DETERMINATION OF REAL RACTIVE INDEX OF SODIUM CHLORIDE SOLUTION USING MICHELSON INTERFEROMETR TECHNIQUE.

BY

Shiferaw Gurmu Geleta

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Acronyms

MI –Michelson interferometer

BS –Beam splitter

WHO –World health organization

BP –Blood pressure

LASER –Light Amplification by stimulated Emission of Radiation

EMR –Electromagnetic radiation

Symbols

C –Samples

t-Thickness of the sample holder

T –Temperature

N –number of fringes

n-Refractive index

λ –wave length

F –Lorentz force

V –velocity

e-Charge of electron

S –screen

B –magnetic field

E –Electric field

M1 –Mirror one

M2 –Mirror two

Abstract

In this research, the refractive index of sodium chloride solution was determined using a Michelson interfermetric technique. In this experiment three lasers of wave length 532nm, 633nm and 650nm were used. Sodium chloride solution was used as sample and the solutions were prepared in mass fraction (m/m). The calculated refractive index of NaCl solutions were found to vary with concentration, temperature and wavelength. The refractive index increases as the concentration of sodium chloride solution increases. Also the temperature dependent of refractive index of the sodium chloride solution were determined; and the result indicates that, as the temperature increases the refractive index of the solutions decrease. In addition, the wavelength dependent of refractive index of the solution was determined; and the result indicates that the refractive index of sodium chloride solution decrease exponentially as the wavelength of light increases Thus,the developed method can be used as an alternative method to check quality of transparent liquid solution.

1. INTRODUCTION

1. 1 Back ground of the study

The optical properties of a medium often manage the interaction of electromagnetic waves incident onto it. Thus an electromagnetic wave starts an interaction with electron in a medium, when the wave is allowed to propagate through it .The electric field associated with the wave causing them to vibrate and this forced oscillations of the electrons in the medium start radiating light by offering secondary sources of radiation. However the speed of new wave changes according to the optical properties of the medium and it is always smaller than the speed of light in vacuum .All materials are characterized by their ability to slow down the waves, classified as optical refractive index [1]. Refractive index is one of the most important physical properties of solutions. By measuring the refractive index of a solution, one can determine the composition of the solution [2].The refractive index of a substance describes an important part of its interaction with electromagnetic radiation. The refractive index is a basic optical property of materials and its accurate measurement is often needed in many branches of physics and chemistry and it has several applications to many industries and materials. It is measured for many reasons. It is clearly important to know the refractive index of materials used for their clarity, such as glasses and solid plastics. In complex fluids such as drinks or foods, the refractive index is a measure of dissolved or submicron material [3, 4, 5].

There are numerous methods used for measuring the refractive index of a liquid solution that are well documented in text books [6], the most suitable and easiest method was reported [7, 8]. The diversity of methods is largely due to differences in applications, test objects and the required measurement accuracy. A separate class ofdevices for measuring the refractive index of transparent liquids consists of systems designed for examining liquids in cuvettes made of glass, quartz or other transparentmaterials**.** During the last decade, numerous practical devices based on the principle described above using various curettes have been constructed for determining the refractive index [9].The refractive index of solutions its measure by various methods, the commonly instrument used know

Abbe refractometer [10], there is also by analysis of dn/dc The dn/dc, also called differential refractive index is the variation of the real refractive index due to a change in concentration of a solute. The present paper reports a relatively simple and effective technique, which can be used to measure the refractive index of the liquid at different temperatures and concentration, it Michelson interferometer.Though in most of the time, by performing the measurement in atmosphere and using specific wavelength, one can eliminate the influences of pressure and wavelength; the effect of temperature should be always considered. Numerous theoretical and experimental studies have focused on the temperature and concentration dependence of the refractive indices of aqueous solutions.[11−15].The Lorentz− Lorenz equation is the most often used formula to estimate thetemperature and concentration dependence of the refractive index. But it does not provide reliable estimation for the derivatives of the refractive index with respect to temperature andconcentration. So the values for the coefficients of temperature and concentration, or the derivatives of the refractive index n with respect to temperature T and concentration c: ($\partial n/\partial T$) and ($\partial n/\partial c$), have to come from experiments. After obtaining the temperature coefficient (AT) or concentration coefficient (Ac), one can give out the empirical expressions for the temperature or concentration dependence of the refractive index.

Most of the empirical expressions available nowadays only give either the concentration coefficient or temperature coefficient [16-17]. However, in some applications, both temperature and concentration change at the same time.For example, in a number of micro bioreactors and micro fluid devices, it is required to monitor the concentration variation in some points/regions of a solution by measuring its refractive index. Since in a stream flow, the mass diffusion is usually accompanied by thermal diffusion so temperature also changes with time from place to place. Therefore, it is needed to know by what extent the detected refractive index variation reflects the real change in concentration under temperature fluctuation. For this reason, empirical expressions with both the concentration coefficient and the temperature coefficient are necessary for binary solutions. Accordingly in this study, we investigated the simultaneous dependence of refractive index on concentration and temperature in sodium chloride solutions, includes both the concentration and the temperature coefficients for the sodium chloride solutions, and then investigated the dependence of $(\partial n/\partial c)$ on temperature and that of $(\partial n/\partial T)$ on concentration in the solutions. The present paper reports the long existing, well-known Michelson interferometer used in the famous Michelson-Morley experiment as an alternative technique, which can be used to measure the refractive index of sodium chloride solution at different temperatures, concentration and wave length.

1.2 Statements of the Problem

Refractive index and concentration of an aqueous solution, especially water salt is not something uncommon to us in everyday life. However, the determination of their relationship and accurate measurement of both the properties are not easy to be carried out under normal circumstances. They involve sophisticated process and instruments that comes with high cost and low availability, which cause difficulty even for average research practitioner to get the hands on. Precise measurement of salt concentration is essential to prevent overtaking of salt level in our human body, which is detrimental to our health as they can cause BP and other associated chronic diseases.

1.3 Objective of the Study

1.3.1 The General Objective of the Study

- ✓ The general objective of this thesis is to measure the refractive index of sodium chloride solution by using Michelson interferometer techniques.

1.3.2The Specific Objectives of the Study

- ➢ To measure the refractive index of sodium chloride solution at various concentration, temperature and wavelength.

1.4 Significant of the study

The purpose of the study is to investigate the real refractive index of sodium chloride solution. The determination of real refractive index of Nacl solution using Michelson interferometer need to compare the experimental refractive index of Nacl solution with world health organization standard to control salt consumption per day. Hence results of this study can be applied routinely in laboratory to ensure complains with the world health organization. In addition to this the study helps us to apply the knowledge of refractive index in such as quality control, semiconductor manufacturing and chemical analysis and processing. Also the result of this study will used as benchmarks for other interested researcher to make further detailed research on the area.

1.5. Out Line of the Thesis

Chapter- deals with some optical properties of a medium are presented. In chapter-2 describes theory of salt consumption and its source, physiological and biological effect of salt .In this chapter Lasers and their properties and applications, theory of interferometer, basic types of interferometer and related phenomenon .In chapter -3,materials and methods used in this study were presented in chapter-4,result and discussions were presented. In chapter -5 Conclusions and recommendation for future works of the research were presented. Finally, Reference materials used in this research were reported as bibliography.

2. Literature Review

In chapter-2,the literatures related to theory of salt consumption and its source, physiological and biological effect of salt, methods developed for determining refractive index of sodium chloride solution were presented.

2.1. Salt consumption and its sources

In the inter-salt study of salt consumption and BP, the median intake in 32 countries was 9.9 g/day. Salt consumption varied from 0.1 g/day in Yanamano, Brazil to 15 g/day in Tianjin, China. In developed countries, salt intake is usually between 9–12 g/day [18], and up to 80% of salt comes from processed foods. In Canada, for example, over half of total salt intake is from ten commonly consumed groups of processed foods/beverages. In Asia and other developing nations, most salt is added during cooking or contained in sauce and seasonings [19,20].Sodium is naturally present in small quantities in unprocessed foods, but is also added to foods either during processing, cooking or at the table. The main reasons for addition of salt in food processing are for flavor, texture, preservation and to increase thirst to sell more beverages [21-22].

2.1.1 The importance of salt in nutrition

Although sodium is vital to our health, an excess of sodium in the diet has been linked to Hypertension .The major source of dietary sodium is salt. In its report on salt and health concluded that reducing population salt intake would confer significant public health benefits by contributing to a reduction in the burden of cardiovascular disease[23]. They supported previous recommendations by that the average salt intake for adults should be reduced from 9g to 6g per day. This was considered to be an achievable goal A doped a plan to reduce average salt intake in adults from 9.5g to 6g per day. It is not possible to meet this target by simply reducing the amount of discretionary salt added to food by consumers as a large proportion of salt intake is non-discretionary. [24] Showed that manufactured foods contributed 86% of the total household dietary salt intake. A previous study found manufactured foods accounted for 60-70% of dietary sodium of which cereal products provided nearly 40% and meat and meat products approximately 21%. It is vital that food manufacturers and retailers assist by reducing the salt in their products if the proposed salt reduction targets are to be met by [25].In order to explore the effect of salt reduction in different food groups on total dietary sodium intake, foodswere divided into nutritionally similar groups and data on food consumption and sodium content were combined to produce weighted average sodium contents for each group. Illustrative averages were assigned to each of the food groups based on levels towards the lower end of existing.

2.1.2Salt as a preservative in foods

Salt is one of the most widely used food additives as a preservative, enhancing the flavor and to improve water adsorption. Common salt does not display antimicrobial action, but its capacity to reduce water activity values (aw) in foods slows down or even interrupts vital microbial processes. A high salt concentration generates changes in cellular metabolism because of its osmotic effect, which, influences microorganisms in different concentrations, but can reduce the nutritional value of preserved foods because water-soluble components such as vitamins and minerals can be eliminated. Moreover, the salting process alone is inadequate as a sole preservation method in ready-to-eat products, necessitating its combination with other preservation processes (drying, osmotic dehydration, etc.) [26].

2.1.3 Physiological effect of salt

Sodium is a major action in the extracellular fluid, with a key role in maintaining fluid balance in the body. The kidneys regulate sodium and water homoeostasis,and the sodium composition is regulated largely by renal excretion and conservation. Sodium is needed for maintaining extracellular fluid, acid–base balance and entotic pressure, as well as muscle and nerve activity.Furthermore, it helps generate trans-membrane gradients which permit the uptake of nutrients by cells of the intestinal mucosa and renal tubules. Most functions of sodium are interdependent with potassium. Although any decrease in extracellular fluid volume, due to falling plasma volume, lowers BP, any rise in extracellular fluid volume increases BP by increasing plasma volume [27-28].

2.1.4. Health effects of salt.

High intake of salt has also been reported to be associated with non-cardiovascular outcomes, such as higher rates of obesity, stomach cancer, urinary calcium excretion that may lead to osteoporosis and formation of kidney stones, and an increased severity of asthma symptoms [29,30–36]. Although many of these health risks remain unproven in randomized controlled trials, they have biological plausibility and underline the significant safety issues with the addition of high quantities of sodium to food.

2.1.5. Benefits of saltreduction.

Decreased salt intake not only reduces BP and related cardiovascular disease risk, but has other beneficial cardiovascular effects that are independent of and additive to its effect on BP [37]. It has been reported to have a direct effect reducing stroke, left ventricular hypertrophy, aortic stiffness, chronic kidney disease and proteinuria [38 -42]. For that reason, it is reasonable to infer that the total impact of reducing salt intake on cardiovascular outcomes could be greater than those expected from BP reduction only.

2.3. Methods Developed for Determining Refractive Index of Sodium chloride Solution

The most widely used methods for the determination of refractive index of sugar solution is based on the refractometry [43-45]. In addition, there are various methods used by different researchers. Some of the methods are: Refractive Index of liquids by measuring displacement ofRefracted Laser Beam, using He-Ne laser [46], using a cylindrical cuvette [47]; using refractometry and densitometry [48]; Super saturation patterns in counter-diffusion crystallization methods followed by Mach-Zehnder interferometer, Crystal Growth [49]; Growthof lysozyme crystals under micro gravity conditions in the LMS (STS-78) mission Journal ofCrystal Growth [50]; Observation of the concentration distribution around a growing lysozyme crystal [51]; using Interdigital Capacitor Sensor [52]; using a Prism spectrometer[53]; UsingOptical Coherence Tomography[54] ;; using surface plasma resonance [55]; In situ refractionindex of liquids measurement using polymer optical fibers [56]; are some of used methods.

2.4. The Nature of Light.

Energy transmitted by waves through a medium is called radiation or radiant energy; it includes electromagnetic, sound, and elastic waves. Electromagnetic energy includes cosmic rays, γ rays, X-rays, light, heat, microwaves, and radio waves. This continuum of energy is called the electromagnetic spectrum. Energy residing in a specific and very narrow band of this spectrum is referred to as ’light’. Wave theory often is used to describe electromagnetic radiation and therefore to describe light. Light waves, sound waves, water waves, etc. share some characteristics and can be studied using the same theories, but only in limited cases. Although similar in some respects, there are considerably more differences than similarities between sound waves and electromagnetic waves. The same holds true when studying details of electromagnetic waves in different bands of the spectrum; theories that apply to one band of wavelengths may not apply well to another band. This document is concerned only with light. Even within this narrow band of electromagnetic radiation, interaction between light and matter may produce very different effects depending on the wavelength of the light or the characteristics of the material; these variables may be referred to as the conditions under which an interaction takes place. Interactions that result in what is called *light scattering* are no exception. So, any description of light scattering must be accompanied by qualifying statements that define the conditions under which the statements (theories, explanations, or conclusions) are believed to be factual. The discussions that follow hold fast to this caveat; terms are defined and statements qualified as they pertain to the theoretical discussion. These definitions and qualifications may be referred to as limitations, conditions, constraints, or boundary conditions. Regardless, they are what ultimately will separate the theoretical ideal from real-world applications of light scattering theory.A few additional facts about light should be mentioned.

The smallest bundle in which electromagnetic energy is packaged is called a *photon*. All photons of light of a specific wavelength have a specific quantity of energy. The intensity of light of a specific wavelength is a function of the total number of photons emitted (or collected per unit area) per unit time. The study of optics also deals with light beams and light waves. A *ray* is the imaginary line that corresponds to the direction in which radiant energy flows. A *light beam* can be thought of as a group of parallel rays and as having finite thickness; a light beam also may be considered a stream of photons all moving in the same direction. To express it another way, a light ray is the limit of narrowness of a light beam. The branch of optics that is concerned with the path of light rays through optical systems is called *geometrical optics*. Light and, in fact, all electromagnetic radiation has a dual personality. Sometimes it behaves like a particle and sometimes it behaves like a wave, the wave most often being depicted as sinusoidal. This is the particle-wave duality characteristic often attributed to photons. In this document, lightwill be treated either as a continuous wave or as a photon, depending on which view best serves the current technical discussion [57].

2.4.1 Theory of light propagation in an isotropic dielectric medium

Propagation of light through material medium is the most important and interesting aspect of light. In this chapter the theories of interactions of light with matter are discussed. Starting from the definition and properties of electromagnetic radiation this chapter presents how and what phenomenon take place when light and matter interacts. More over it deals about mathematical representations that can often be used for qualitative and quantitative expressions of varied optical phenomenon exhibited by medium like reflection, absorption and scattering of light.

2.4.2. Electromagnetic Radiation

Electromagnetic radiation (EMR) is radiant energy that travels outward in all directions from its source through space with or without the need of a material medium. There are different types of EMR, some very familiar, and others rarely mentioned outside scientific discussions. Electromagnetic radiation includes AM/FM radio waves, microwaves, visible light (red to violet), ultraviolet radiation, X-rays, and gamma rays. Light is a form of electromagnetic radiation in the visible range from its broadened spectrum [58]. Electromagnetic radiation types are identified based on their frequency, wavelength, and source. The energy sources that produce EMR vary greatly, from nuclear reactions in the Sun, which generate gamma radiation, to chemical reactions in the human body that generate infrared radiation (heat). The electromagnetic spectrum is the term applied to all the types of EMR considered together in terms of frequency, wavelength, or energy. All parts of the spectrum are found, with varying intensity, in our natural environment. We are most familiar with the visible spectrum since we sense it directly with our eyes. And it ranges from 390nm to 780nm wavelength.

The infrared spectrum in which it's Wavelengths $\lambda >$ 780nm is sensed as heat and the ultraviolet spectrum ($\lambda <$ 390nm) includes radiation that can damage living cells, often causing a physiological response such as sun burn. Other parts of the spectrum may be present as background radiation. Natural background radiation originates from two primary sources: cosmic radiation and terrestrial sources. Cosmic radiation from deep space interacts with atoms in the atmosphere producing X-rays and unstable isotopes. Terrestrial sources of gamma radiation include radioactive isotopes of uranium, radon, potassium, and carbon [58]. The relative energy of the different types of EMR varies with frequency across the spectrum. Here below figure (2.1) shows the distribution of electromagnetic radiation spectrum.

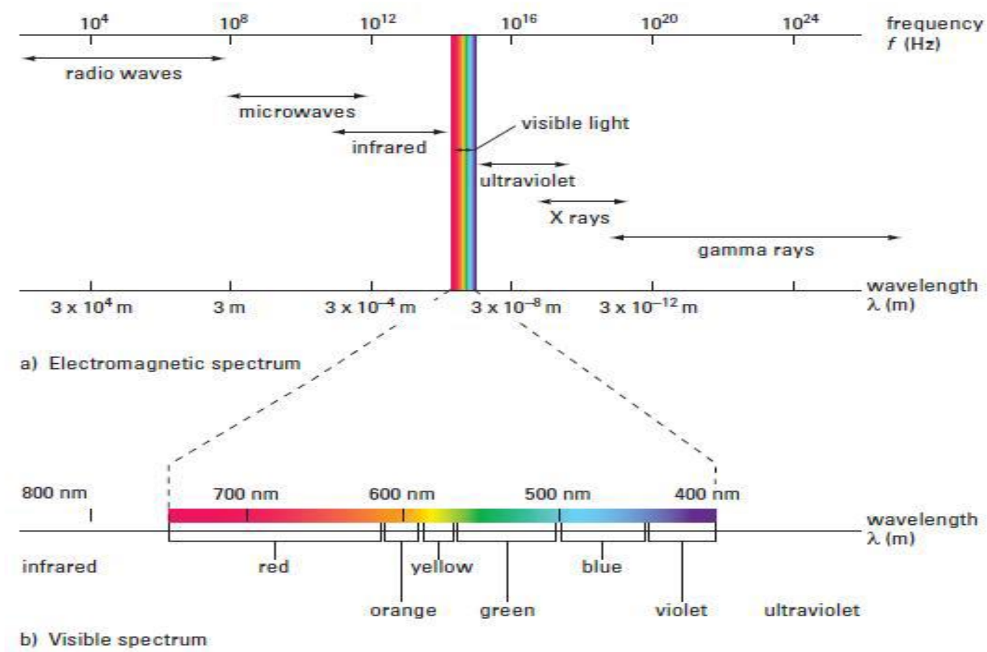


Figure2. 1: The electromagnetic spectrum showing the visible range.

The actual light wave may be treated as a collection of plane monochromatic polarized waves of various frequencies. It may be more correct physically to represent an actual light wave as stream of micro particles, called photons [59]. Depending on the former nature of light, propagation of Electromagnetic Radiation or light through the material medium can be described by Helmoltz wave equation derived from four Maxwell's equations. The dual natures of light categorize its properties as wave like properties, (interference, polarization etc) and particles like properties, (photoelectric effect, and Compton Effect). The study of EMR specifically light propagation through material medium needs special properties of light which can be maintained constant or variable depending on the objective and the method of study.

2.4.3 Laser and Laser Applications

Most spectroscopic measurement techniques use a special light which has special properties for special conditions. The most known special light is laser light. The word LASER is an acronym for the most significant feature of laser action: Light Amplification by Stimulated Emission of Radiation. There are many different kinds of lasers, but they all share a crucial element: Each contains material capable of amplifying radiation. Thus Laser is a device that produces a beam of intense, directional (linearly polarized) and monochromatic light in which all the waves are in phase or are coherent. Lasers have three basic components: laser active medium, energy source (or pumping system), and resonant optical cavity with reflecting mirrors [60]. Active medium: contains atoms or molecules whose electrons may be excited to an elevated energy level by an external energy source (pumping source) to form population inversion. The excitation mechanism functions by pumping energy into the active medium by one or more basic methods such as optical, electrical, chemical, etc. The resonator is composed of high reflectance mirror that reflects essentially 100% of light, and a mirror that allows partial transmission.

Many scientific, military, medical and commercial laser applications have been developed since the invention of laser in 1958. The coherency, high mono-chromaticity, ability to reach extremely high powers with narrow band width, large frequency tuning range over considerable values and all other properties of Laser light allows it to play tremendous specialized applications [61]. The numerous fields of laser applications may be broadly categorized in to two groups.One group involves applications where laser beams play a role of high power beam. This is exploited to produce a targeted effect on material. These applications include material processing (e.g., welding, heat treatment, cutting, hole burning, isotopes separation etc.).The other group includes data transmission and processing, measurements and quality control applications .The high purity/mono-chromaticity of laser makes it as a very useful source for spectroscopy. For many years measurement techniques based on laser light scattering theory have been applied to obtain information about the size, structure, shape, composition, concentration of substances and refractive indices. Thus, for this Michelson interferometer experiment, monochromatic green diode laser at 532nm wavelength is used to find refractive index of sodium chloride solution.

2.5. Theory of interferometer

There are, in general, a number of types of optical instruments that produce optical interference. These instruments are grouped under the generic name of interferometers. The Michelson interferometer is perhaps the best known and most basic in a family of interferometers which includes the Fabry-Perot interferometer, the Tyumen-Green interferometer and the Mach-Zehnder interferometer. The Michelson Interferometer, first developed by Albert Michelson in 1881, has proved of vital importance in the development of modem physics and is an optical instrument of high precision and versatility. This versatile instrument was used to establish experimental evidence for the development for the validity of the special theory of relativity, to detect and measure hyperfine structure in line spectra, to measure the tidal effect of the moon on the earth and to provide a substitute standard for the meter in terms of wavelengths of light [62-63].

Michelson himself pioneered much of this work. It is generally used in investigations that involve small changes in optical path lengths and is able to detect very small movements (on the order of nanometers).With Michelson interferometer Circular and straight-line fringes of both monochromatic light and white light can be produced. These fringes can be used to make an accurate comparison of wavelengths, measure the refractive index of gases and transparent solids, and determine small changes in length quite precisely. The instrument can be used as a stable mode selecting resonator element in laser cavities as well. Interferometer has been used for thickness and index measurements of thin films [64-65] and optical fibers [66].In principle, these measurements can be made to great precision, typically on the order of nanometers, since interferometric technique uses the interference of nanometer wavelengths.

2.5.1 Basic Types of Interferometers

There are two main types of interferometers: two beam interferometers and multiple beam interferometers. A typical interferometer involves an optical arrangement in which a beam splitter splits a light beam generated from one coherent light source into two identical beams (a reference beam and a measurement or objective beam). A beam splitter is a partially reflecting metal or dielectric film on a transparent substance. Polarizing prisms and diffraction gratings can also be used to split light beams. These beams are derived from the same source but travel along separate paths. The measurement beam is either reflected or passes through the medium under investigation. These experiments can be set up in many different configurations depending on their application. There are several common types of interferometers used in both research and industry. The most common two-beam interferometers are the Fizeau, the Michelson, the Mach-Zehnder and the Sagnac interferometers. The most common multiple-beam interferometer is the Fabry-Perot interferometer.

2.5.2 Michelson Interferometer

The Michelson interferometer is the oldest and simplest type of interferometer. This interferometer is used for many scientific applications including measurements of highly sensitive deflection, flatness, temperature and refractive index [67]. The Michelson interferometer uses a coherent light source (such as a laser) which emits a single beam that is then divided by a beam splitter into two identical beams. These beams are then reflected by mirrors back towards the beam splitter. During this event, one beam is passed through a glass plate in order to compensate for the phase difference caused by the thickness of the beam splitter.

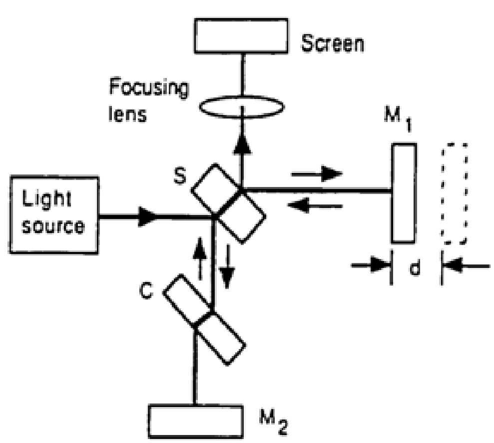


Figure2.2.Schematic illustration of Michelson interferometer

Where C is liquid sample, S is beam splitter, M_1&M_2 are mirror one and mirror two respectively.

2.6 Procedure for alignment

The alignment of the Michelson interferometer can be accomplished in several simple, logical steps. With the Helium Neon source S centered at one end of the table, it is positioned to a height above the optical table that allows the beam to be approximately 6-8 inches above the table surface. The source is then turned on, waiting several minutes for the light to reach full intensity. The mirror M_3 is used to deflect the light to the beam splitter; it is carefully aligned so as to reflect the whole light to the major part of the optical table so that there is sufficient space for the whole setup. The beam splitter is taken out of the way of the laser beam initially.

Making use of two pinholes kept a long distance away from each other, it is made sure that the laser beam is straight and at the same height. The stationary mirror M_I is now mounted and its position is adjusted until the beam reflected from it re-enters the laser. That is, the mirror reflects the light perfectly back into the barrel of the laser. It is always a good idea to have the laser dot in the center of the mirror rather than the edge for proper alignment. Putting a screen behind the mirror, it will be possible to see several red dots surrounding a bright red spot. These several dots are focused to one spot by adjusting the knobs on the back of the mirrors. Now the movable mirror is exactly perpendicular to the laser beam. The beam-splitter is now mounted in between M_3 and M_I on a manual rotation stage and is rotated 45° so that the laser beam is now split into two beams. One beam is transmitted through the beam splitter to mirror M1 and the other beam is reflected at 90 degrees to mirror M_2. Again mirror M_2 is mounted in such a way that the reflected beam hits the mirror at the center. The two paths BM_1 and $BM_2$are made equal to within a millimeter, using a white index card or small ruler. The reflected beams from both the mirrors pass through the beam splitter again and hit the screen. By means of the two adjusting mirror screws in mirrors M_1 and M_2, both points of light are made to coincide. The test sample is then mounted on a manual rotation stage and inserted into the optical path BM_I. By making use of the micrometer screws in the sample mirror mount, the height of the reflected beam from the sample is adjusted in reference to the interfering dots on the screen. The two dots from the reflection of the sample is then superimposed with the already superimposed dots due to the reflected beam from the mirrors to align the sample perpendicular to the path BM_1 and to obtain the zero fringe position. A diverging camera lens (25 mm) is now placed in the light beam between mirror M_3 and the beam splitter to expand the beam so that the points of light are enlarged and the interference patterns are observed on the screen (bands, circles). By careful readjustment, an interference image of concentric circles will be obtained.

2.7 Interference of waves with a single frequency

If two waves simultaneously propagate through the space region of space, the result electric field at any point in the region is the vector sum of the electric field of each wave. This is the principle of superposition (it is assumes that all waves have the same polarization) If two beams emanate from a common source, but travel over two different paths to detector, the field at the detector will be determined by the optical path difference, which we will denote by $\Delta x = x_1 - x_2$ ..So if two waves of the same frequency ω but if different amplitude and different phase image on one point they are superimposed, or interfere so that;

$$y_1 = a_1 \sin(\omega t - \alpha_1) + a_2 \sin(\omega t - \alpha_2) \tag{2.1}$$

Where a_1 and a_2 are the amplitudes of both the waves and α_1 and α_2 the phase angle at any time t. The resulting wave can be described as

$$y = A\sin(\omega t - \alpha) \tag{2.2}$$

With A being the resulting amplitude and α the resulting phase

$$A = a_1^{\ 2} + a^2{}_2 + 2a_1 a_2 \cos\Delta\Phi \tag{2.3}$$

Where $\Delta\Phi$? is the phase difference which is given by

$\Delta\phi = \alpha_1 - \alpha_2 = \dfrac{2\pi\Delta X}{\lambda}$ (2.4) Where λ is the wave length of light source used.

In a Michelson interferometer light is split in to two beams by the beam splitter

For intensity distribution;

$$a_1 = a_2 = a; I \propto A^2 = 4a^2 \cos^2 \frac{\Delta\Phi}{2} \tag{2.5}$$

(Amplitude splitter), reflected by two mirrors and passed again through the sample to produce interference phenomenon behind it. A lens is inserted between the light beam and the beam splitter so that the light source lies at the focal point, since only enlarged light spots can exhibit interference rings.

If the actual mirror M_2 is replaced by its virtual image m'_2 which is formed by reflection at the glass plate, a point p of areal light source is formed as points p' and p'' of the virtual light sources L_1 and L_2 as shown in fig 2.3

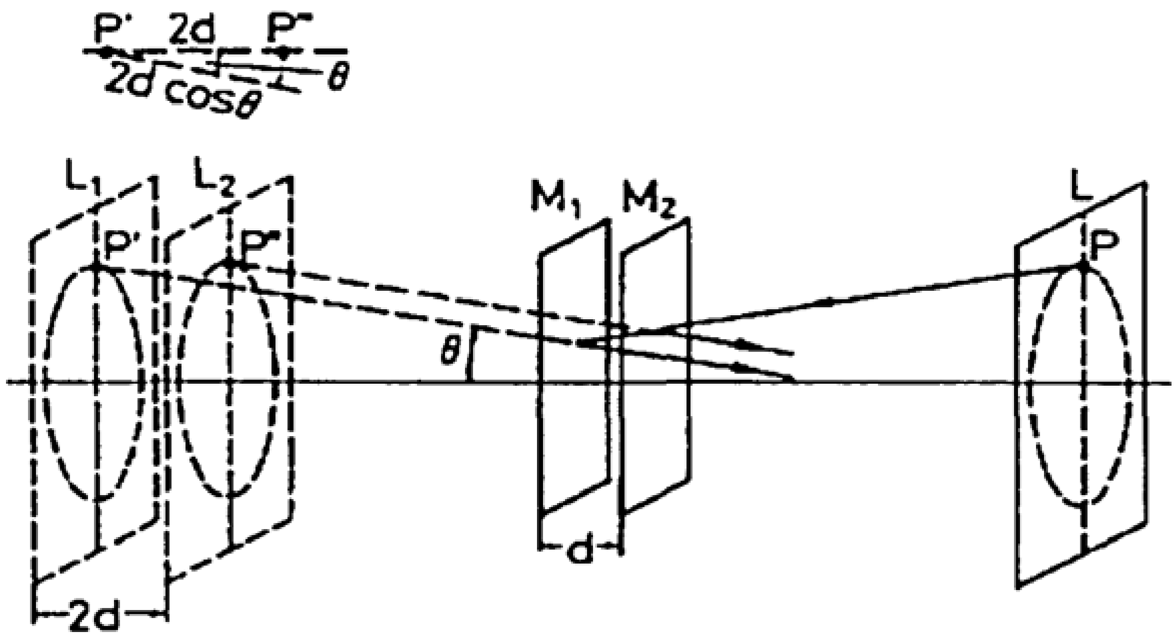


Figure2. 3: Formation of circles on interference

So based on the different light paths, the phase difference using the symbols of fig 2.3 is

$$\Delta\Phi = \alpha_1 - \alpha_2 = \frac{2\pi\Delta X}{\lambda} = \frac{2\pi}{2d\cos\theta}\frac{\Delta\varphi}{2} \tag{2.6}$$

The intensity distribution for $a_1=a_2=a$ according to (3) is

$$I \approx A^2 = 4a^2 \cos^2 \frac{\Delta\varphi}{2} \tag{2.7}$$

2.7.1 Condition Requirement for inducing interference

In order for optical interference to occur several conditions are required to present and fulfill. First of all, the light source must be monochromatic, which means the light beam must only possess a single wavelength (λ) or frequency. Under the usual condition, the light sources must also remain spatially coherent (constant phase difference) with each of them. Amplitudes of two waves having interference are required to be approximately equal to each other so that general illumination can be avoided. Light interference will result in two different phases, namely constructive interference and destructive interference.

Constructive interference (bright fringes) occurs when

$$\Delta\varphi = 2m\pi$$

m=0, $\pm$ 1, +2, $\pm$3 so on

So we have;-

$$\Delta\varphi = 2m\pi \tag{2.8}$$

m=0, $\pm 1, \pm 2, \pm 3$ so on

That is circles are produced for affixed value of m and d since θ remain constant, so if both the optical path lengths are the same or if these two paths differ by an integral number of wave lengths, the condition for constructive interference is met .Thus bright fringes will be formed for that wave length. If one the other hand ,the two optical paths differ by an odd integer number of half wave length $\frac{m\lambda}{2}$,where m=$\pm$1 ,$\pm$3, $\pm$5 and so on

,the condition for destructive interference is met and dark fringes will be formed so destructive interference occurs when;

$$\Delta\varphi = \pm(2m+1) \qquad (2.9)$$

Where, m=0, 1, 2, 3 so on

This might appear at first sight to violet conservation of energy .However energy is conserved because; there is are-distribution of the energy at the detector in which the energy at the destructive site are re-distributed to the constructive sites. The effect of the interference is to alter the share of the reflected light which heads for the detector and the remainder which heads back in the direction of the source.

2.7.2. Interference of two waves with different frequencies

We will now consider the case of two frequencies with wave numbers k_1 and k_2 that together follows two different paths with a difference of Δx. The sum of the waves with different amplitude at point x along the given axis is given by:

$$E_T = (e^{\iota x k_1} + e^{(x+\Delta X)+k_1})E_1 + (e^{\iota x k_2} + e^{(x+\Delta X)k}{}_2)E_2 \qquad 2.10$$

If we let $a = \frac{E_1}{E_2}$ and define $\delta k = \frac{k_1 - k_2}{2}$ after a lot of algebra we can intensity

(E_T, E_T) as:

$$2(a \ + a^2 + a\cos^2 \delta\kappa\Delta X + (1+a)(\cos k_1\Delta X + a\cos K\Delta X \qquad 2.11$$

The expected signal which consists of a fast oscillation as well as slow oscillationCharacteristic of $\delta\kappa$ is shown in Fig. 2.4

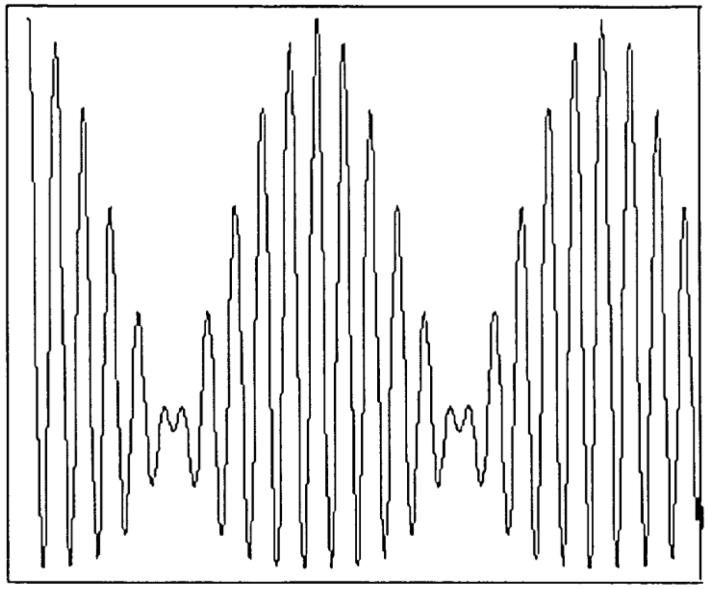


Figure2. 4: Beat signal from two in put frequencies in to a Michelson interferometer.

2.8. Michelson interferometer and refractive index

There are many instruments that produce optical interference. These instruments are grouped under the generic name interferometer. Michelson interferometer is one of example of optical interferometer some of parameters can be measured by this Michelson interferometer as wave length of light, refractive index of materials and the width of spectral lines. A Michelson interferometer was constructed from He-Ne laser, a beam splitter, two mirrors and white screen is used; this instrument to measure the refractive index of sodium chloride solution placed in one of the two interferometer arms optical cell content sample solution [68]. After the laser beam interferes with another beam from the second arms of the interferometer, the interference fringes appears on the screen placed in front of the laser.

If the temperature changes then so does the refractive index of the sodium chloride solution, which affects the manner in which laser beam from each arm, the interferometer, this is seen as measurement of the interference fringes on screen. The change in the refractive index of sodium chloride as a function of temperature given by [69]

$$\frac{\Delta n}{\Delta T} = \frac{\Delta N}{\Delta T} \bullet \frac{\lambda}{2t} \quad 2.12$$

Whereis the change in refractive index $\Delta n = n_2 - n_1$

T is the change in temperature $\Delta T = T_2 - T_1$ and the change in interferometer fringes $\Delta N = N_2 - N_1$

λ= wavelength of laser beam

t= the thickness of the glass cell

The refractive index n of water is linearly dependent on temperature and determined the change in the refractive index at any change in temperature by equation [67].

$$n_2 = n(T_1) - [\Delta T] \bullet \left[\frac{\Delta n}{\Delta T} \right] \qquad 2.13$$

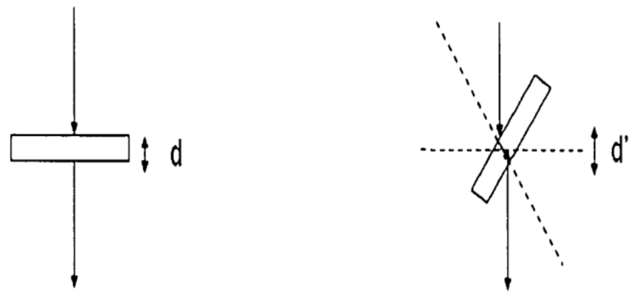
Also we can use the Michelson interferometer to measure the change of refractive index as function of concentration as same as above but one different it placed the optical cell content sample water on rotating stage and determine the refractive index by equation [70].

$$n = \frac{(2t - N\lambda)(1 - \cos i)}{2t(1 - \cos i) - N\lambda} \qquad 2.14$$

where: i is the angle of rotation in degree

2.8.1 Theory behind rotating the sample:

If a plane parallel plate of index of refraction n is inserted normal to the path of one of the beams of light traversing the arms of a Michelson interferometer, the increase of optical path introduced will be 2(n - 1)t, where t is the thickness of the sample. The factor 2 occurs because light traverses twice through the sample. For light of wave length λ, the difference of path introduced is $N\lambda$, where N is the number of fringes displaced when the sample is inserted. If the sample is rotated through a small measured angle, the path of the light will be changed, and the number of fringes N corresponding to this change is counted. This is because of the fact that as the plate is rotated, the length of the sample in the path will increase and therefore number of wavelengths in that path will increase. This will change the interference pattern.



$$d' = \frac{d}{\cos\theta} \quad d' > d$$

Figure2.5. Demonstrating the change in path length

As θ increases, $\cos\theta$ decreases, so d' increases. Thus we can see that the path length through the sample increases as we rotate it through some angle. When projected on a screen, it can be seen that the fringes collapse as the glass plate is rotated. The change of the path through the glass plate depends upon the thickness of the plate, the angle through which it is rotated and the index of refraction. So the index of refraction may be calculated if the other two values are known.

2.8.2. Derivation of the relationship between the refractive index, number of fringes collapsing and the angle of rotation of the sample

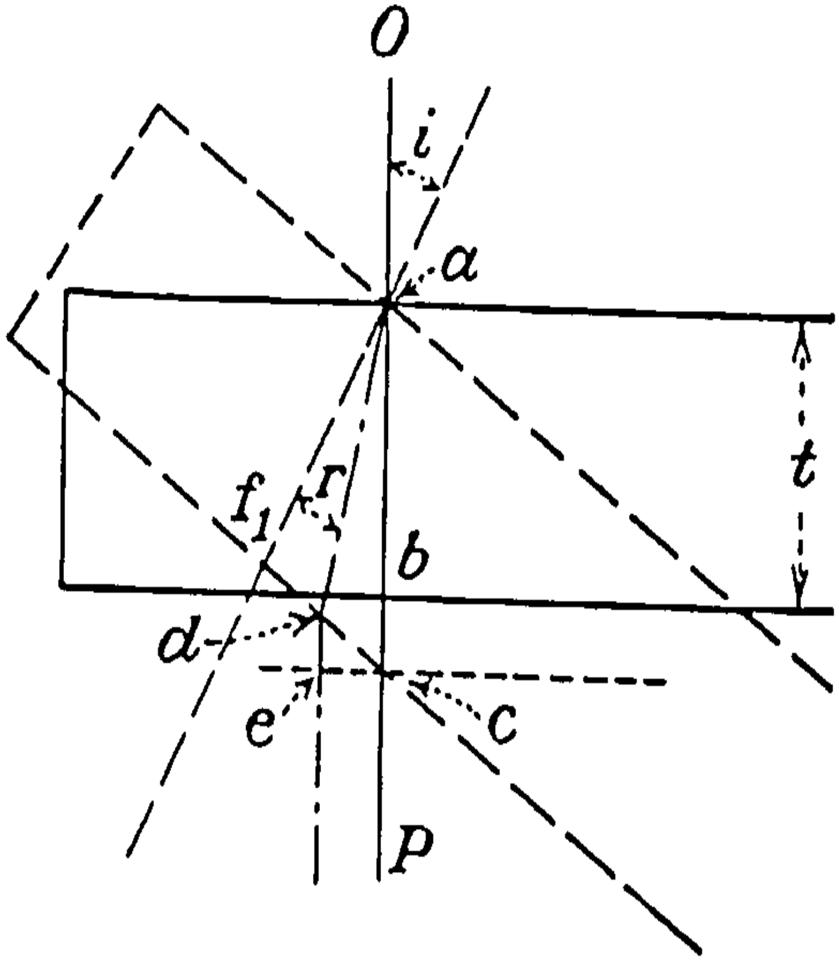


Figure2. 6. Analysis of the samplebeing rotated.

The expression for index of refraction of the sample in terms of the number of fringes collapsing and the angle by which the sample has been rotated is given by [71].

Let OP be the original direction of light normal to plate of thickness't as shown in Figure. 2. 6 .The total optical path between a and c initially for the propagation of light is $nt + bc$ where n is the index of refraction of the sample. When sample is rotated through an angle ' i ' optical path is increased to:

$$(a\,d\,n) + (d\ e)$$

So the total increase in optical path is;

$$\sigma_1 - \sigma_2 = 2(a\ d\ n + d\,e - n\,t - b\,c) = N\lambda \tag{2.15}$$

where N is the number of fringes collapsing or appearing on the screen and i, is the wavelength of the light source used.

But we have

$$ab = \frac{t}{\cos r} \tag{2.16}$$

Where' r ' is the angle of refraction of the light beam.

We also have

$$dc = dc \sin i = (fc - fd)\sin i = t \tan i \sin i - t \tan r \sin i \tag{2.17}$$

$$bc = \frac{t}{\cos i} - t \tag{2.18}$$

Substituting equations. (2.16-2.18) into (2.15), we have

$$\sigma_1 - \sigma_2 = 2(\frac{nt}{\cos r} + t \tan r \sin i - nt - \frac{t}{\cos i} + t) \tag{2.19}$$

Now using Snell's Law

$n \sin r = \sin i$

We get the expression for index of refraction as:-

$$n = \frac{(2t - N\lambda)(1 - \cos i)}{2t(1 - \cos i) - N\lambda} \tag{2.20}$$

$$N = \frac{2t(1 - \cos i)(n - 1)}{n\lambda - \lambda(1 - \cos i)} \tag{2.21}$$

2. 9. Refractive index measurement principle

Refractive index (RI) relates to of the speed of light in a medium. The refractive index (n)of a medium is defined as the ratio of the speed of light in vacuum (c =299 792458 m/s) in to that in the medium (v)

$$n = \frac{c}{v} \tag{2.22}$$

As the speed of light is highest in vacuum c $>n$ is always greater than 1.

The speed of light in a medium depends on the temperature and wavelength. Due to the wavelength dependency, the refractive index is measured with monochromatic light. The common practice is to use the yellow sodium D-line wavelength 589.3 nm. The refractive index measured at this wavelength is usually denoted by n_D .The standard temperature is +20ºC or+25ºC.Refractometry should be considered as the oldest of the used optical research methods.

2.9. 1. Concentration of the components of the liquids, its density and refractive index

Refractive index (RI) is an important characteristic of liquid substances for analyzing, monitoring, and identification of liquids in several industries now days. Accurate determination of the concentration of the solution by measuring the RI is widely used in chemical and physical studies, food technology, materials processing, medical diagnostics, monitoring systems, fuel cells directly measuring pollution, and many other fields.In general, the measured refractive index of a multi component mixture is a function of its temperature T, concentration C and the wave length of the incident light [72].

$$n = n(T, C, \lambda) \tag{2.23}$$

In sections 2.23 and 2.24 the dependence of temperature and wavelength of light on RI Δn will be considered in detail. From Eq.(2.23), the change of RI of a multi component mixture is:

$$\Delta n \approx \frac{\partial n}{\partial T}\Delta T + \frac{\partial n}{\partial c}\Delta c + \frac{\partial n}{\Delta \lambda}\Delta \lambda \tag{2.24}$$

For small changes of the temperature, concentration, and wavelength. Since laser light is highly monochromatic and wavelength-stable, $\Delta n \approx 0$ and wave length effects can be neglected. In this work, the concentration is defined on a mass basis for liquids A and B,

$$C_A = \frac{M_A}{M_A + M_B} and C_B = \frac{M_B}{M_B + M_A} \tag{2.25}$$

where M mass in kg.

Thus, by measuring the change in refractive index and the liquid temperature, the concentration change can be expressed using Eq. (2.24) as follows:

$$\Delta C \approx \left(\Delta C - \frac{\partial n}{\partial T}\Delta T\right)\left(\frac{\partial n}{\partial C}\right)^{-1} \tag{2.26}$$

Changes in the density of matter are always accompanied by some change of RI. Usually RI increases with increasing density. Theoretical study of the relationship between the density of matter and its RI, as well as the experimental data shows that there is a direct proportion between some RI function $f(n)$ and density d :

$$f(n) = rd$$

The constant factor r that is specific for this substance is called as specific refraction. As distinct from n and d the specific refraction does not depend on external conditions (temperature, pressure) and very slightly depends on the state of aggregation of matter.

2.9.2. The influence of temperature of liquids on the refractive index

The first created refractometers in the world were not equipped with any temperature compensation. Therefore, they almost did not find any wide application in practice. And only then, when it was possible to manufacture refractometers with thermal stabilization, and it happened in the late 19th century, refractometers have been widely used in practice [73-75]. The influence of temperature and pressure on the RI is determined by the following two factors:Changing the number of particles per unit of volume when we have heating or pressure (i.e., expansion coefficient and compressibility coefficient), and dependence on the polarizability of the molecules according to the temperature and pressure.The second of these factors usually becomes significant only at very high pressures and a wide range of temperatures.

The general expression for the temperature coefficients of the RI can describe it:

$$\frac{\partial n}{\partial t} = (\frac{\partial f(n)}{\partial n}^{-1}) \left(\frac{r\partial d}{\partial t}\right) + \frac{r\partial d}{\partial t} \qquad (2.\ 27)$$

where r – refraction,d –dispersion and t - temperature.

For the vast majority of liquids, the value $\frac{\partial n}{\partial t}$ is in a narrow range from -0.0004 to 0.0006 deg^{-1}, on the average itis 0.0005deg^{-1}. Some important exceptions are water and dilutedaqueous solutions ($\frac{\partial n}{\partial t} = 0.0001$), glycerin (-0.0002) glycol (-0.00026) as well as some high refractive liquids, such as carbon disulfide (-0.0008). The relation shows that

$\frac{\partial n}{\partial t}$ as well as n are wavelengths dependent. These values increase with decreasing of $\frac{\partial n}{\partial t}$ .However, thisincrease in the visible range is negligible.

The following formula can describe it:

$$(n_\lambda - 1)^{-1} \frac{\partial n_\lambda}{\partial t} = (n_\infty - 1) \frac{\partial n_\infty}{\partial t} + \frac{n}{\lambda^2} \qquad (2.28)$$

A linear extrapolation of the variables n is permissible for some small temperature difference (10-20˚C). Already in the temperature range of 40-60˚C for organic liquids a clearly expressed (and not strictly linear) dependence $\frac{\partial n}{\partial t}$ on the temperature is found. Accurate calculations n for a wide temperature range are made from the empirical formulas as follows:

$$n_t = n + at + bt^2 ... \qquad (2.29)$$

where a, b are coefficients.

As an example we can use the empirical formula expressing the temperature dependence of the benzol RI up to the boiling point:

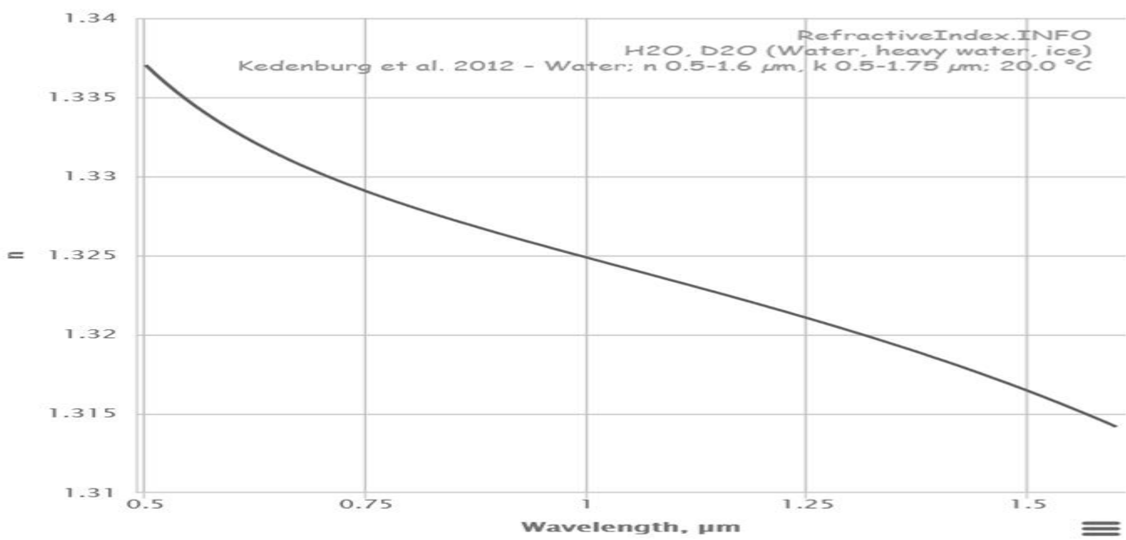
$$n = 1.51431 - 6.44(10^{-4})t + 0.033(10^{-6})t^2 - 2.391(10^{-9})t^3 \qquad (2.30)$$

In liquids and solids, the compressibility is very small; the increase in pressure of 1 atm is generally increasing n by several units of 10^{-5}.For example, for water $\frac{\partial n}{\partial p} = 1.48(10^{-5})$ for alcohol $3.95(10^{-5})$ and for Benzene $4.8(10^{-5})$ .The growth of the temperature leads to an increase of the coefficient, this is $\frac{\partial n}{\partial p}$ about 1% when the temperature is 1˚C. Consequently, some fluctuations in atmospheric pressure so slightly affect the refraction of solids and liquids that this usually is not taken into account. For gases, on the other hand, the influence of pressure so as great as the influence of the temperature, and is always taken into consideration when measuring RI.

2.9.3. Relation between Refractive index and wavelength

The refractive index can be seen as the factor by which the speed and the wavelength of the radiation are reduced with respect to their vacuum values: the speed of light in a medium isEq.(2.31), and similarly the wavelength in that medium is:

$\lambda = \dfrac{\lambda_o}{n}$ (2.31)where λ_o is the wavelength of that light in vacuum. The refractive index varies with the wavelength of light. In the reference literature for the media materials the data *n* are mainly referred. These data correspond to the standard wavelength. In these developed refractometers a laser with a nonstandard wavelength is employed and for mathematical calculations empirically obtained approximation formulas are used. The resolution of the RI measurements obtained in this manner can reach to 10^{-5}. There is an extensive database of RI depending on the wavelength of the laser [84]. Below are some graphs, showing dependence of λ on the RI



$$n^2 - 1 = \frac{0.75831\lambda^2}{\lambda^2 - 0.01007} + \frac{0.08495\lambda^2}{\lambda^2 - 8.91377}$$

Figure2. 7: Influence of wavelength of the laser on water's refractive index.

2.10 Description of refractive index using electron oscillator model.

From classical electron oscillator model the Lorenz force is given by [76]

$$\vec{F} = e(\vec{E} + \vec{v} \times \vec{B}) \tag{2.32}$$

where: $\vec{F}$ is Lorentz force, $\vec{v}$ is velocity, e is electron charge, $\vec{E}$ is electric field and $\vec{B}$ ismagnetic field We assume that equation (2.32) applies to the individual protons and electrons in atoms. Although these particles and their interactions can be properly treated only using quantum theory, their interaction with light can be treated very accurately in most cases with classicallaws and concepts. The electron has mass m_e and charge e and nucleus has mass m_n and charge +e .The nucleus exerts a binding force $\vec{F}$ en on the electron, depending on the relativeseparation $r_{en} = r_e - r_n$. The electron also exerts a force $\vec{F}_{en}$ on the nucleus, and according to Newton's third law,

$$\vec{F}_{en}(r_{en}) = -\vec{F}_{en}(r_{en}) \tag{2.33}$$

The Newton equations of motion for the electron is therefore

$$\frac{md^2\vec{x}}{dt^2} = e\vec{E}(\vec{x}, t) + \vec{F}\,en(\vec{x}) \tag{2.34}$$

Assume R as position of nucleus and m = mass of electron

In the absence of external force, the atom has a certain equilibrium position. Under the influenceof an electromagnetic field, the electron experiences the Lorentz force (2.34) and is displacedfrom its equilibrium position; according to Lorentz "the displacement will immediately give riseto a new force by which the particle is pulled back towards its original position, and which wemay therefore appropriately distinguish by the name of elastic force" [77]. Lorentz's assertion isequivalent to the replacement $\vec{F}$ en(x) by $-k_s\,\vec{x}$, where: ks is the "spring constant" associated withthe hypothetical elastic force. This leads to the equation

$$\left.\begin{aligned} m\frac{d^2\vec{x}}{dt^2} &= e\vec{E}(R,t) - k_S\,\vec{x} \\ \left(\frac{d^2}{dt^2} + \omega_0{}^2\right)\vec{x} &= \frac{e\vec{E}}{m}(R,t) \end{aligned}\right\} \tag{2.35}$$

where: $\omega_o = \sqrt{\frac{k_s}{m}}$ is the electron's natural frequency of oscillator

'

If we take a frictional force for granted and explore its consequences, we simply amend theNewton force law (2.35) to be written as:

$$m\frac{d^2 \vec{x}}{dt^2} == e\vec{E}(R,t) - k_s\vec{x} + \vec{F}_{fric} \tag{2.36}$$

Thisfrictional (drag) force can be given as:

$$\vec{F}_{fric} = -b\vec{v} = b\frac{d\vec{x}}{dt} \tag{2.37}$$

For an electron oscillator in a linearly polarized monochromatic plane wave equation (2.36) takesthe form [78]:

$$\frac{d^2\vec{x}}{dt^2} + 2\beta\frac{d\vec{x}}{dt} + \omega_0{}^2\vec{x} = \hat{\varepsilon}\frac{e}{\vec{E}}\vec{E}_0\cos(\omega t - k\ z) \tag{2.38}$$

where $\beta = \frac{b}{2m}$ the unit vector $\hat{\varepsilon}$ defines the polarization of the applied field. And then equation(2.38) for the electron oscillator with frictional damping is most easily solved by first writing it in complex form as

$$\frac{d^2\vec{x}}{dt^2} + 2\beta\frac{d\vec{x}}{dt} + \omega_0{}^2\vec{x} = \hat{\varepsilon}\frac{e}{\vec{E}}\vec{E}_0\, e^{-i(\omega t - kz)} \tag{2.39}$$

where: we follow the convention of writing:

$$\vec{E}_0\cos(\omega t - kz)\ as\ \vec{E}_0\, e^{-i(\omega t - kz)}$$

$$\vec{E}_0\cos(\omega t - kz)\ \text{is real part of}\ \vec{E}_0\, e^{-i(\omega t - kz)}$$

This means that $\vec{x}$ (t) in (2.39) is also regarded mathematically as a complex quantity in our calculations, but only its real part is physically meaningful. In other words, we may submit the process of taking the real part of (2.31) until after our calculations, at which point the real part of our solution for $\vec{x}$ (t) is the (real) electron displacement. This approach is used frequently in solving linear equations such as (2.39). We solve (2.39) by writing

$$\vec{x}(t) = a\ e^{-i(\omega t - kz)} \tag{2.40}$$

and after inserting this into equation 2.39 we obtain

$$(-\omega^2 - 2i\beta\omega + \omega_0^{\ 2})a = \hat{\varepsilon}\frac{e}{m}\vec{E}_0 \tag{2.41}$$

Therefore, the assumed solution (2.40) satisfy equation (2.39)

$$a\ = \frac{\hat{e}\frac{e}{m}\vec{E}_0}{(\omega^2 - \omega_0^{\ 2} + 2i\beta\omega} \tag{2.42}$$

In view of equation (2.40) and (2.42) the physically relevant solution is expressed as

$$\vec{x}(t) = \mathrm{Re}\left[\frac{\hat{\varepsilon}(\frac{e}{m})\vec{E}_0\, e^{-i(\omega t - kz)}}{\omega_0^{\ 2} - \omega^2 - 2i\beta\omega}\right] \tag{2.43}$$

From equation (2.43) for classical oscillator, the electron displacement due to an applied electricfield $\hat{\varepsilon}\vec{E}_0$(cos (ωt − kz)) is given as:

$$\vec{x}(t) = \hat{\varepsilon}\frac{\bar{e}}{m}\vec{E}_0\left[\frac{\omega_0^{\ 2} - \omega^2}{(\omega_0^{\ 2} - \omega^2)^2 + 4\beta^2\omega^2}\cos(\omega t - kz) + \frac{2\beta\omega}{(\omega_0^{\ 2} - \omega^2)^2 + 4\beta^2\omega^2}\sin(\omega t - kz)\right]$$

(2.44)

The first term in brackets is in phase with the electric field, whereas the second term is "inquadrature," that is, its phase differs is by $\frac{\pi}{2}$ from that of the field. The in-quadrature part of the induced electric dipole moment $\vec{p}$ = e $\vec{x}$ is responsible for absorption (or stimulated emission) of light. The in-phase part of the induced dipole moment is responsible for the refractive index.According to basic electromagnetic theory the refractive index at frequency ω of a medium of N atoms per unit volume is given by the formula

$$n^2\alpha(\omega) = 1 + N\alpha(\omega)/\varepsilon_0 \qquad (2.45)$$

where the polarzability α(ω) is defined by writing the in-phase component of $\vec{p}$ as;

$\alpha\hat{\varepsilon}$ (cos (ωt − kz) Thus, from Eq.(2.45)

$$\alpha(\omega) = \frac{e^2}{m}\left[\frac{\omega_0{}^2 - \omega^2}{(\omega_0{}^2 - \omega^2)^2 + 4\beta^2\omega}\right] \qquad (2.46)$$

and:

$$n^2(\omega) - 1 = \frac{Ne^2}{m\varepsilon_0}\left[\frac{\omega_0{}^2 - \omega^2}{(\omega_0{}^2 - \omega^2)^2 + 4\beta^2\omega}\right] \qquad (2.47)$$

As in the case of spontaneous emission and absorption, this result of the classical oscillator model must be modified to include the oscillator strength *f*:

$$n^2(\omega) - 1 = \frac{Ne^2 f}{m\varepsilon_0}\left[\frac{\omega_0{}^2 - \omega^2}{(\omega_0{}^2 - \omega^2)^2 + 4\beta^2\omega}\right] \qquad (2.48)$$

Unlike absorption, the refractive index is usually attributable to non-resonant transitions, that is, transitions such that, $\left|\omega_0{}^2 - \omega^2\right| \gg \beta\omega$. In this case

$$n^2(\omega) - 1 \approx \frac{Ne^2 f}{m\varepsilon_0\left[\omega_0{}^2 - \omega^2\right]} \qquad (2.49)$$

In this non resonant situation, however, no one transition is necessarily dominant, and so we must add the contributions of all transitions connected to the ground state in which the atoms are presumed (for now) to reside. Thus, if the transitions from the ground state have oscillator strengths f_j and transition frequencies ω_j the refractive index at the radiation frequency ω is given by the formula:

$$n^2(\omega) - 1 = \frac{Ne^2 f}{m\varepsilon_0}\sum\frac{f_j}{\omega^2{}_j - \omega^2} \qquad (2.50)$$

This result applies when there is one type of atom or molecule in the medium; more generally we simply add the contributions of the different species. In a gas, furthermore, the density N is generally sufficiently low that $n(\omega) \approx 1$ and therefore, $n^2 - 1 = (n-1)(n+1) \approx 2(n-1)$. Thus, for a gas consisting of a single type of atom or molecule with number density N, the formula for the refractive index is approximately:

$$n(\omega) = 1 + \frac{Ne^2}{2m\varepsilon_0} \sum \frac{f_j}{\omega^2{}_j - \omega^2} \tag{2.51}$$

It is interesting to relate this result to a formula that is often used in tabulations of the refractiveindex of gases. For this purpose, we first rewrite (2.51) in terms of radiation wavelength $(\lambda = \frac{2\pi c}{\omega})$ and transition wavelengths $(\lambda_j = \frac{2\pi c}{\omega_j})$

$$n(\omega) = 1 + \frac{Ne^2}{8\pi^2 \varepsilon_0 mc^2} \sum_j \frac{f_j \lambda^2}{1 - \lambda^2{}_j / \lambda^2} \tag{2.52}$$

As noted, electronic resonance in molecules (and in many atoms) tends to lie in the ultraviolet, inwhich case $\lambda_j \ll \lambda$ for optical wave length λ. In this case we can approximate $(1 - \lambda^2{}_j / \lambda^2)^{-1}$ by the first two terms of its binomial series expansion, $1 + \frac{\lambda^2{}_j}{\lambda^2}$ then;

$$n(\lambda) - 1 \approx A_1 (1 + \frac{B_1}{\lambda^2}) \tag{2.53}$$ •

$$\text{Where } A_1 = \frac{Ne^2}{8\pi^2 \varepsilon_0 mc^2} \sum_j f_j \lambda_j{}^2 \tag{2.54}$$

$$B_1 = \sum_j \lambda_j{}^4 \tag{2.55}$$

An empirical relation of the form (2.53) was proposed by Cauchy in 1830, before theelectromagnetic theory of light. Our derivation of Cauchy's formula gives explicit expressions for the coefficients A_1 and B_1. Unfortunately, it is difficult to calculate the numerical values of A_1 and B_1 for a given atom or molecule because we require the transition wavelengths and the oscillator strengths of all transitions connected to the ground state, including transitions to "continuum" states in which the electrons are unbound, that is, in which an atom is ionized. For a gas at STP [P =760Torr, T = 273K, and, N = 2.69 x1025 /m^3],

$$A_1 = 1.2\times10^{10}\sum f_j\lambda^2{}_j \qquad (2.56)$$

.

Cauchy's formula correctly accounts for the fact that most transparent materials we encounter daily (e.g., water, air, glass) have refractive indices greater than unity at visible wavelengths.According to our analysis, this is a consequence of these materials having resonance wavelengthsλj that are small compared to optical wavelengths (which lie roughly between 400 and 700 nm) [79].It also follows from (2.53) that $dn/d\lambda < 0$, which is also a familiar feature of refractive indices in the visible. A glass prism, for instance, causes violet to be dispersed more than red when it separates white light into its spectral components. In fact, the increase of n (λ) with decreasingλ ($dn/d\lambda,<0$) is sufficiently ubiquitous that it is called "normal dispersion." An example of normal dispersion appears in Fig. 2.5

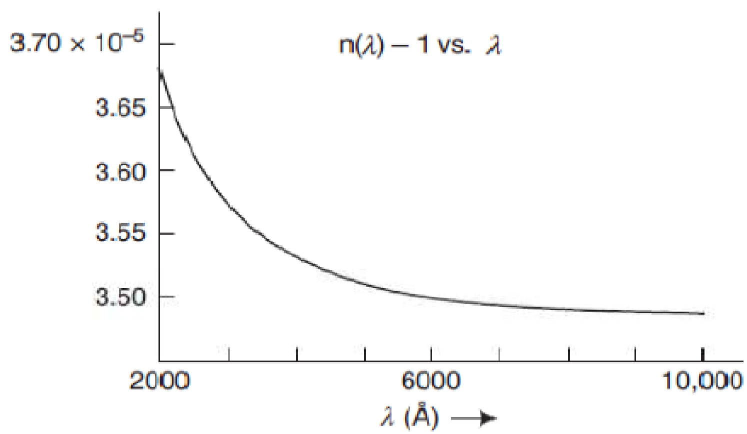


Figure2. 8. Refractive index of helium at standard temperature and pressure.

3. Materials and Methods

In this chapter, the materials and methods employed in the thesis were presented. The first section of this chapter describes the various materials used for the experiment; the second section describes the methods of the research; and in the last section the experimental setup was presented.

3.1 Materials

Two mirrors M_1 and M_2, abeam splitter, white screen, glass cell, Beam expander, a diverging camera lens(25mm) to expand the beam, Optical Bench, rotating stage, red and green diode laser and He-Ne laser as a light source, glass cuvvette of thickness 5cmand digital electronic balance with a good accuracy. In addition to these, different instruments such as measuring cylinder to measure the volume of water, mercury thermometer and magnetic stirrer with hot plate were used. The samples are de-ionized water used as solvents; sodium chloride solution was used.

3.2 Methods

3.2.1 Methods of measuring refractive index of sodium chloride solution by using Michelson interferometer.

3.2.1.1 Preparation of Standard Samples of Varying Concentration of Sodium Chloride.

For the quantitative analysis of sodium chloride present in the unknown sample solution, we have to draw proper calibration curves. Thus for the calibration curve (a graph between refractive index and concentration of Nacl in the matrix different liquid sample having a known concentration of Nacl are required. In this work, standard solution method [80] was preferred for the preparation of standard sample, to maintain the homogeneity of the liquid samples.The standard solution having different concentration of Nacl that is 5%,10%,15% 20% were prepared 5% Nacl solution is meant by 5gm of Nacl is dissolved in 100ml distilled water, Since the percentage equivalent of Na in Nacl is 39.3371% then 1gm of Nacl contain 0.39gm of Na.Thus the equivalent percentage of Na in these standard Nacl solution is give by 0.78%(0.78%=0.78gm/100ml, 1.95%,3.9% 5.8% and 7.8% respectively. After that there is a weak dependency concentration of refractive index as the result of salt solution, the effect of concentration is strong up to

20% concentration .However after this value the dependence become weak. These solutions have been used to calculate the refractiveindex of solutions. In the present experiment distilled water is used to avoid any type of contamination error.

Table3. 1. Prepared samples ofsodium chloride solutionof variousconcentration.

Sample name	A	B	C	D	E
Nacl in (gm)	0	5	10	15	20
De-ionized water in ml	100	100	100	100	100
% of Nacl (gm/100ml)	0	5	10	15	20

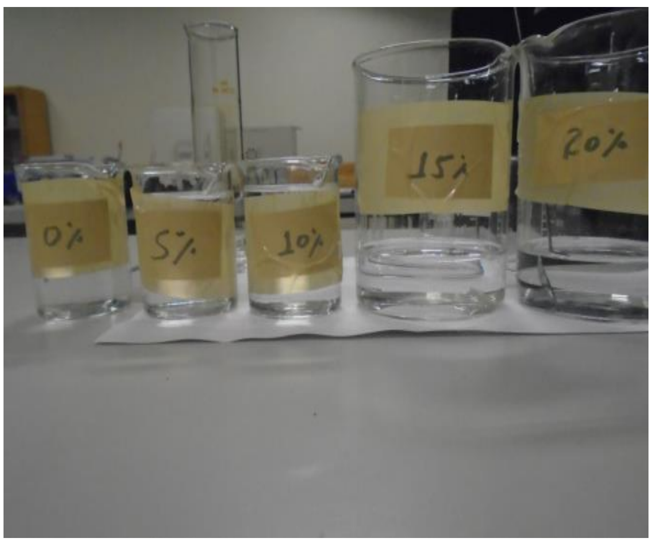


Figure3. 1: Preparation of sodium chloride solution with different concentration

3.2.1.2. Method of measuring angle incidence.

In order to measure the angle incidence, the set up were arranged as shown in figure 3.2. The sample prepared for each concentration of sodium chloride solution was poured into the sample holder (cuvette) which is placed on one of interferometric arms. And for each sodium chloride solution, the angles of incidence and number of fringes have been measured three times using red, green diodes and He-Ne laser lights and the averages were calculated. The refractive index of each solutionwas calculated by keeping angle of incidence constant (1^0) for different values of number of fringes (N) using equation (2.13).

3.2.2. Method of measuring temperature dependence of refractive index of sodium chloride solution.

In order to measure the temperature dependence of refractive indexof sodium chloride solution, each of the prepared solution of sodium was poured into a beaker and heated using magnetic stirrer with a hot plate until the temperature reached 70^oc by placing the thermometer inside a solution. Then after, the solution is poured into the sample holder (cuvettes)and the sample be on one of interferometric arms as shown in the setup of figure 3.2; the angle incidence was measured it was 1^0in each interval of 10^oC while the solution is cooling down from (70^oc -30^oc) temperature. Thiswas done using red, gree
and He-Ne diodes laser lights for 0%, 5%, 10% 15%, and 20%. From the measured angle of incidence and number of fringes the refractive index was calculated using equation (2.12) for each concentration. Numerical procedure of fitting theexperimental data was carried out by linear curve fitting based on Levenberg-Marquardtalgorithm using origin 8 software for correlation.

3.3. Experimental Set Up

A sketch of the experimental set up used to measure the refractive index as a function of temperature , concentration and wave length is shown in a photograph.

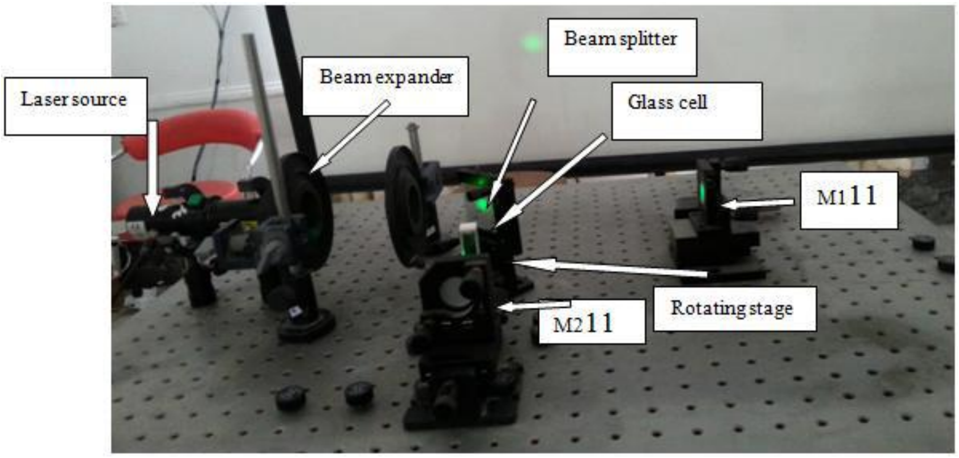


Figure3. 2: Experimental setup of Michelson interferometer and observed fringe

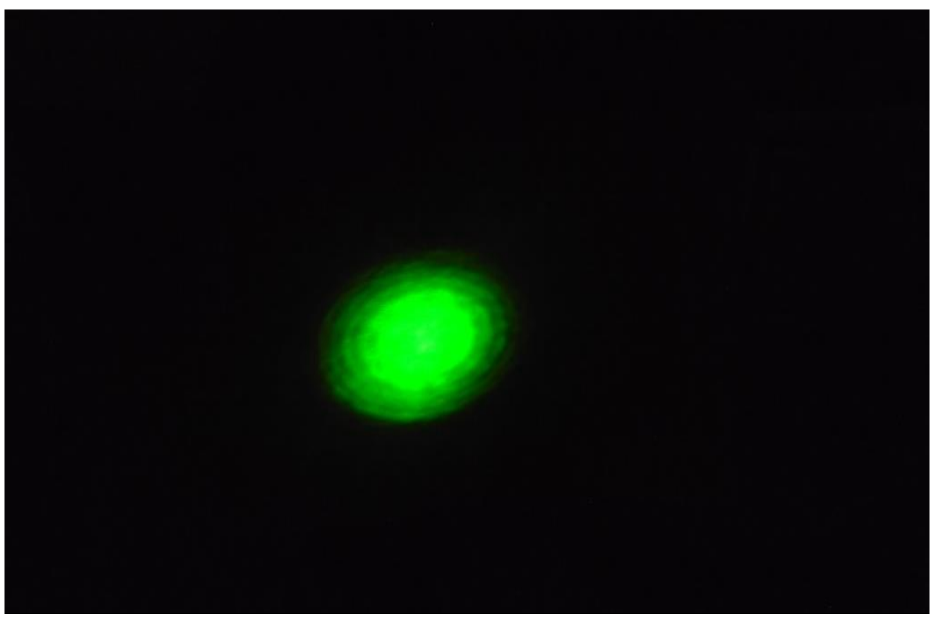


Figure3. 3Produced fringe.

4. Result and discussion

In this chapter, the results and discussion of the thesis were presented. In the first sections of this chapter the results of refractive indices of sodium chloride solutions determined bythe three lasers were presented; graph of refractive index versus concentration, graph of refractive index versus temperature and refractive index versus wave length were presented.

4.1 Refractive index of sodium chloride solution using green diode laser.

4.1.1 Concentration dependent of refractive index of sodium chloride solutions

Table 4.1-4.3 show the refractive indices of sodium chloride solution measured at different concentrations using red diode laser**,** green diode laser and He-Ne laser. The results in the tables indicate the refractive index of the solutions in the mentioned concentration range were found to be using red diode, green diode lasers and He-Ne laser light respectively. The refractive index increases linearly as the concentration of sodium chloride solution increases. In the mentioned concentration range, the minimum value of refractive index was 1.3082±0.0004 obtained using red diode laser for 0% concentration and the maximum value was 1.4135±0.0000 obtained using green diode laser for 20% concentration. The obtained results are in a good agreement with the reported results by[4, 81-82].

Table4. 1 Results of refractive index for sodium chloride solution for different concentration, determined using red diode laser.

concentration in %	Cumulative number of fringes(N)	Refractive index(n)
0	7.25±0.5	1.3082±0.0004
5	7.5±0.5	1.3222±0.0003
10	8±0.0	1.3513±0.0000
15	8.25±0.5	1.3663±0.0001
20	8.5±0.5	1.3816±0.0002

Table4. 2 Results of refractive index for sodium chloride solution for different concentration, determined using green diode laser.

concentration in %	Cumulative number of fringes(N)	Refractive index(n)
0	9±0.5	1.3146±0.0000
5	9.5±0.0	1.3381±0.0002
10	10±0.0	1.3623±0.0000
15	10.5±0.5	1.3875±0.0001
20	11±0.0	1.4135±0.0000

Table4. 3 Results of Refractive index for sodium chloride solution of different concentration, determined using He-Ne laser.

concentration	Cumulative number of fringes (N)	Refractive index (n)
0	7.5±0.5	1.3112±0.0002
5	7.75±0.5	1.3243±0.0001
10	8.25±0.5	1.3533±0.0002
15	8.5±0.5	1.3680±0.0002
20	9±0.0	1.3829±0.0000

Figure 4.1 shows the plot of refractive index versus concentration of sodium chloride solution measured using red diode laser, green diode laser and He-Ne laser. As shown in the figure the experimental values are best linearly fitted (R^2 = 0.988, 0.994, 0.977) for red diode, green diode and He-Ne laser respectively. The regression equations of the graph obtained using different laser light are shown in table 4.4.

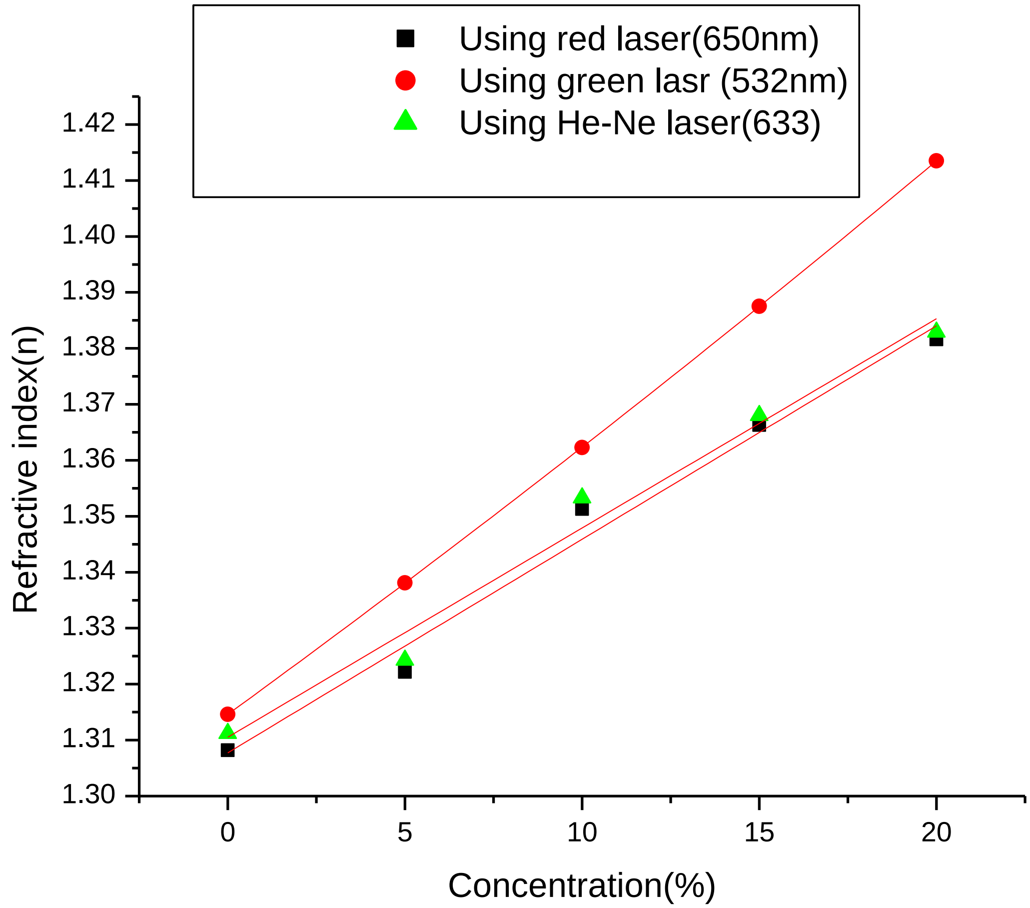


Figure4. 1.Graph of refractive index versus concentration using red, green diode and He-Ne laser.

From this plot in Fig. 4.1 it is clear that the refractive index varies linearly with the concentration of NaCl. For better accuracy, we drew the calibration plots up to the concentrations 20%. We obtained the slopes of these calibration curves by fitting data in the linear regression functions for the concentrations up to 20%. We have seen that at low concentration, the variation of the refractive index is linear with the concentration as shown in table 4.4.

Table4. 4Results of refractive index versus concentration graph for the three lasers (red diode green diode and He-Ne) laser.

source of light	slope($\frac{dn}{dc}$)	Intercept	Adj. R^2	Regression equation
Green diode laser (532nm)	0.0049 ± 0.0004	1.314 ± 0.0006	0.994	n=1.31+0.00494C
He-Ne laser (632.8nm)	0.0037 ± 0.0007	1.311 ± 0.0003	0.977	n=1.31+0.00374C
Red diode laser (650nm)	0.0038 ± 0.0003	1.308 ± 0.0004	0.988	n=1.31+0.0004C

Where C is the concentration of the sample

Table4.5. Values of refractive indices experimentally determined and the literatures values

Concentration (%)	Experimental values Using red diode (λ = 650nm)	Experimental values Using He-Ne diode (λ = 633nm)	Experimental values Using red diode (λ = 532nm)	Literatures value (λ = 589.29nm) [81-87]
0	1.3082	1.3112	1.3146	1.330
5	1.3222	1.3243	1.3381	1.345
10	1.3513	1.3533	1.3623	1.350
15	1.3663	1.3680	1.3875	1.365
20	1.3816	1.3829	1.4135	1.382

4.1.2. Wavelength dependence of the refractive index of sodium chloride solutions

Figure 4.2 shows the refractive index versus wavelength graph for different lasers. The graph indicates that the refractive index of sodium chloride solutions decreases as the wavelength of the laser light increases. Hence the obtained results are in a good agreement with the theoretical description expressed in equation (2.46). In equation

(2.46), the refractive index decreases asthe wavelength of laser light increases($\frac{dn}{d\lambda} < 0$) [72].

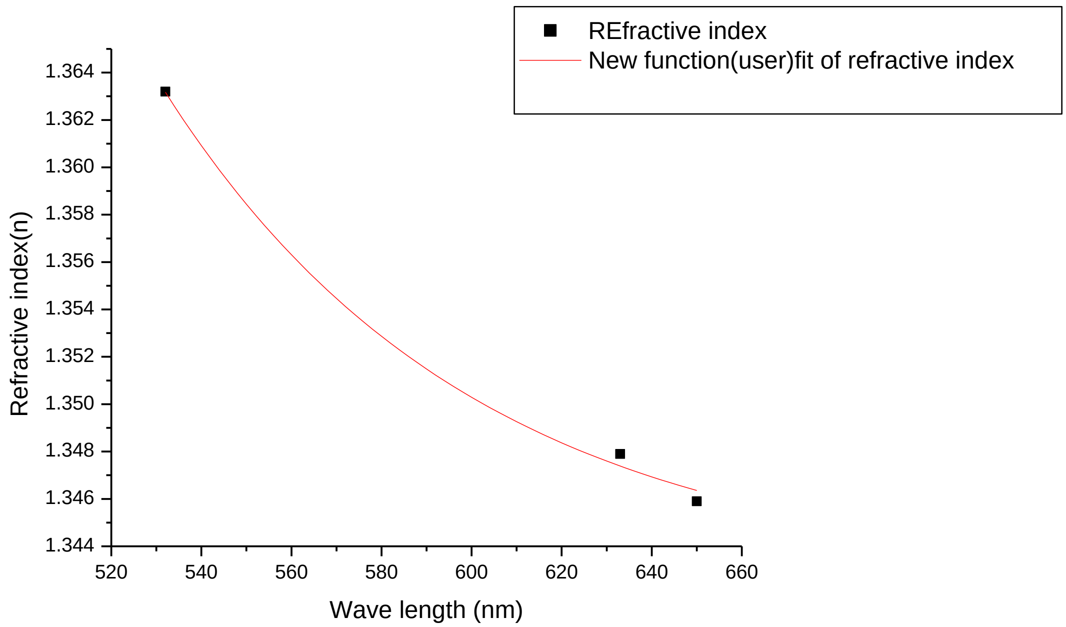


Figure4. 2Graph of refractive index versus wave length.

4.1.3. Temperature dependent of refractive index of sodium chloride solutions using green diode laser.

Table: 4.6, 4.7 and 4.8 show the refractive index of sodium chloride solutions at different temperature. As shown in the table, the refractive index of sodium chloride solutions decrease as the temperature increases. In the mentioned temperatures (30^0C – 70^0C), The minimum value of refractive index of the sodium chloride solution at the temperature of 70^0C was found to be 1.3078±0.0001 at 0% concentration and the maximum value was found to be 1.3815±0.0002 at 30C for 20% concentration using red diode laser; and 1.3141±0.0002 at 70^oC for (0%) concentration and 1.4134±0.0001 at 30^oC for (20%) concentration using green diode laser. In general in the mentioned temperature range (30-70)^{0}C the minimum refractive index was found to be 1.3078±0.0001 at 70^0C for (0%) concentration using red diode laser and the maximum value was 1.4134±0.0001 at 30^oC for (20%) concentration using green diode laser. These results are in a good agreement with the reported results by [67, 70,83]

Table4. 6 Results of refractive index for sodium chloride solution at different temperatures determined using red diode laser.

Tem. (^{0}C)	Concentration (%)				
	0%	5%	10%	15%	20%
30	1.3081±0.0002	1.3221±0.0001	1.3512±0.0002	1.3661±0.0001	1.3816±0.0002
40	1.3080±0.0001	1.3220±0.0000	1.3511±0.0001	1.3661±0.0002	1.3814±0.0001
50	1.3080±0.0000	1.3219±0.0002	1.3510±0.0000	1.3659±0.0002	1.3814±0.0001
60	1.3079±0.0003	1.3219±0.0003	1.3509±0.0001	1.3658±0.0000	1.3812±0.0002
70	1.3078±0.0001	1.3217±0.0001	1.3509±0.0002	1.3657±0.0001	1.3811±0.0000

Table4. 7 Results of refractive index for sodium chloride solution at different temperatures, determined using green diode laser.

Tem. (^{0}C)	Concentration (%)				
	0%	5%	10%	15%	20%
30	1.3145±0.0002	1.3380±0.0000	1.3622±0.0001	1.3874±0.0002	1.4134±0.0001
40	1.3144±0.0000	1.3379±0.0001	1.3621±0.0000	1.3873±0.0001	1.4134±0.0000
50	1.3243±0.0001	1.3379±0.0003	1.3621±0.0003	1.3872±0.0000	1.4132±0.0002
60	1.3143±0.0003	1.3377±0.0002	1.3619±0.0004	1.3871±0.0001	1.4131±0.0003
70	1.3141±0.0002	1.3376±0.0002	1.3618±0.0002	1.3871±0.0003	1.4130±0.0000

Figure 4.3 shows the graph of refractive index versus temperature of sodium chloride solution measured using red diode laser. As shown in the graph the experimental values are best linearly fitted with negative slope as shown in table 4.8.

Table4. 8Results of slopes and intercept for refractive index versus temperature graph.

For red diode	concentration 5%	Concentration 10%	Concentration 15%	Concentration 20%
Adj.R-square	0.900	0.921	0.928	0.9001
Intercept	1.322 ±0.00008	1.351±0.00006	1.37±0.00005	1.36647±0.00008
Slope(dn/dT)	-9E-06±0.000002	-8E-06±0.000001	-8E-06±0.00001	-1E-05±0.00006

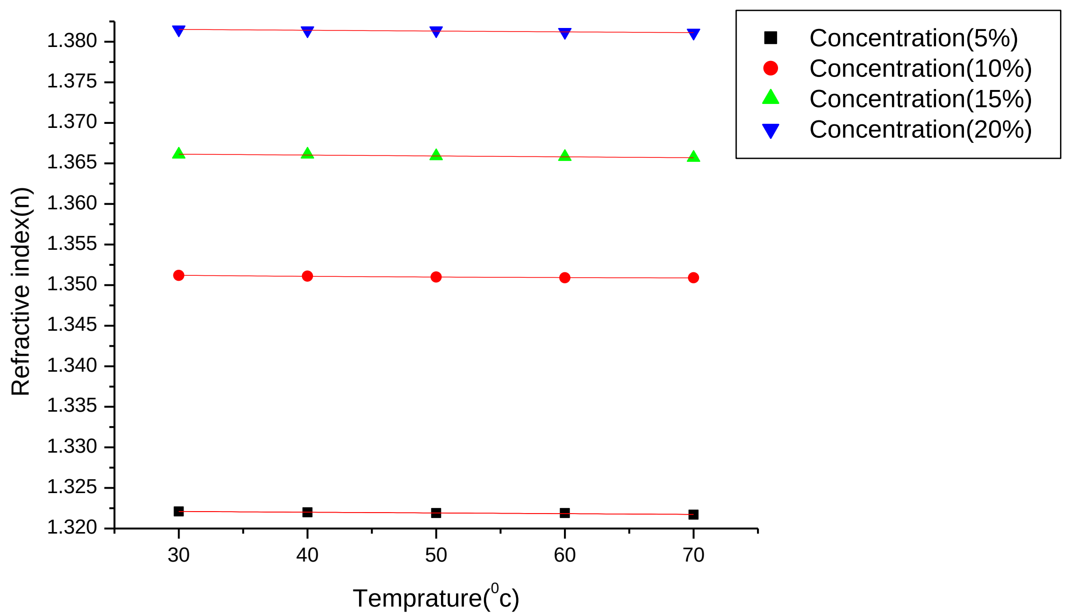


Figure4. 3 Shows the graph of refractive index versus temperature of sodium chloride solutions using red diode laser as a light source.

As shown in the graph the experimental values are best linearly fitted with negative slope as shown in table 4.9.

Table4. 9. Results of slope and intercept for refractive index versus temperature graph.

green diode laser(532)	Concentration 5%	Concentration1 0%	Concentration 15%	Concentration 20%
adj-R-square	0.901	0.901	0.922	0.927
Intercept	1.338$\pm$0.00008	1.362$\pm$0.00008	1.387$\pm$0.00006	1.414 $\pm$ 0.00008
slope($\frac{dn}{dT}$)	-1E-5$\pm -2E-6$	-E-5$\pm 2E-6$	-8E-6$\pm -1E-6$	-1E-5$\pm 2E-6$

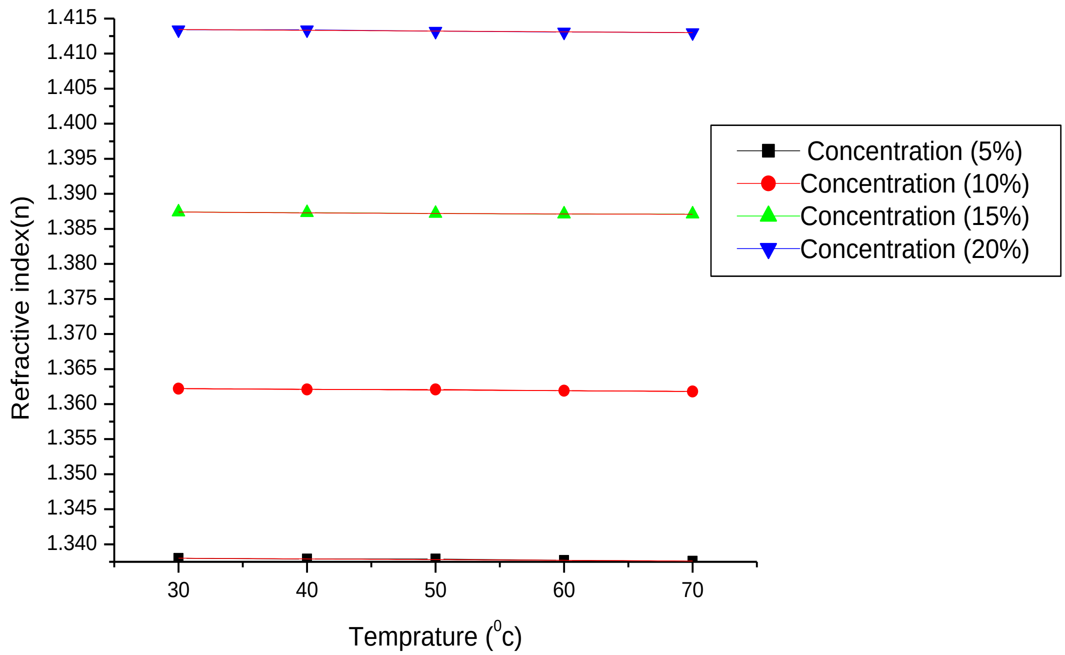


Figure4. 4. Graph of refractive index versus temperature using green diode laser as a light source.

5. Conclusions and Recommendations

5.1 Conclusions

We have been able to design a Michelson interferometer suitable for the measurement of refractive index of sodium chloride solution. Experimental results showed that this technique could be safely employed to study the dependence of refractive index of sodium chloride solutions on their concentration, temperature as well as on the their wave length. Then the concentration, temperature and wave length dependent of refractive indices for sodium chloride solutions were determined. The calculated refractive index of the solutions for the (0%- 20%) concentrations were to be found in the range of (1.3082±0.0001 -1.3816±0.0002), (1.3146±0.0000 -1.4135±0.0000) and (1.3112±0.0002 -1.3829±0.0000) using red diode laser, Green diode laser and He-Ne laser light respectively. The refractive index increases as the concentration of sodium chloride solution increases. Also the temperature dependent of refractive index of the sodium chloride solution for the (30^0c-70^0c) temperature were to be found in the range (1.3816±0.0002-1.3078±0.0001) and (1.4134±0.0001-1.3141±0.0002) using red and green laser diode respectively. The refractive index decrease as temperature increases. In addition, the wavelength dependent of refractive index of the solution for (532nm-650nm) wave length found in the range (1.4135±0.0000-1.3146±0.0000), (1.3829±0.0000-1.3112±0.0002) and (1.3816±0.0002-1.3082±0.0001.The refractive index decreases as wave length increase and it is in good agreement with the reported value in literatures. Therefore, the developed method can be applied for other types of solutions.

5.2 Recommendations

The developed methods can also be applied for other types of solutions. On top of this, in a future work, the Michelson interferometer made by expert or industrially made would need to be used to provide better predictive results. The sodium chloride samples need also to be subjected to different pH and then their concentrations is monitored. Therefore further studies are required to be done in order to see the effects of substances like acid on the refractive index of sodium chloride solution.

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