | 24.00 | 25.02 | 26.49 | 27.98 | 29.18 | 31.11 | 32.16 |
| 50               | 22.42                          | 24.06 | 25.09 | 26.56 | 28.05 | 29.26 | 31.20 | 32.24 |
| 45               | 22.50                          | 24.13 | 25.16 | 26.64 | 28.13 | 29.33 | 31.27 | 32.32 |
| 40               | 22.57                          | 24.21 | 25.23 | 26.72 | 28.21 | 29.40 | 31.34 | 32.39 |
| 35               | 22.65                          | 24.28 | 25.30 | 26.78 | 28.29 | 29.48 | 31.43 | 32.46 |
| 30               | 22.71                          | 24.35 | 25.38 | 26.86 | 28.36 | 29.55 | 31.50 | 32.55 |
| 25               | 22.78                          | 24.42 | 25.45 | 26.93 | 28.43 | 29.63 | 31.57 | 32.62 |

Table 4.5 Results of temperature, concentration and refractive index for white sugar solutions using sodium lamp as light source.

| Temperature (°C) | Refractive Index, n |        |        |        |        |        |        |        |
|------------------|---------------------|--------|--------|--------|--------|--------|--------|--------|
|                  | 0 %                 | 10 %   | 20 %   | 30 %   | 40 %   | 50 %   | 60 %   | 70 %   |
| 65               | 1.3150              | 1.3363 | 1.3496 | 1.3684 | 1.3873 | 1.4022 | 1.4261 | 1.4388 |
| 60               | 1.3159              | 1.3372 | 1.3505 | 1.3693 | 1.3882 | 1.4031 | 1.4270 | 1.4397 |
| 55               | 1.3169              | 1.3382 | 1.3514 | 1.3702 | 1.3891 | 1.4040 | 1.4279 | 1.4406 |
| 50               | 1.3177              | 1.3390 | 1.3524 | 1.3711 | 1.3900 | 1.4050 | 1.4289 | 1.4416 |
| 45               | 1.3187              | 1.3400 | 1.3533 | 1.3721 | 1.3910 | 1.4059 | 1.4298 | 1.4425 |
| 40               | 1.3196              | 1.3410 | 1.3542 | 1.3731 | 1.3919 | 1.4068 | 1.4307 | 1.4434 |
| 35               | 1.3206              | 1.3419 | 1.3551 | 1.3739 | 1.3929 | 1.4078 | 1.4317 | 1.4443 |
| 30               | 1.3215              | 1.3428 | 1.3561 | 1.3749 | 1.3938 | 1.4086 | 1.4326 | 1.4453 |
| 25               | 1.3224              | 1.3437 | 1.3570 | 1.3758 | 1.3947 | 1.4096 | 1.4335 | 1.4462 |

### 4.2.2 Graphs and analysis

The following is a presentation of the data graphically.

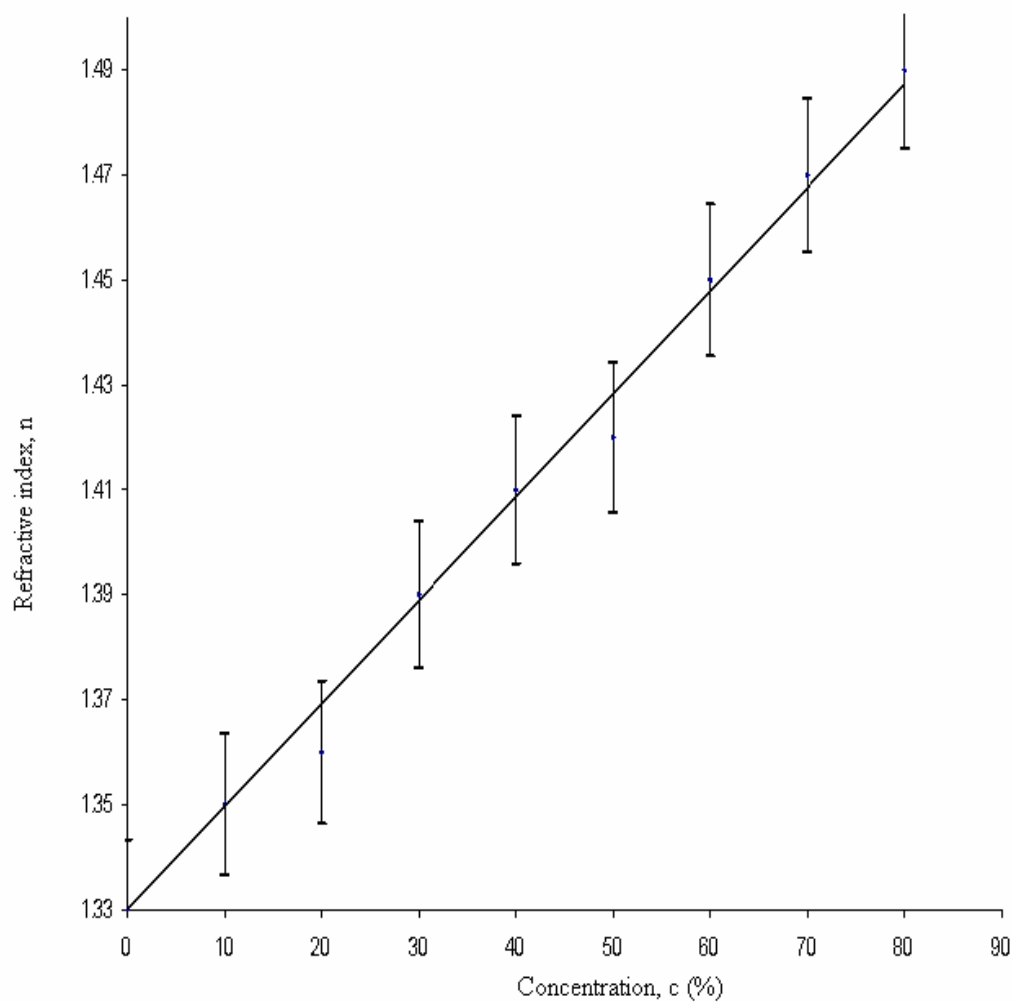


Figure 4.1: A graph of refractive index versus concentration for white sugar solution using sodium lamp as light source

The graph of refractive index against concentration is a straight line as shown in Figure 4.1. Given a solution with an unknown concentration, its refractive index can be determined experimentally. The graph can be extrapolated or interpolated to determine its concentration.

The gradient of the curve is:

$$\left[ \frac{dn}{dc} \right]_{21} = 0.002$$

where the subscript 21 refers to the temperature at which the experiment was done.

Using the equation of the straight line the concentration can also be determined where the intercept is 1.33.

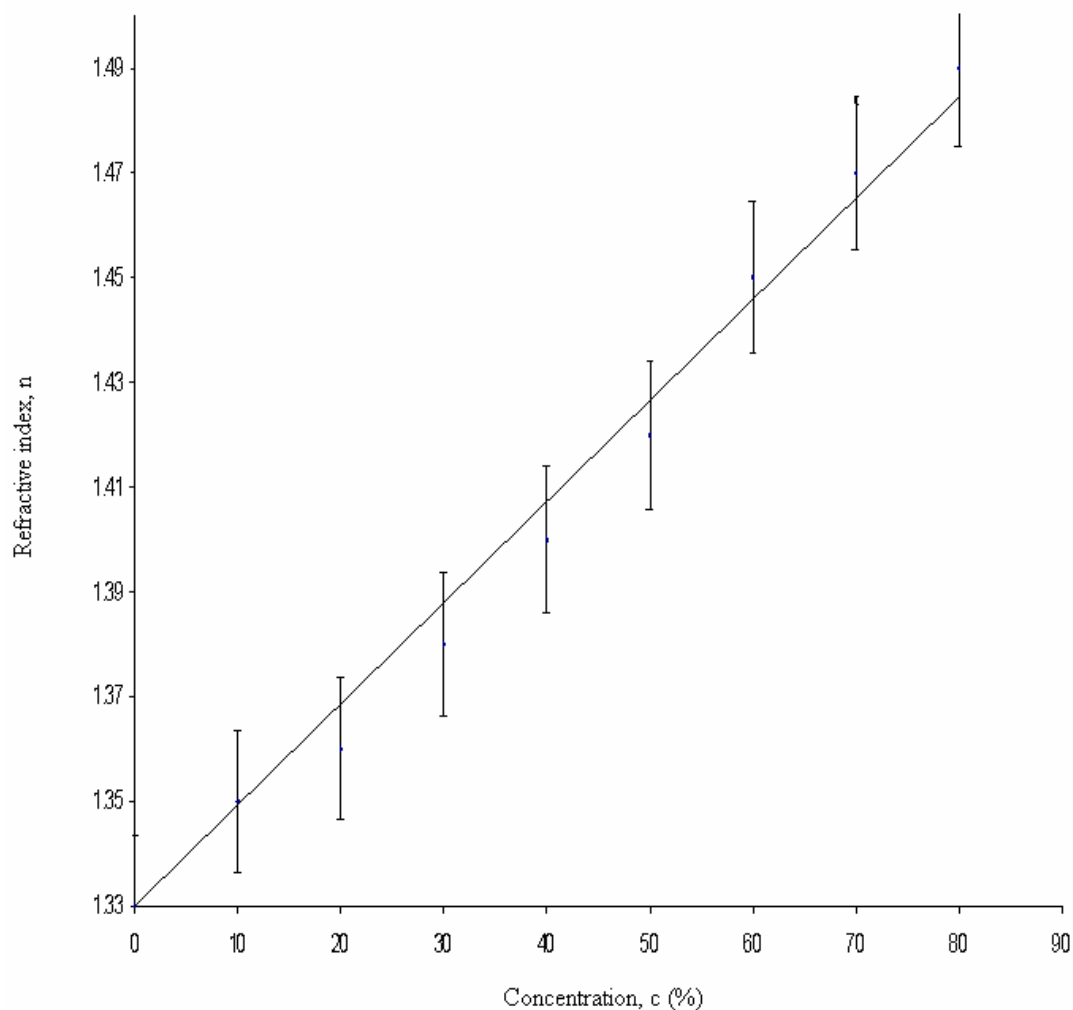


Figure 4.2: A graph of refractive index versus concentration for white sugar solution using sodium lamp as light source

The graph of refractive index against concentration is a straight line as shown in Figure 4.2. Given a solution with an unknown concentration, its refractive index can be determined experimentally. The graph can be extrapolated or interpolated to determine its concentration.

The gradient of the curve is:

$$\left[ \frac{dn}{dc} \right]_{21} = 0.0019$$

where the subscript 21 refers to the temperature at which the experiment was done.

Using the equation of the straight line the concentration can also be determined where the intercept is 1.33.

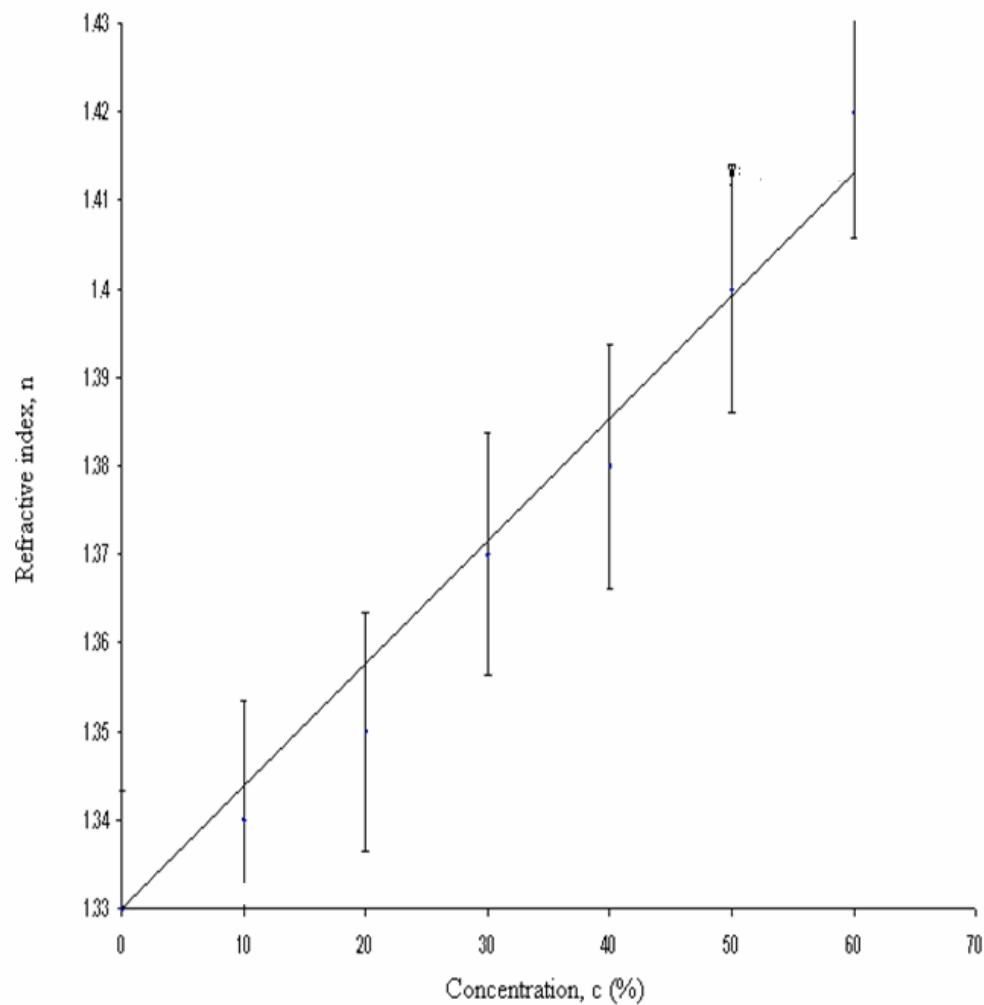


Figure 4.3: A graph of refractive index versus concentration for brown sugar solution using sodium lamp as light source

The graph of refractive index against concentration is a straight line. Given a solution with an unknown concentration, its refractive index is determined experimentally and the concentration is determined through extrapolation or interpolation of the curve.

The slope of the curve is:

$$\left[ \frac{dn}{dc} \right]_{21} = 0.0014$$

The concentration can also be determined using the equation of the straight line with intercept of 1.33.

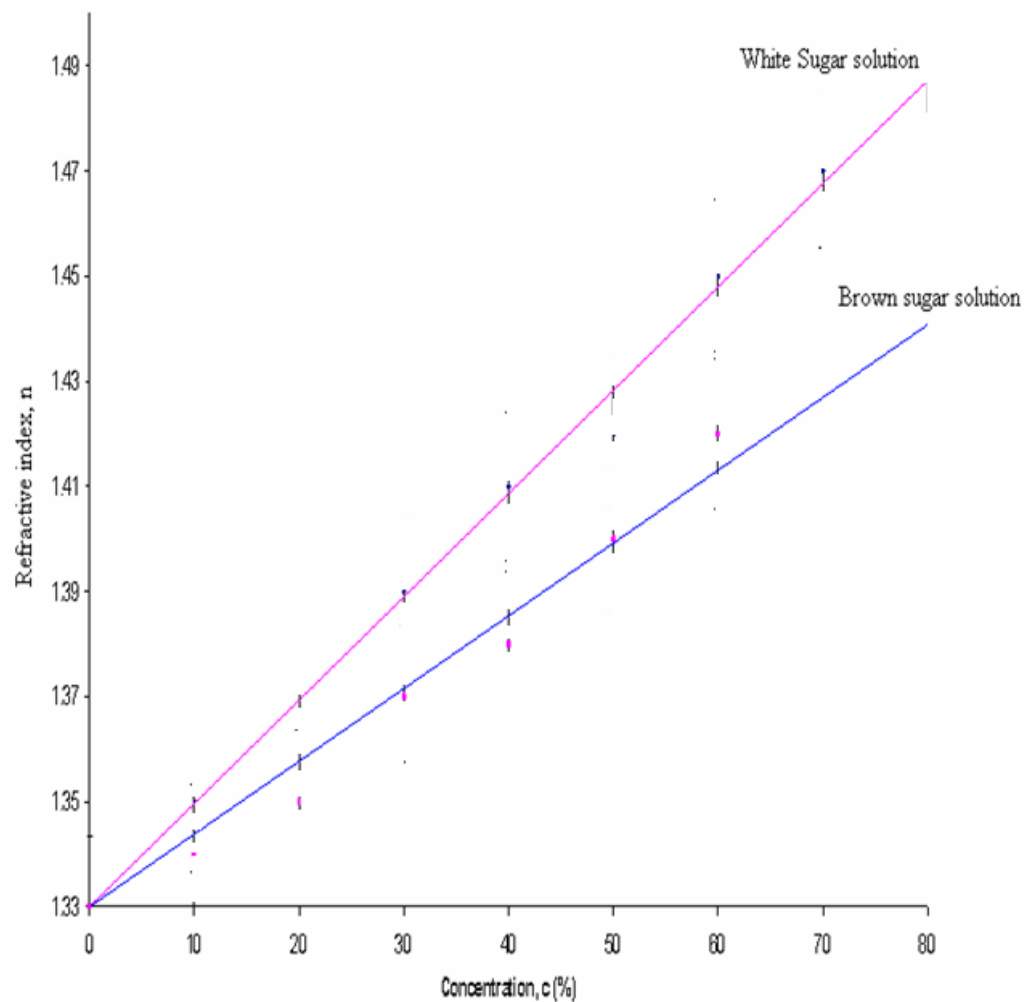


Figure 4.4 Graphs of refractive index versus concentration for different sugar solutions using sodium lamp as light source

The curves in figure 4.4 show that white sugar is more refined than brown sugar. Both sugars are sucrose but have different refractive indices for the same concentration. This means that brown sugar contains some non-sucrose elements, which are removed during refining to produce white sugar, which is more concentrated.

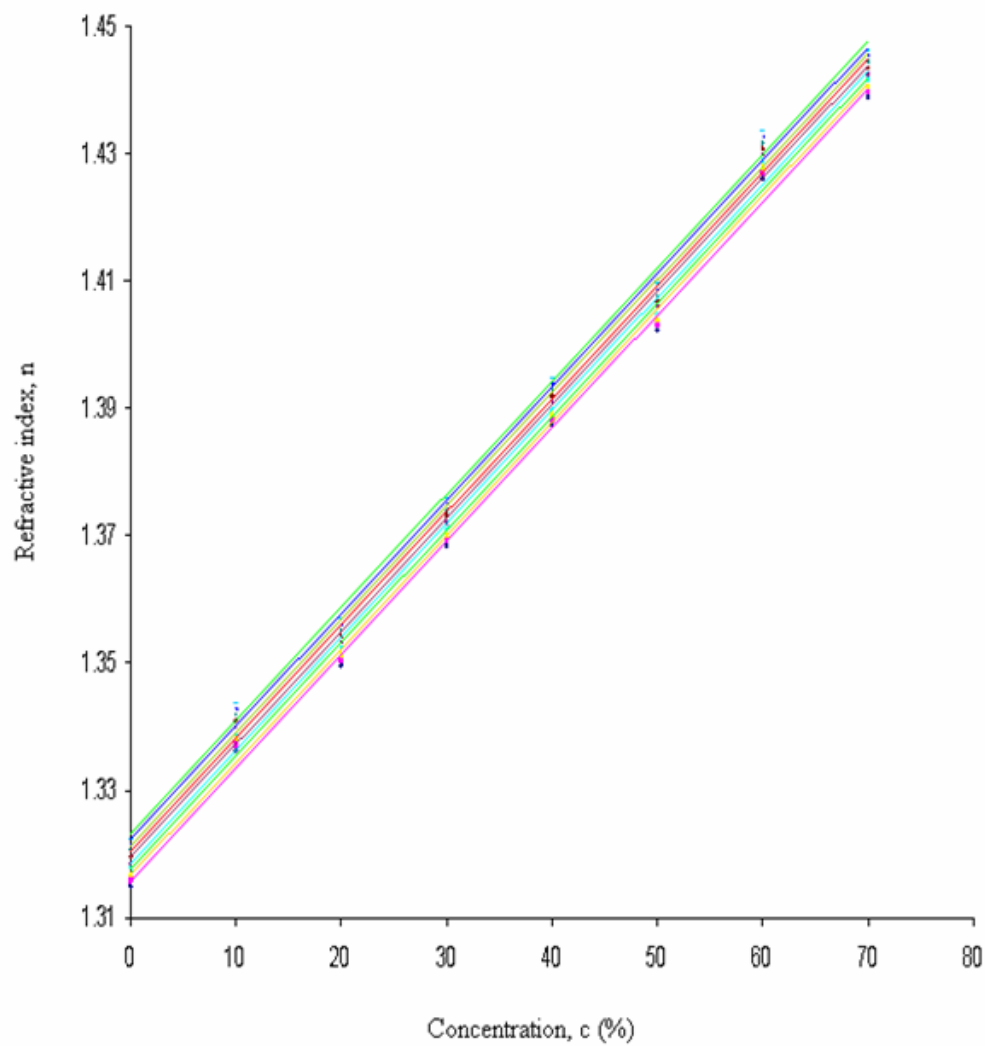


Figure 4.5 Graphs of refractive index versus concentration for white sugar solution at different temperatures

Linear 1 is 65 °C (bottom line)  
 Linear 2 is 60 °C  
 Linear 3 is 55 °C  
 Linear 4 is 50 °C  
 Linear 5 is 45 °C  
 Linear 6 is 40 °C  
 Linear 7 is 35 °C  
 Linear 8 is 30 °C  
 Linear 9 is 25 °C (top line)

Table 4.6 Results for slopes of concentration of white sugar solutions at different temperatures

| $\left[\frac{dn}{dc}\right]_T$ | $\left(\left[\frac{dn}{dc}\right]_T - \left[\frac{dn}{dc}\right]_T\right)$ | $\left(\left[\frac{dn}{dc}\right]_T - \left[\frac{dn}{dc}\right]_T\right)^2 \times 10^{-12}$ |
|--------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| 0.001769                       | 0                                                                          | 0                                                                                            |
| 0.001769                       | 0                                                                          | 0                                                                                            |
| 0.001767                       | -0.000002                                                                  | 4.0                                                                                          |
| 0.001769                       | 0                                                                          | 0                                                                                            |
| 0.001770                       | 0.000001                                                                   | 1.0                                                                                          |
| 0.001767                       | -0.000002                                                                  | 4.0                                                                                          |
| 0.001769                       | 0                                                                          | 0                                                                                            |
| 0.001769                       | 0                                                                          | 0                                                                                            |
| 0.001769                       | 0                                                                          | 0                                                                                            |
|                                |                                                                            | $\Sigma = 9.0 \times 10^{-12}$                                                               |

The subscript represents the temperature of the solution.

#### 4.2.2.1 Determination of standard deviation from the mean of the slopes

$$\sigma = \sqrt{\sum \left( \left[\frac{dn}{dc}\right]_T - \left[\frac{dn}{dc}\right]_T \right)^2 \times \frac{1}{N(N-1)}}$$

$$\sigma = \sqrt{\frac{9 \times 10^{-12}}{9 \times 8}}$$

$$\sigma = 3.5 \times 10^{-7}$$

$$\sigma = \pm 0.0004 \times 10^{-3}$$

Therefore the concentration coefficient of refractive index is:

$$\left[\frac{dn}{dc}\right]_T = (1.7690 \pm 0.0004) \times 10^{-3}$$

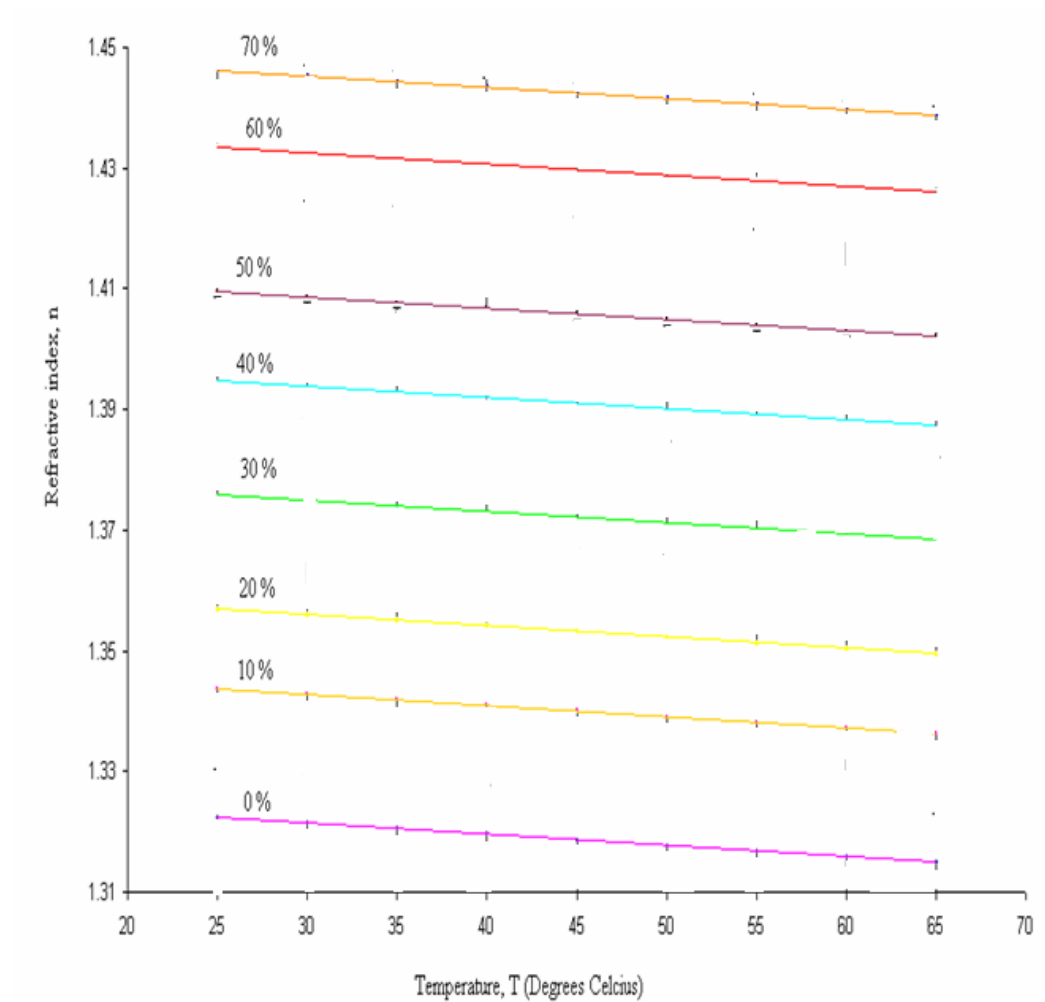


Figure 4.6: Graphs of refractive index versus temperature for white sugar solutions of different concentrations

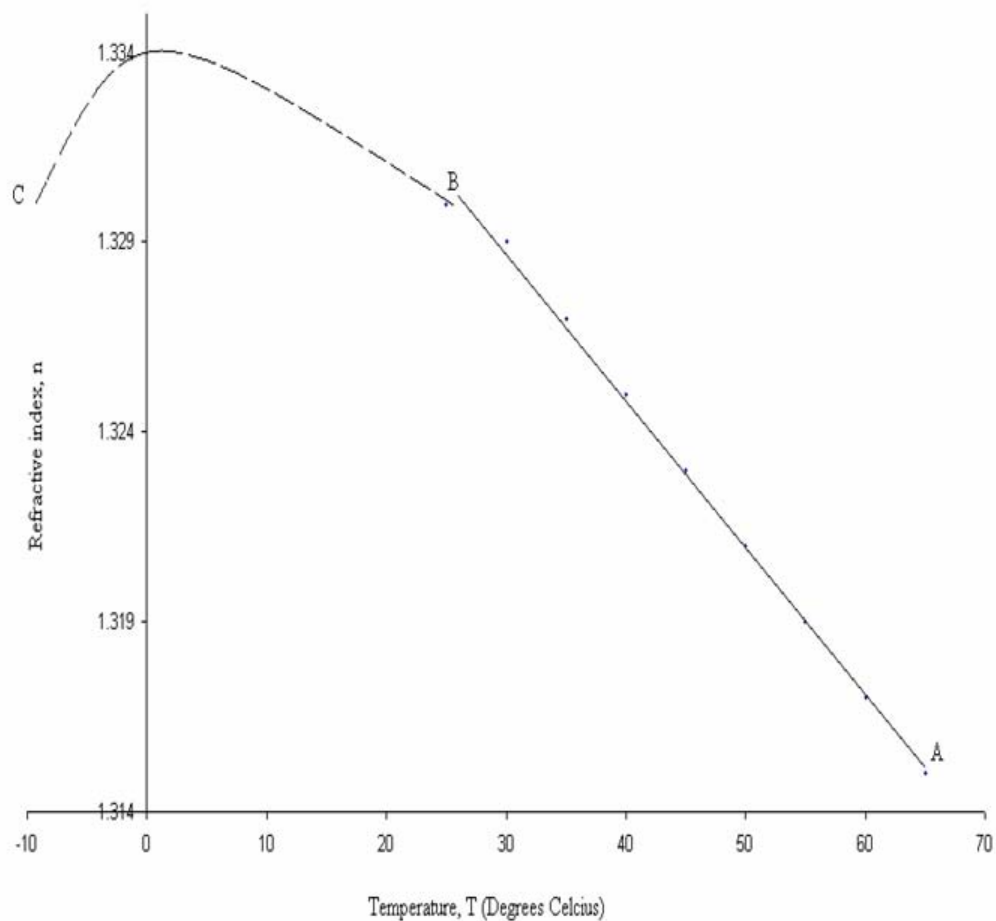


Figure 4.6b: A graph of refractive index versus temperature for water

A to B represents part of the curve determined from experimental results. B to C represents part of the curve determined by other researchers who managed to measure the refractive index of water taken from  $20^{\circ}\text{C}$  up to a temperature of about  $-10^{\circ}\text{C}$ .<sup>10,19,21</sup>

The shape of the graph from  $20^{\circ}\text{C}$  up to  $100^{\circ}\text{C}$  is expected to be a straight line with a negative gradient. The shape of the graph from  $20^{\circ}\text{C}$  to  $-10^{\circ}\text{C}$  could be contributed by the change in hydrogen bonding of water molecules as it freezes.

Table 4.7 Results for slopes of refractive indices versus temperature

| $\left[\frac{dn}{dT}\right]_c / ^\circ C$             | $\left[\frac{dn}{dT}\right]_c - \left[\frac{dn}{dT}\right]_c / ^\circ C$ | $\left(\left[\frac{dn}{dT}\right]_c - \left[\frac{dn}{dT}\right]_c\right)^2 \times 10^{-14} / ^\circ C^2$ |
|-------------------------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| -0.0001850                                            | 0                                                                        | 0                                                                                                         |
| -0.0001850                                            | 0                                                                        | 0                                                                                                         |
| -0.0001848                                            | 0.0000002                                                                | 4.0                                                                                                       |
| -0.0001852                                            | -0.0000002                                                               | 4.0                                                                                                       |
| -0.0001849                                            | 0.0000001                                                                | 1.0                                                                                                       |
| -0.0001851                                            | -0.0000001                                                               | 1.0                                                                                                       |
| -0.0001850                                            | 0                                                                        | 0                                                                                                         |
| -0.0001850                                            | 0                                                                        | 0                                                                                                         |
| $\left[\frac{dn}{dT}\right]_c = -0.000185 / ^\circ C$ |                                                                          | $\sum = 10.0 \times 10^{-14} / (^\circ C)^2$                                                              |

The subscript represents the concentration of the solution under investigation.

#### 4.2.2.2 Determining standard deviation from the mean of the slopes

$$\sigma = \sqrt{\sum \left( \left[ \frac{dn}{dT} \right]_c - \left[ \overline{\frac{dn}{dT}} \right]_c \right)^2 \times \frac{1}{N(N-1)}}$$

Where  $\sigma$  is the standard deviation from the mean and N is the number of entries.

$$\sigma = \sqrt{\frac{10 \times 10^{-14}}{8 \times 7}}$$

$$\sigma = 4.23 \times 10^{-8} / ^\circ C$$

$$\sigma = \pm 0.0004 \times 10^{-4} / ^\circ C$$

Therefore the temperature coefficient of refractive index is:

$$\left[ \frac{dn}{dT} \right]_c = (-1.8500 \pm 0.0004) \times 10^{-4} / ^\circ C$$

Table 4.8 Results for concentration versus angle of rotation for white sugar

solutions: Sample 1

| Concentration (%) | Concentration (mol/dm <sup>3</sup> ) | Angle of rotation (°) |         |         |         |
|-------------------|--------------------------------------|-----------------------|---------|---------|---------|
|                   |                                      | 1                     | 2       | 3       | Average |
| 10                | 0.111                                | +7.38                 | +7.39   | +7.40   | +7.39   |
| 20                | 0.250                                | +16.63                | +16.63  | +16.64  | +16.63  |
| 30                | 0.429                                | +28.53                | +28.55  | +28.54  | +28.54  |
| 40                | 0.667                                | +44.32                | +44.33  | +44.33  | +44.33  |
| 50                | 1.000                                | +66.48                | +66.49  | +66.49  | +66.49  |
| 60                | 1.500                                | +99.67                | +99.68  | +99.68  | +99.68  |
| 70                | 2.333                                | +155.03               | +155.04 | +155.04 | +155.04 |
| 80                | 4.000                                | +265.81               | +265.82 | +265.83 | +265.82 |

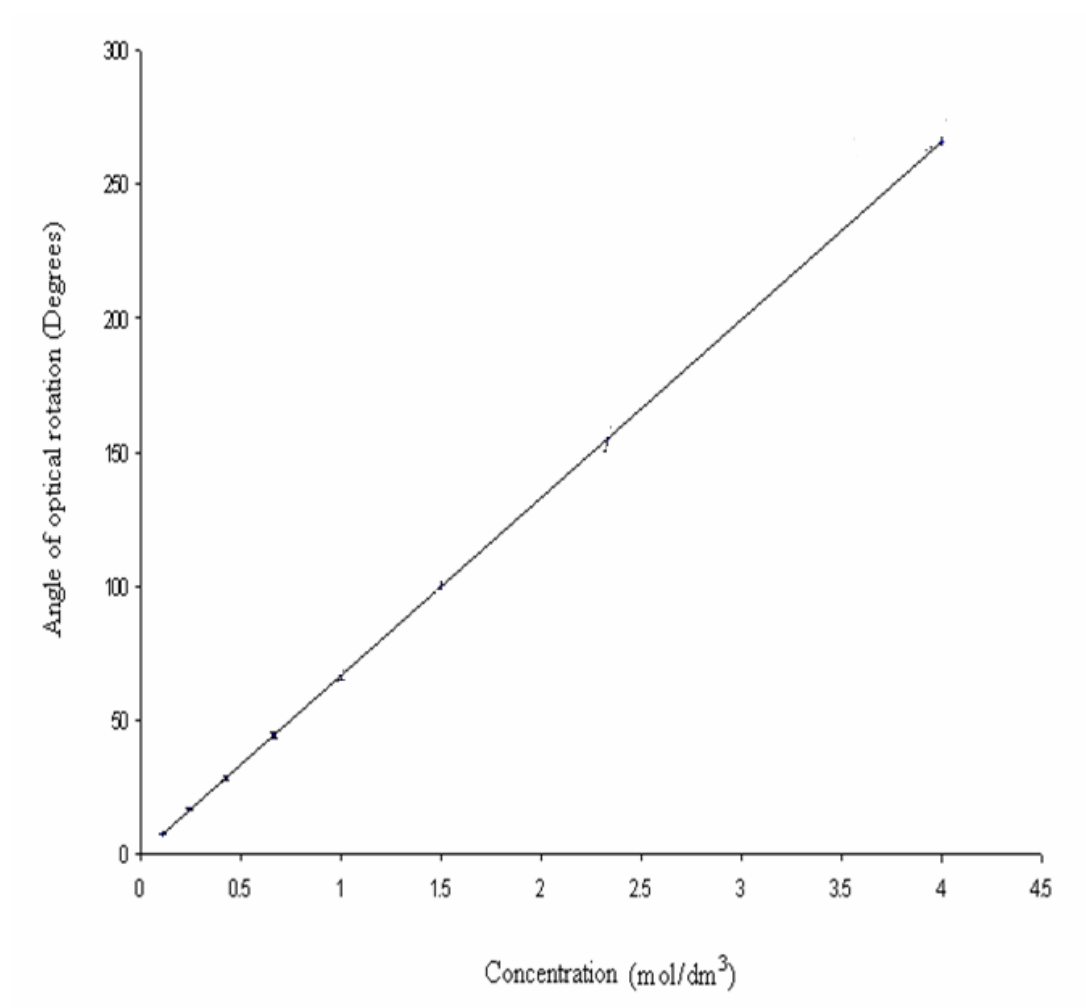


Figure 4.7: A graph of angle of optical rotation versus concentration for sample 1

The graph of angle of rotation against concentration is a straight line. Given a sugar solution with an unknown concentration, its optical angle of rotation can be determined experimentally and the graph either interpolated or extrapolated to determine the concentration of the sugar solution.

The gradient of the curve is:

$$\left[ \frac{d\alpha}{dc} \right] = 66.457^\circ \text{ dm}^2 / \text{ kg}$$

$$\text{But } [\alpha]_{\lambda}^T = \left[ \frac{d\alpha}{dc} \right]$$

Therefore the specific optical rotation of sugar (sucrose) solution: Sample 1 is:

$$[\alpha]_{589}^{20.5} = 66.45^\circ \text{ dm}^2 / \text{ kg}$$

Using equation (2.23) to effect the correction,

$$[\alpha]_{589}^{20^\circ} = \frac{66.457}{1 - 0.00037(20.5 - 20)}$$

$$[\alpha]_{589}^{20^\circ} = (66.47 \pm 0.03)^\circ \text{ dm}^2 / \text{ kg}$$

Table 4.9      Results for concentration versus angle of rotation for white sugar  
solutions: Sample 2

| Concentration (%) | Concentration (mol/dm <sup>3</sup> ) | Angle of rotation (°) |         |         |         |
|-------------------|--------------------------------------|-----------------------|---------|---------|---------|
|                   |                                      | 1                     | 2       | 3       | Average |
| 10                | 0.111                                | +7.45                 | +7.45   | +7.46   | +7.45   |
| 20                | 0.250                                | +16.70                | +16.70  | +16.71  | +16.70  |
| 30                | 0.429                                | +28.55                | +28.55  | +28.57  | +28.56  |
| 40                | 0.667                                | +44.38                | +44.38  | +44.39  | +44.38  |
| 50                | 1.000                                | +66.50                | +66.49  | +66.49  | +66.50  |
| 60                | 1.500                                | +99.75                | +99.76  | +99.75  | +99.75  |
| 70                | 2.333                                | +155.10               | +155.10 | +155.09 | +155.10 |
| 80                | 4.000                                | +265.85               | +265.86 | +265.87 | +265.86 |

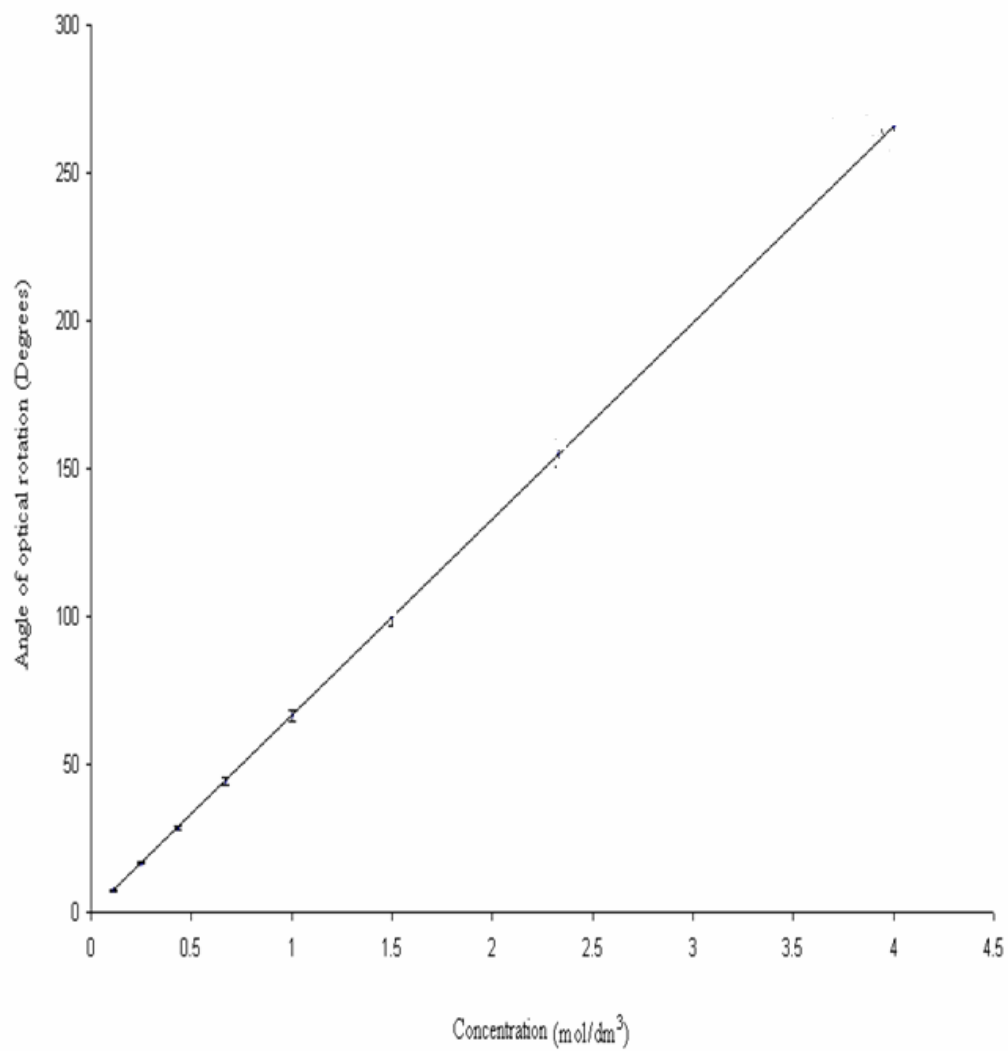


Figure 4.7: A graph of angle of optical rotation versus concentration for sample 2

The graph of angle against concentration is a straight line. Given a solution with an unknown concentration, its optical angle of rotation can be determined experimentally and the graph is either interpolated or extrapolated to determine its concentration.

The gradient of the curve is:

$$\left[ \frac{d\alpha}{dc} \right] = 66.476^\circ \text{ dm}^2 / \text{kg}$$

$$\text{But } [\alpha]_{\lambda}^T = \left[ \frac{d\alpha}{dc} \right]$$

Therefore the specific optical rotation of sugar (sucrose) solution: Sample 2 is:

$$[\alpha]_{589}^{20.5} = 66.476^\circ \text{ dm}^2 / \text{kg}$$

After effecting the correction:

$$[\alpha]_{589}^{20^\circ} = (66.49 \pm 0.02)^\circ \text{ dm}^2 / \text{kg}$$

### 4.2.3 Results from other substances

Table 4.10 Results of angle of minimum deviation for raw orange juice

| Sample | Angle of minimum deviation |       |       |         | Refractive index |
|--------|----------------------------|-------|-------|---------|------------------|
|        | 1                          | 2     | 3     | Average |                  |
| 1      | 25.75                      | 26.00 | 26.08 | 25.94   | 1.363            |
| 2      | 26.33                      | 25.08 | 25.00 | 25.47   | 1.357            |
| 3      | 24.25                      | 25.17 | 24.25 | 24.56   | 1.358            |
| 4      | 25.20                      | 25.35 | 25.50 | 25.35   | 1.356            |
| 5      | 25.50                      | 25.55 | 25.57 | 25.54   | 1.358            |
| 6      | 25.62                      | 25.60 | 25.53 | 25.58   | 1.359            |
| 7      | 26.00                      | 26.02 | 26.03 | 26.02   | 1.364            |
| 8      | 25.50                      | 25.58 | 25.60 | 25.56   | 1.358            |
| 9      | 25.43                      | 25.47 | 25.50 | 25.47   | 1.357            |
| 10     | 26.00                      | 25.67 | 25.75 | 25.81   | 1.362            |

Table 4.11 Results of refractive indices for raw orange juice

| Refractive index, $n$ | $(n - \bar{n})$ | $(n - \bar{n})^2 \times 10^{-5}$ |
|-----------------------|-----------------|----------------------------------|
| 1.363                 | 0.004           | 1.60                             |
| 1.357                 | -0.002          | 0.40                             |
| 1.358                 | -0.001          | 0.10                             |
| 1.356                 | -0.003          | 0.90                             |
| 1.358                 | -0.001          | 0.10                             |
| 1.359                 | 0               | 0                                |
| 1.364                 | 0.005           | 2.50                             |
| 1.358                 | -0.001          | 0.10                             |
| 1.357                 | -0.002          | 0.40                             |
| 1.362                 | 0.003           | 0.90                             |
| $\bar{n} = 1.359$     |                 | $\sum = 7.0 \times 10^{-5}$      |

#### 4.2.3.1 Determination of standard deviation and concentration of raw orange juice

$$\sigma = \sqrt{\frac{7.0 \times 10^{-5}}{10 \times 9}}$$

$$\sigma = \pm 0.001$$

Therefore the refractive index of orange juice is:

$$n = (1.359 \pm 0.001)$$

Using the equation of a straight line on figure 4.1:

$$n = 0.002c + 1.33$$

Where  $n$  is the refractive index and  $c$  is the concentration.

Substituting for the refractive index of orange juice, the concentration of sugar in orange juice is found to be:

$$c = (14.5 \pm 0.5)\%$$

Table 4.12 Results of angle of minimum deviation for raw apple juice

| Sample | Angle of minimum deviation |       |       |         | Refractive index |
|--------|----------------------------|-------|-------|---------|------------------|
|        | 1                          | 2     | 3     | Average |                  |
| 1      | 25.42                      | 25.40 | 25.42 | 25.41   | 1.356            |
| 2      | 25.50                      | 25.52 | 25.55 | 25.52   | 1.358            |
| 3      | 25.60                      | 25.62 | 25.62 | 25.61   | 1.359            |
| 4      | 25.43                      | 25.45 | 25.48 | 25.45   | 1.357            |
| 5      | 26.02                      | 26.00 | 26.03 | 26.02   | 1.364            |
| 6      | 25.52                      | 25.55 | 25.00 | 25.36   | 1.356            |
| 7      | 25.58                      | 25.62 | 25.68 | 25.63   | 1.359            |
| 8      | 25.35                      | 25.38 | 25.50 | 25.41   | 1.356            |
| 9      | 25.63                      | 25.72 | 25.55 | 25.63   | 1.359            |
| 10     | 25.83                      | 25.80 | 25.88 | 25.84   | 1.362            |

Table 4.13 Results of refractive indices for raw apple juice

| Refractive index, n | $(n - \bar{n})$ | $(n - \bar{n})^2 \times 10^{-5}$ |
|---------------------|-----------------|----------------------------------|
| 1.356               | -0.003          | 0.90                             |
| 1.358               | -0.001          | 0.10                             |
| 1.359               | 0               | 0                                |
| 1.357               | -0.002          | 0.40                             |
| 1.364               | 0.005           | 2.50                             |
| 1.356               | -0.003          | 0.90                             |
| 1.359               | 0               | 0                                |
| 1.356               | -0.003          | 0.90                             |
| 1.359               | 0               | 0                                |
| 1.362               | 0.003           | 0.90                             |
| $\bar{n} = 1.359$   |                 | $\sum = 6.6 \times 10^{-5}$      |

#### 4.2.3.2 Determination of standard deviation and concentration of apple juice

$$\sigma = \sqrt{\frac{6.6 \times 10^{-5}}{10 \times 9}}$$

$$\sigma = \pm 0.001$$

Therefore the refractive index of apple juice is:

$$n = (1.359 \pm 0.001)$$

Using the equation of a straight line on figure 4.1:

$$n = 0.002c + 1.33$$

Where  $n$  is the refractive index and  $c$  is the concentration.

Substituting for the refractive index of apple juice, the concentration of sugar in apple juice is found to be:

$$c = (14.5 \pm 0.5)\%$$

Table 4.14 Results of refractive index in salt and sugar solution and black tea

| Substance  |                     | Angle of minimum deviation |       |       |         | Refractive index |
|------------|---------------------|----------------------------|-------|-------|---------|------------------|
|            |                     | 1                          | 2     | 3     | Average |                  |
| Oral water | With only sugar     | 24.50                      | 24.52 | 24.50 | 24.51   | 1.345            |
|            | With salt and sugar | 25.33                      | 25.37 | 25.32 | 25.34   | 1.356            |
| Black tea  |                     | 26.33                      | 26.34 | 26.30 | 26.32   | 1.368            |

#### Note

The oral water was made of 750 ml of water, 6 level teaspoons (60 g) of white sugar and half teaspoon (2.7 g) of table salt.

Black tea was made of 245 ml of water and 6 teaspoons (62 g) of white sugar.

#### 4.2.3.3 Calculations of concentration of sugar

The concentration of sugar from the actual values used in making the salt and sugar solution is 7.2%

Using equation of straight in figure 4.1 to calculate the concentration of sugar using the refractive index value:

$$n = 0.002c + 1.33$$

$$c = \frac{1.345 - 1.330}{0.002}$$

$$c = 7.5\%$$

The concentration of sugar in black tea is:

$$c = 22.8\%$$

Using equation of straight in figure 4.1 to calculate the concentration of sugar using the refractive index value:

$$n = 0.002c + 1.33$$

$$c = \frac{1.368 - 1.330}{0.002}$$

$$c = 19.0\%$$

Table 4.15 Results of refractive indices of salt and sugar solutions

| Substance    | Concentration (%) | Angle of deviation |       |       |         | Refractive index |
|--------------|-------------------|--------------------|-------|-------|---------|------------------|
|              |                   | 1                  | 2     | 3     | Average |                  |
| Sugar        | 10                | 24.59              | 24.57 | 24.59 | 24.58   | 1.346            |
| Salt         | 10                | 24.90              | 24.91 | 24.90 | 24.90   | 1.350            |
| Salt + sugar | 10                | 28.85              | 28.84 | 28.85 | 28.85   | 1.400            |

Salt increases the refractive index of sugar solution.

Table 4.16 Results of angle of optical rotation of salt and sugar solutions

| Substance   | Concentration (%) | Angle of rotation(Degrees) |       |       |         |
|-------------|-------------------|----------------------------|-------|-------|---------|
|             |                   | 1                          | 2     | 3     | Average |
| Sugar       | 10                | +7.45                      | +7.45 | +7.46 | +7.45   |
| Salt        | 10                | 0                          | 0     | 0     | 0       |
| Salt +sugar | 10                | +5.63                      | +5.65 | +5.64 | +5.64   |

Salt reduces the dextrous behaviour of sugar.

Table 4.17 Results of angle of minimum deviation for raw sugar cane juice

| Sample | Angle of minimum deviation |       |       |         | Refractive index |
|--------|----------------------------|-------|-------|---------|------------------|
|        | 1                          | 2     | 3     | Average |                  |
| 1      | 25.38                      | 25.37 | 25.39 | 25.38   | 1.356            |
| 2      | 25.61                      | 25.62 | 25.59 | 25.61   | 1.359            |
| 3      | 25.36                      | 25.37 | 25.35 | 25.36   | 1.356            |
| 4      | 25.47                      | 25.47 | 25.48 | 25.47   | 1.357            |
| 5      | 25.30                      | 25.31 | 25.33 | 25.31   | 1.355            |
| 6      | 25.43                      | 25.44 | 25.41 | 25.43   | 1.357            |
| 7      | 25.29                      | 25.30 | 25.28 | 25.29   | 1.355            |
| 8      | 25.26                      | 25.27 | 25.29 | 25.27   | 1.355            |
| 9      | 25.42                      | 25.39 | 25.37 | 25.39   | 1.356            |
| 10     | 25.35                      | 25.34 | 25.33 | 25.34   | 1.356            |

Table 4.18 Results of refractive indices for raw sugar cane juice

| Refractive index, n | $(n - \bar{n})$ | $(n - \bar{n})^2 \times 10^{-5}$ |
|---------------------|-----------------|----------------------------------|
| 1.356               | 0               | 0                                |
| 1.359               | 0.003           | 0.90                             |
| 1.356               | 0               | 0                                |
| 1.357               | 0.001           | 0.10                             |
| 1.355               | -0.001          | 0.10                             |
| 1.357               | 0.001           | 0.10                             |
| 1.355               | -0.001          | 0.10                             |
| 1.355               | -0.001          | 0.10                             |
| 1.356               | 0               | 0                                |
| 1.356               | 0               | 0                                |
| $\bar{n} = 1.356$   |                 | $\sum = 1.4 \times 10^{-5}$      |

#### 4.2.3.4 Determination of standard deviation and concentration of raw sugar cane juice

$$\sigma = \sqrt{\frac{1.4 \times 10^{-5}}{10 \times 9}}$$

$$\sigma = \pm 0.0004$$

Therefore the refractive index of sugar cane juice is:

$$n = (1.356 \pm 0.0004)$$

Using the equation of a straight line on figure 4.1:

$$n = 0.002c + 1.33$$

Where  $n$  is the refractive index and  $c$  is the concentration.

Substituting for the refractive index of sugar cane juice, the concentration of sugar in sugar cane juice is found to be:

$$c = (13.0 \pm 0.4)\%$$

Table 4.19 Results of angle of rotation for orange juice

| Sample | Angle of rotation, $\alpha$ |       |       |         |
|--------|-----------------------------|-------|-------|---------|
|        | 1                           | 2     | 3     | Average |
| 1      | 15.10                       | 15.13 | 15.12 | 15.12   |
| 2      | 14.97                       | 14.98 | 14.96 | 14.97   |
| 3      | 14.92                       | 14.93 | 14.95 | 14.93   |
| 4      | 15.01                       | 15.05 | 15.07 | 15.04   |
| 5      | 15.19                       | 15.21 | 15.21 | 15.20   |
| 6      | 15.13                       | 15.15 | 15.16 | 15.15   |
| 7      | 15.00                       | 14.99 | 14.97 | 14.98   |
| 8      | 14.93                       | 14.94 | 14.91 | 14.93   |
| 9      | 14.96                       | 14.93 | 14.94 | 14.94   |
| 10     | 15.01                       | 15.02 | 14.99 | 15.01   |

Table 4.20 Results of deviation from the mean for orange juice

| Angle of rotation, $\alpha$<br>(Degrees) | $(\alpha - \bar{\alpha})^\circ$ | $(\alpha - \bar{\alpha})^2 \times 10^{-3}$<br>(Degrees) <sup>2</sup> |
|------------------------------------------|---------------------------------|----------------------------------------------------------------------|
| 15.12                                    | 0.093                           | 8.649                                                                |
| 14.97                                    | -0.057                          | 3.249                                                                |
| 14.93                                    | -0.097                          | 9.409                                                                |
| 15.04                                    | 0.013                           | 0.169                                                                |
| 15.20                                    | 0.173                           | 29.929                                                               |
| 15.15                                    | 0.123                           | 15.129                                                               |
| 14.98                                    | -0.047                          | 2.209                                                                |
| 14.93                                    | -0.097                          | 9.409                                                                |
| 14.94                                    | -0.087                          | 7.569                                                                |
| 15.01                                    | -0.017                          | 0.289                                                                |
| $\bar{\alpha} = 15.027^\circ$            |                                 | $\sum = 86.01 \times 10^{-3}$<br>(Degrees) <sup>2</sup>              |

#### 4.2.3.5 Determination of standard deviation and concentration of orange juice

$$\sigma = \sqrt{\frac{86.01 \times 10^{-3}}{10 \times 9}}$$

$$\sigma = \pm 0.03^\circ$$

Therefore the angle of rotation for orange juice is:

$$(\alpha = 15.03 \pm 0.03)^\circ$$

Using equation of a straight line on Figure 4.7:

$$\alpha = 66.449c + 0.0199$$

The concentration of sugar in orange juice is:

$$(c = 0.23 \pm 0.02) \text{ mol} / \text{dm}^3$$

This is equivalent to about 13 % to 15 % concentration.

Table 4.21 Results of angle of rotation for apple juice

| Sample | Angle of rotation, $\alpha$ |       |       |         |
|--------|-----------------------------|-------|-------|---------|
|        | 1                           | 2     | 3     | Average |
| 1      | 14.88                       | 14.86 | 14.85 | 14.86   |
| 2      | 14.93                       | 14.90 | 14.91 | 14.91   |
| 3      | 14.79                       | 14.80 | 14.78 | 14.79   |
| 4      | 15.01                       | 15.00 | 14.99 | 15.00   |
| 5      | 14.67                       | 14.72 | 14.69 | 14.69   |
| 6      | 14.86                       | 14.85 | 14.87 | 14.86   |
| 7      | 14.96                       | 14.94 | 14.93 | 14.94   |
| 8      | 14.90                       | 14.93 | 14.91 | 14.92   |
| 9      | 14.92                       | 14.93 | 14.92 | 14.92   |
| 10     | 14.91                       | 14.90 | 14.92 | 14.91   |

Table 4.22 Results of deviation from the mean for raw apple juice

| Angle of rotation, $\alpha$<br>(Degrees) | $(\alpha - \bar{\alpha})^\circ$ | $(\alpha - \bar{\alpha})^2 \times 10^{-3}$<br>(Degrees) <sup>2</sup> |
|------------------------------------------|---------------------------------|----------------------------------------------------------------------|
| 14.86                                    | -0.02                           | 0.40                                                                 |
| 14.91                                    | 0.03                            | 0.90                                                                 |
| 14.79                                    | -0.09                           | 8.10                                                                 |
| 15.00                                    | 0.12                            | 14.40                                                                |
| 14.69                                    | -0.19                           | 36.10                                                                |
| 14.86                                    | -0.02                           | 0.40                                                                 |
| 14.94                                    | 0.06                            | 3.60                                                                 |
| 14.92                                    | 0.04                            | 1.60                                                                 |
| 14.92                                    | 0.04                            | 1.60                                                                 |
| 14.91                                    | 0.03                            | 0.90                                                                 |
| $\bar{\alpha} = 14.88^\circ$             |                                 | $\sum = 68.0 \times 10^{-3}$<br>(Degrees) <sup>2</sup>               |

#### 4.2.3.6 Determination of standard deviation and concentration of apple juice

$$\sigma = \sqrt{\frac{68.0 \times 10^{-3}}{10 \times 9}}$$

$$\sigma = \pm 0.03^\circ$$

Therefore the angle of rotation for apple juice is:

$$(\alpha = 14.88 \pm 0.03)^\circ$$

Using equation of a straight line on Figure 4.7:

$$\alpha = 66.449c + 0.0199$$

The concentration of sugar in apple juice is:

$$(c = 0.22 \pm 0.02) \text{ mol} / \text{dm}^3$$

This is equivalent to about 13 % to 15 % concentration.

Table 4.23 Results of angle of rotation for raw sugar cane juice

| Sample | Angle of rotation, $\alpha$ |       |       |         |
|--------|-----------------------------|-------|-------|---------|
|        | 1                           | 2     | 3     | Average |
| 1      | 14.92                       | 14.93 | 14.93 | 14.93   |
| 2      | 14.91                       | 14.93 | 14.92 | 14.92   |
| 3      | 14.90                       | 14.94 | 14.93 | 14.92   |
| 4      | 14.89                       | 14.91 | 14.90 | 14.90   |
| 5      | 14.91                       | 14.91 | 14.93 | 14.92   |
| 6      | 14.93                       | 14.92 | 14.94 | 14.93   |
| 7      | 14.90                       | 14.91 | 14.89 | 14.90   |
| 8      | 14.92                       | 14.92 | 14.93 | 14.92   |
| 9      | 14.88                       | 14.89 | 14.87 | 14.88   |
| 10     | 14.94                       | 14.91 | 14.90 | 14.93   |

Table 4.24 Results of deviation from the mean for raw sugar cane juice

| Angle of rotation, $\alpha$<br>(Degrees) | $(\alpha - \bar{\alpha})^\circ$ | $(\alpha - \bar{\alpha})^2 \times 10^{-3}$<br>(Degrees) <sup>2</sup> |
|------------------------------------------|---------------------------------|----------------------------------------------------------------------|
| 14.93                                    | 0.015                           | 0.225                                                                |
| 14.92                                    | 0.005                           | 0.025                                                                |
| 14.92                                    | 0.005                           | 0.025                                                                |
| 14.90                                    | -0.015                          | 0.225                                                                |
| 14.92                                    | 0.005                           | 0.025                                                                |
| 14.93                                    | 0.015                           | 0.225                                                                |
| 14.90                                    | -0.015                          | 0.225                                                                |
| 14.92                                    | 0.005                           | 0.025                                                                |
| 14.88                                    | -0.035                          | 1.225                                                                |
| 14.93                                    | 0.015                           | 0.225                                                                |
| $\bar{\alpha} = 14.915^\circ$            |                                 | $\sum = 2.45 \times 10^{-3}$<br>(Degrees) <sup>2</sup>               |

#### 4.2.3.7 Determination of standard deviation and concentration of raw sugar cane juice

$$\sigma = \sqrt{\frac{2.45 \times 10^{-3}}{10 \times 9}}$$

$$\sigma = \pm 0.005^\circ$$

Therefore the angle of rotation for sugar cane juice is:

$$(\alpha = 14.915 \pm 0.005)^\circ$$

Using equation of a straight line on Figure 4.7:

$$\alpha = 66.449c + 0.0199$$

The concentration of sugar in sugar cane juice is:

$$(c = 0.224 \pm 0.009) \text{ mol} / \text{dm}^3$$

This is equivalent to about 13 % to 15 % concentration.

### 4.3 Conclusion

This chapter dealt with data presentation and analysis. The next chapter will talk about the discussion of results.

## CHAPTER 5 DISCUSSION OF RESULTS

### 5.1 Introduction

This chapter will talk about the discussion of results presented in chapter 4.

### 5.2 Refractive index

Figures 4.1, 4.2 and 4.3 show that refractive index and concentration are linearly related with a positive correlation. This is supported by literature.<sup>4,6,8,16</sup>

The experimental value of the concentration coefficient of refractive index is  $(1.7690 \pm 0.0004) \times 10^{-3}$ .

Figure 4.4 shows that white sugar (sucrose) is more refined than brown sugar (sucrose). In the refining of brown sugar to white sugar, the optical rotation or refractive index of sucrose is monitored until the required concentration is reached. This should be maintained at temperatures between 20 °C and 25 °C. Brown sugar has a refractive index of 1.47 before being refined to white sugar.<sup>6,15,22</sup>

Table 5.1 Values of refractive indices of sugar solution ( $\lambda = 589nm$ )

| Concentration (%) | Theoretical Refractive index <sup>21</sup> | Experimental refractive index |
|-------------------|--------------------------------------------|-------------------------------|
| 0                 | 1.33                                       | 1.33                          |
| 10                | 1.35                                       | 1.35                          |
| 30                | 1.38                                       | 1.39                          |
| 80                | 1.49                                       | 1.49                          |

Table 5.1 shows that the experimental results are comparable to the theoretical results.

The graphs in figure 4.6 show that the refractive index and temperature are linear with a negative correlation as suggested by the theory.<sup>1,6,8,17</sup>

The value of the experimental temperature coefficient of refractive index of sucrose

solution was  $\left[ \frac{dn}{dT} \right]_c = (-1.8500 \pm 0.0004) \times 10^{-4} / ^\circ C$ .

The values found by other researchers range from  $-1.850 \times 10^{-4} / ^\circ C$  to  $-1.860 \times 10^{-4} / ^\circ C$  depending on the equipment used.<sup>16,22</sup>

The value of the experimental temperature coefficient of refractive index lies within the range of values determined by other researchers.

The concentration of sugar in orange juice using the refractive index method is  $c = (14.5 \pm 0.5)\%$ .

The concentration of sugar in apple juice using the refractive index method is  $c = (14.5 \pm 0.5)\%$ .

Table 5.2 Results of concentration of sugar in oral water and black tea

| Substance  | Calculated concentration % | Experimental concentration % |
|------------|----------------------------|------------------------------|
| Oral water | 7.2                        | 7.5                          |
| Black tea  | 22.8                       | 19.0                         |

Table 5.2 shows that the calculated and experimental values of the concentrations of oral water are a bit different. This could have been affected by some experimental errors such as the amount of sugar and salt used. Maybe salt and sugar will help in the absorption and scattering of light and hence the results will divert a bit.

The experimental and calculated values for black tea are different. This could have been as a result of the effect of tea on the passage of light.

Table 5.3 Refractive indices and concentration from other substances

| Substance            | Refractive index | Concentration % |
|----------------------|------------------|-----------------|
| Orange juice         | 1.359            | 14.5            |
| Apple juice          | 1.359            | 14.5            |
| Raw sugar cane juice | 1.356            | 13.0            |

The values of the refractive indices and concentrations of fruit juices shown in Table 5.3 are not exact. This might be as a result of the difference in concentrations of other substance such as citric acid. Generally these values are indicative of the refractive indices of fruit juices and the amount of sugar in fruit juices.

### 5.3 Polarimetry

White sugar (sucrose) is dextrorotatory. It rotates the plane of polarisation of light to the right (clockwise). This is evidenced by the positive angles determined during the experiments as shown in Tables 4.8 and 4.9.

Sample 1 had a rotatory power of  $[\alpha]_{589}^{20} = (66.47 \pm 0.03)^{\circ} \text{ dm}^2 / \text{ kg} .$

Sample 2 had a rotatory power of  $[\alpha]_{589}^{20} = (66.49 \pm 0.02)^{\circ} \text{ dm}^2 / \text{ kg} .$

The samples yielded the specific optical rotations that are the same to 2 decimal places.

The theoretical value of the optical rotatory power of sucrose is  $66.50^{\circ} \text{ m}^2 / \text{ kg} .^{8,11,17}$

Table 5.4 Polarimetry results of other substances

| Substance            | Angle of rotation<br>(Degrees) | Concentration<br>mol/dm <sup>3</sup> |
|----------------------|--------------------------------|--------------------------------------|
| Orange juice         | 15.03                          | 0.230                                |
| Apple juice          | 14.88                          | 0.220                                |
| Raw sugar cane juice | 14.92                          | 0.224                                |

Orange juice, apple juice and raw sugar cane juice are dextrous, that is they rotate the plane of polarisation of light to the right (clockwise). Generally the values are indicative of the optical angle of rotation of fruit juices and the amount of sugar in fruit juices.

## CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

The experimental values of the refractive indices of water and sugar solutions were the same as the expected values with an error of ( $\pm 0.001$ ) as shown in Table 5.1. Therefore the method can be used to determine the refractive indices of solutions accurately.

The value of the temperature coefficient of refractive index of sucrose found agrees with other researchers.<sup>16,22</sup> Therefore this method can be used to determine the concentration of sugar solutions with accuracy with an error of ( $\pm 0.0004$ )/ $^{\circ}\text{C}$ .

The values of the specific optical rotation of sucrose lie within the expected values found by other researchers with an error of ( $\pm 0.03$ ) $^{\circ}\text{dm}^2/\text{kg}$ . Therefore this method can be used to determine the concentration of sugar solutions accurately.

The concentration of sugar in oranges and apples is the same. This might not be the exact concentration as there are other substances e.g. citric acid which might affect the value of the refractive index determined.

Sugar solution is optically active and dextrous because it rotates the plane of polarisation of light in a clockwise direction.

Salt increases the refractive index of sugar solution and reduces the dextrous behaviour of sugar.

Salt is not optically active because it does not have optical isomers. Therefore it does not rotate the plane of polarisation of light.

The calculated and experimental values of concentration for oral water have a difference of 0.3%.

The calculated and experimental values of concentration for black tea have a difference of 3.8%.

The concentration of orange juice, apple juice and raw sugar cane juice are almost the same. Therefore the amount of sugar in sweet fruits is almost similar.

The orange juice, apple juice and raw sugar cane juice are dextrous (They rotate the plane of polarisation of light in a clockwise direction).

The methods of refractive index data and determining the optical angle produce the same results. Therefore both methods can be used to determine the concentration of sugar in fluids accurately.

## **6.2 Recommendations**

The project was done in a short space of time and not many results were taken. This project needs to be done for at least six months in order to come out with a more accurate analysis. There are also certain factors that affect the concentration of sugar e.g. pH. The sugar samples need also to be subjected to different pH and then their concentrations be monitored.

Optical rotation should also be monitored at specific time intervals, e.g. hourly, daily and so forth in order to determine how fast sugar can be purified at certain conditions.

The effect of temperature on the refractive index should also be done more accurately and should be monitored from very low temperatures such as freezing point of water up to the boiling point of water.

The construction of the prisms should be done by experts and should be very precise in order to get accurate results.

Experiments need to be done in order to see the effects of substances like citric acid on the refractive index and optical angle of rotation of fruit juices. These were not done because of time constraints and lack of necessary equipment.

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## APPENDICES

### Appendix 1: Refractive indices of various materials

Table 1.1 Values of refractive indices of different materials<sup>22</sup>

| Material                 | Refractive index |
|--------------------------|------------------|
| Vacuum                   | 1.00000          |
| Air at STP               | 1.00029          |
| Ice                      | 1.31             |
| Water at 20 C            | 1.33             |
| Acetone                  | 1.36             |
| Ethyl alcohol            | 1.36             |
| Sugar solution(30%)      | 1.38             |
| Fluorite                 | 1.433            |
| Fused quartz             | 1.46             |
| Glycerine                | 1.473            |
| Sugar solution (80%)     | 1.49             |
| Typical crown glass      | 1.52             |
| Crown glasses            | 1.52-1.62        |
| Spectacle crown, C-1     | 1.523            |
| Sodium chloride          | 1.54             |
| Polystyrene              | 1.55-1.59        |
| Carbon disulfide         | 1.63             |
| Flint glasses            | 1.57-1.75        |
| Heavy flint glass        | 1.65             |
| Extra dense flint, EDF-3 | 1.7200           |
| Methylene iodide         | 1.74             |
| Sapphire                 | 1.77             |
| Rare earth flint         | 1.7-1.84         |
| Lanthanum flint          | 1.82-1.98        |
| Arsenic trisulfide glass | 2.04             |
| Diamond                  | 2.417            |

## **Appendix 2: Temperature Coefficient of Refractive Index**

A liquid's temperature coefficient of refractive index can be expressed as the change in refractive index per °C  $\left(\frac{dn}{dT}\right)$ . It is always negative so that as temperature increases, refractive index decreases. Liquid temperature coefficients are usually so much higher than for solids that the user must know the temperature of a liquid to know its refractive index. With solids, temperature is less critical. It is sometimes advantageous to adjust the refractive index of a liquid by adjusting the temperature. Optical liquids with refractive indices less than 1.63 tend to have temperature coefficients  $\left(\frac{dn}{dT}\right)$  of -0.0003 to -0.0004. Temperature coefficients for liquids with refractive indices above 1.63 and up to 1.70 tend to be about -0.0005.

### Appendix 3: Specific rotation (degrees) at 20 °C

#### A Solution in Polarized Light

Specific Rotation of Aqueous Sucrose at 20°C [3]

| Wavelength<br>(nm) | Color        | Concentration (moles sucrose/liter of solution) |                |                |
|--------------------|--------------|-------------------------------------------------|----------------|----------------|
|                    |              | $\frac{1}{8}$                                   | $\frac{1}{16}$ | $\frac{1}{32}$ |
|                    |              | Specific rotation, $[\alpha]_D^{20}$            |                |                |
| 656                | red          | 53.18                                           | 53.22          | 53.48          |
| 589                | orange       | 66.50                                           | 66.71          | 66.81          |
| 535                | yellow       | 82.25                                           | 82.76          | 82.93          |
| 508                | yellow-green | 91.53                                           | 91.79          | 92.59          |
| 479                | green        | 104.24                                          | 104.67         | 105.42         |
| 447                | blue         | 121.63                                          | 122.80         | 123.80         |

#### Appendix 4: Derivation of Snell's law

Snell's law may be derived from Fermat's principle, which states that when a light wave is emitted from a point source in an inhomogeneous medium, it will choose the route that takes the minimum time.<sup>10</sup>

Suppose we have an optical path from A to B, then:

$$\overline{AB} = \int_A^B n(s) ds \quad (A1)$$

Where  $n(s)$  is the refractive index at a point, a distance  $s$ , along the route.

Time,  $T$ , taken for light to travel from A to B is then given by:

$$T = \frac{\overline{AB}}{c} \quad (A2)$$

Where  $c$  is the speed of light in the vacuum.

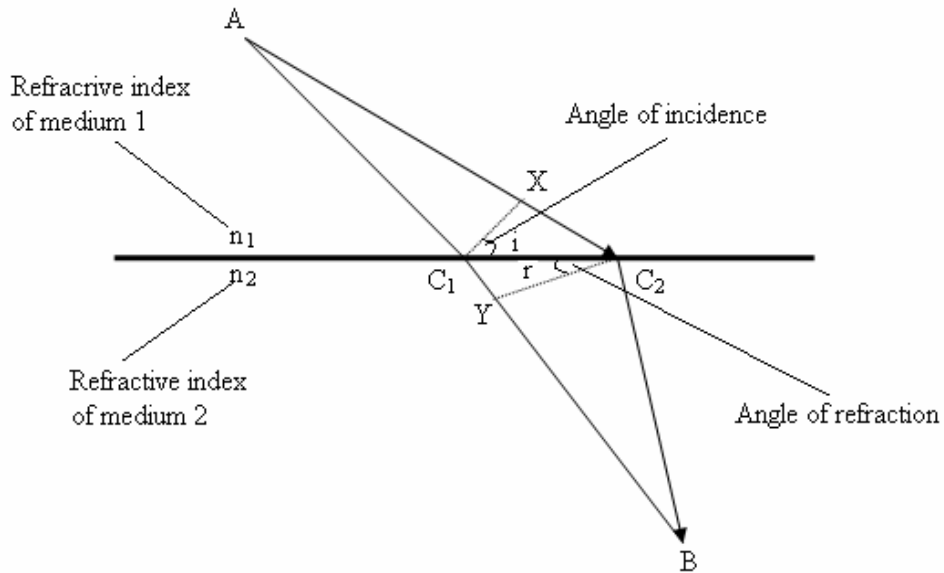


Figure A.1 A diagram to show the derivation of Snell's law

Two neighbouring routes from A to B pass through  $C_1$  and  $C_2$  where  $C_1C_2 = d$  and  $d$  is the path difference.

Then the difference in optical path between the two is:

$$\Pi = E \times H \quad (A3)$$

Where  $d = AC_1BC_1$

But  $n_1XC_2 - n_2YC_1 = 0$  indicating minima or maxima optical path  $\overline{AB}$ .

Then  $n_1d \sin i = n_2d \sin r$  and,

$$n_1 \sin i = n_2 \sin r \quad (A4)$$

Equation (4) is called the Snell's law.

Alternatively, Snell's law can be derived using interference of all possible paths of light wave from source to observer. It results in destructive interference everywhere except extrema of phase (where interference is constructive), which become actual paths.

Another way to derive Snell's Law involves an application of the general boundary conditions of Maxwell equations for electromagnetic radiation.

## Appendix 5: Effects of the liquid medium on light passing through it

When a beam of light passes through a matter in a liquid, its propagation is affected in two important ways. Intensity will always decrease as light penetrates further into the medium and the velocity of light will be less in the medium than in free space. Loss of intensity is chiefly due to absorption although scattering may play an important role.

A substance is said to show general absorption if it reduces the intensity of all wavelengths of light by nearly the same amount. If it absorbs certain wavelengths of light preferentially, then it is said to be a selective absorber.<sup>7</sup>

### A5.1 Absorption coefficient ( $\alpha$ )

It is the measure of rate of loss of light from direct beam.<sup>21</sup>

$$I = I_0 e^{-\alpha l} \quad (\text{A5})$$

Where  $I$  is the intensity of emerging beam,  $I_0$  is the light intensity entering the medium and  $l$  is the length of the column (distance moved by light).

$$\alpha = 2k_o n k \quad (\text{A6})$$

Where  $k_o = \omega/c$  is the free space wave number,  $k$  is the attenuation index of the medium and  $n$  is the refractive index of the medium.

If  $\alpha$  is not constant but varies with position,  $r$ , then,

$$I = I_0 \exp \left( - \int_a^b \alpha(r) dl \right) \quad (\text{A7})$$

Where  $a$  and  $b$  are the ends of the column.

Equation A7 is often called the Beer's law.

If both absorption and scattering are taking place, equation A5 can be written as,

$$I = I_0 e^{-(\alpha_a + \alpha_s)l} \quad (\text{A8})$$

Where  $\alpha_a$  and  $\alpha_s$  are absorption and scattering coefficients respectively.

### A5.2 Beer-Lambert law

The law states that there is a logarithmic dependence between the transmission (or transmissivity),  $T$  of light through a substance and the product of the absorption coefficient of the substance,  $\alpha$  and the distance the light travels through the material,  $l$ . The absorption coefficient can, in turn, be written as a product of either a molar absorptivity of the absorber,  $\varepsilon$  and the concentration of absorbing species in the material,  $c$ .

For liquids,

$$T = \frac{I}{I_o} = 10^{-\alpha l} \quad (\text{A9})$$

But  $\alpha = \varepsilon c$

$$\text{Therefore } T = 10^{-\varepsilon l c} \quad (\text{A10})$$

The transmission (or transmissivity) is expressed in terms of an absorbance,  $A$ , and is defined as,

$$A = -\log_{10} \left( \frac{I}{I_o} \right) \quad (\text{A11})$$

Equating (A9) and (A11) produces,

$$A = \varepsilon l c = \alpha l \quad (\text{A12})$$

This shows that absorbance is linear with concentration.