زانکۆی سەلاحەدین - هەولێر
Salahaddin University-Erbil

# Effect of Annealing Temperature on Physical and Optical Properties of Soda–Lime Glass

**A Research Project**
**Submitted to the department of Physics in partial fulfillment of the requirements for the degree of BSc. in Physics**

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**April– 2024**

**بِسْمِ اللهِ الرَّحْمنِ الرَّحِيمِ**
**قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ**
**صدق الله العظيم**

**سورة البقرة الاية32**

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**Date Approved: April 1, 2020**

# DEDICATION

**Special dedicated:**

- To my dear parents, whose love, kindness patience and prayer have brought me this far
- To all my very diligent teachers, for their endless help and effective teachings

Thank you very much!

# ACKNOWLEDGEMENTS

Firstly, and the most importantly, I would like to thank Allah the ultimate until the end day comes who have wonderful plans for me and have guided me to here at this moment. He has kept me strong and focused so that I would not go wrong, higher council and presidency of the Salahaddin university would like to express my deepest thanks and gratitude to my supervisor Assist. Prof. Dr. Saman Qadir Maulud, for his keen supervision initiating and planning this study, great help, and scientific guidance I am grateful for his patient and valuable comments sincere thanks and appreciation to all my friends in the physics department who supported me during my study last but not least would like to express my appreciation and gratitude to my parents, sister and brothers, for all the supports, patience and encouragement they provide during my studies.

# SUMMARY

Soda-lime glass, commonly known as “float glass” is used in everyday products and devices such as solar cells, household mirrors, automobile glass, architectural building windows, etc. Understanding the bulk optical properties of soda-lime float glass and the surface layers which form on the air and tin sides is important for subsequent characterization of deposited coatings on soda-lime glass. Float glass typically has a characteristic green tint, resulting in absorption over a broad spectral range from visible to infrared wavelengths. This bulk absorption and green tint are generally attributed to addition of iron oxide into the glass; other additives can also be used to produce different colors of soda-lime glass. In this project, we used UV-Vis-NIR spectroscopy for characterizing the absorption properties of annealed soda-lime float glass at different annealing temperatures. In summary, while there may be some indirect correlations between density and absorption in glass, the relationship is complex and depends on various factors such as atomic packing density, impurity content, crystallinity, and structural arrangement. Therefore, it is essential to consider multiple factors when studying the absorption properties of glass, rather than relying solely on density as a predictor of absorption. Generally, a higher density implies a more tightly packed structure with fewer void spaces between atoms. In such cases, there may be fewer opportunities for light to penetrate the material, leading to lower absorption. In summary, the effect of annealing temperature on absorption in glass is complex and depends on various factors including structural changes, crystallization, defects and impurities, annealing stress, and chemical composition. Experimentation and analysis are often required to understand how annealing temperature specifically influences the absorption properties of a particular type of glass.

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# CHAPTER ONE

# INTRODUCTION

## 1.1 Introduction and Background

During the past 100 years, commercial flat glasses have acquired a reputation as being among the most durable of materials used in the construction and fabrication industries. As far as packaged food products are concerned, people, more often than not, tend to concentrate only on the quality of the food product itself and seem to overlook relevant quality issues in respect to the packaging. The latter is far from a trivial issue. Indeed, inappropriate packaging can lead to grievous health risks, not to mention the adverse effects it can have on both the quality of the food product and its characteristics, for example its flavor and aroma. As such it should not come as a surprise that glass bottle packaging has attracted, especially in recent years, the attention of the food industry (Mauro, 2010). All glass materials can react with the surrounded environmental (e.g., temperature, pH, solution composition and flow, glass composition) these reactions will cause degradation in their optical and structural properties; the amount of the degradation depends mainly on the glass material composition types and mole ratio as well as the surrounded environment. The corrosion of soda-lime glasses has received great attention. Glass is thought of as a corrosion proof material but under certain exposure conditions its chemistry, structure and properties are affected (Agrawal, 2013). Whenever water is permitted to remain on a glass surface for longer than a moment, several unique chemical reactions can occur that cause corrosion damage, or stain. The first of these begins almost immediately after water contacts the glass, even at room temperature.

Glass is optically transparent solid material which is typically hard, fragile and show glass transition. It is prepared by cooling molten constituents fast enough, to avoid visible crystallization formation. Glasses are usually poor conductor of heat and electricity and the incorporation of certain metal oxides in glasses give them colors. New Science and technology have dynamically given great improvement in glass manufacture and their new technological applications. The main advantages of this will be to provide the fundamental base of new optical glasses with number of applications especially, tellurite-glass base solid state lasers, optical fibers and amplifiers. Great research attention is needed for the development of new material for solid state lasers, optical switches, third order nonlinear optical materials, optical amplifiers, light emitting diodes and up-conversion glasses (Agrawal, 2013).

There is variety of techniques used for manufacturing of glass material such as thermal evaporation, sputtering, chemical reaction, amorphization, irradiation, melt quenching, sol gel, etc. (Cao and Wang, 2011). Among these techniques the melt quenching technique is most important and widely used technique. In last few decades, research on glass has been very active due to the increasing awareness of industry that from fabrication point of view, glasses are better than crystalline material and glasses can play important role in electronics development (Agrawal, 2013).

Glass is usually used to store materials that would be corrosive to other materials or it is used for the packaging foods and other materials, but it's not impervious to corrosion altogether. According to several researches, glass is, in fact, quite susceptible to degradation under particular conditions. the study aimed to identify the impact of the types of the transition metal elements (glass) to food and the effect of acid and storage in the concentration of these elements. The study focus on the selection of the type of the glass composition for the food packaging, and their positive, as well as negative, which may harm human health and make it defenseless to many diseases, including cancer.

## 1.2 History of Glass

Glass is a non- crystalline (amorphous) solid material that mostly exhibit glass transition and typically hard, brittle, optically transparent and clear with different colors. It can be used for various kinds of utensils such as mirrors, windows and bottles, etc. It is thought that glass has been first created during the Bronze Age around 3000 BC. But according to the evidence of archeologist, the first true man-made glass was found in coastal north Syria, Mesopotamia. Around 1500BC, first glass container was made in Egypt and Mesopotamia. For the next 300 years, the glass industry was developed rapidly and then it declined. It was revitalized in the 700BC in Mesopotamia and in 500's BC in Egypt. Egypt, Syria and the eastern coast of the Mediterranean Sea were glass manufacturing centers for next 500 years (Agrawal, 2013).

Glass has been found around 3000 BC in the Middle East. It is one of the oldest as well as newest material that is man's most valuables and versatile material in everyday life. A great research interest in the science and technology of glasses has received a great attention. Progress in the development of the glasses for different scientific applications was rapid and advanced through and early 20th century, in parallel with many other technology areas. Unfortunately, until 20th century mostly development was made experimentally by using common sense to guide experiment. The significant theoretical problems are amplified in non-crystalline solids specially, in glasses to understand their optical, structural and thermal properties due to lack of precise experimental information. There is tremendous need to accelerate the research to fill this gap.

Glass is one of the most common and versatile materials made by Man in our1 daily lives where millions of tons are produced annually. The word 'glass' is defined as a solid material, typically brittle and optically transparent substance. The 'glass' derivation from an Indo-European root which mean shiny, glare, glow or glaze. It is not known where, when or how the exactly time glass was first manufactured, although there is little doubt that the industry was established since 1500 B.C. The American Society for Testing and Materials (ASTM) standards defined that "Glass is an organic product of fusion which has been cooled to a rigid condition without crystallization". Glasses and glazes were manufactured far back in human history where natural glasses have been used by human being from the earliest times, which there is the archeological evidence found. The earliest pure glass dated from about 7000 B.C. where it was found in Egypt.

Glass manufacturing was very difficult and slow in the beginning because glass melting furnaces were very small and they produced hardly enough heat to melt glass. But in the 1st century BC, blow pipe was invented by Syrian craftsmen and this discovery, made glass manufacturing process easier, faster and cheaper. The most important center of glass manufacturing was the Egyptian city of Alexandria in 1000 AD. The first glass factory was built in Jamestown, Virginia in 1608. In the early 1800's, there was a big demand for window glass. Discovery of glass as a building material was first marked by Joseph Paxton's Crystal Palace in 1851 at the Great Exhibition. After 1890, glass manufacture and development began to increase rapidly along with its application in many other fields of technology.

The trend of basic scientific understanding of glasses in order to their manufacturing improvement and develop their new application has occurred only in last few decades. Micheal Faraday (1830) studied the conductivity and electrolysis of various glasses and he was among the researchers who initially studied the glasses in more basic way. By following the Fraday's Law the electrolysis of the glasses was evaluated by Warburg and Tegetmeier in 1984. At the same time, work on glass viscosity, glass transitions and the relationship between viscosity and crystallization rate was initiated by Tammann (1884).

The optical glasses were successfully prepared by Joseph Fraunhopper (1826). A great theoretical and experimental research on glass technology was carried out by a group, Department at Shelfeild University England under the supervision of W.E.S.Turner. This group was actively measuring the properties of optical glasses such as density, chemical durability, viscosity, electrical conductivity, and thermal expansion of wide variety of lab and commercial glasses. In the recent years, great research interest on rare earth doped glass technology has received great attention due to their potential applications such as sensors, detectors, receivers, optical amplifiers and solid-state laser sources. These days, the trend has been increased on co-doping of two different rare earth ions because of the possibility of enhancing the optical properties based on sequential energy transfer between two different rare earths (Atkins, 2010).

## 1.3 Definition of Glass

In everyday language the term glass designates a transparent substance, possessing the properties of hardness, rigidity, and brittleness, and, apart from transparency, these are the typical properties one normally associates with a solid. Glass also possesses a number of properties which are characteristic of the liquid state, and classification of glass as a liquid of very high viscosity rather than a solid would be in accordance with modern views (McMillan, 1979). Unlike crystals, glass does not have a sharp melting point, but like crystalline solids, glasses show elasticity (Paul, 1990). Due to the complexity of the structure of glass, it is not altogether surprising that an exact, all-encompassing definition for glass remains elusive, and instead a number of definitions have been suggested over the years. A more generally accepted definition is that offered by ASTM (C162) which states “a glass is an inorganic product of fusion which has cooled to a rigid condition without crystallization.” However, the ASTM definition limits the definition of glass to inorganic constituents, which fails to explain organic and molecular glasses that now represent a rapidly growing area of study (Varshneya and Mauro,2010; Doremus,1994). Newly developed solution-based sol–gel synthesis of oxide materials occurs at much lower temperature than traditional solid-state fusion processes and also allows powder lessnon-fusion processing of glasses. X-ray and electronic diffraction studies have shown that glass lacks long-range periodic atomic arrangement, and every type of glass exhibits time-dependent glass transformation behavior (Paul, 1990; Shelby and Lopes,2005). Pointing this out, Varshneya and Mauro (2010) suggest a scientific definition of glass as “a solid having a non-crystalline structure, which continuously converts to a liquid up on heating.” Zarzycki (1991) favors a more simplified definition: “a glass is a non-crystalline solid exhibiting the phenomenon of glass transition.” There by this definition also conveniently separates non-crystalline materials into the categories of glass and amorphous materials.

### 1.3.1 The Glass Transition

Glass is usually formed on solidification from the melting stage. The cooling is so rapid that crystallization does not have the time to occur. With a further decrease in temperature, viscosity continues to increase, resulting in a progressive freezing of the liquid to its final solidification. The relationship between crystal, liquid, and glass can be explained by means of specific volume as a function of temperature (see Figure 1.1).

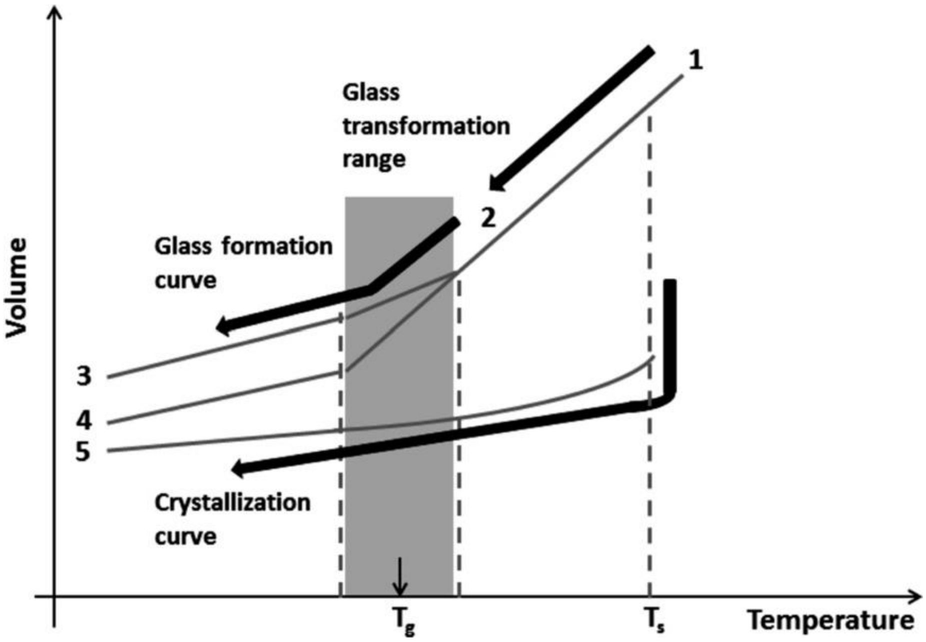

Figure 1.1 Schematic specific volume–temperature relationships for crystallization and glass formation. 1: liquid, 2: super cooled liquid, 3: glass on fast cooling, 4: glass on slow cooling, 5: crystal; Ts: melting temperature, Tg: glass transition temperature.

On cooling from an elevated temperature (Ts), at the point of solidification (or freezing), two phenomena may occur. There is either a discontinuous change in volume at the melting point if the liquid crystallizes, or crystallization is a voided and liquid passes to a super cooled state (between Ts and Tg) and the volume of the liquid decreases steadily until there is a decrease in the expansion coefficient at arrange in temperature called the glass transformation range. Below this temperature range the glass structure does not relax and the expansion coefficient is usually same as that for the crystalline solid. The intersection between the curve of the glassy state and that for the super cooled liquid is known as the glass transition temperature, Tg (Kingery and Uhlmann et al., 1976). This Tg varies with cooling rate (see Figure 1) and thus it is more accurate to call it a transformation range rather than a fixed point (Lancry and Régnier et al., 2012). The glass transition temperature increases with increasing cooling rate. The specific volume of the formed glass follows this same trend, increasing with increased cooling rate. With a slower cooling rate, the time available for the structure to relax increases and the super cooled liquid persists to a lower temperature resulting in a higher- density glass.

### 1.3.2 The Structure of Glass

Glasses exhibit broad, smeared out spectral transitions with typical bandwidths of tens of nanometers compare to crystals which possess sharp line spectra. These differences emerge from inhomogeneous broadening in glasses. The optically active ions inserted into the glass network experienced different environments due to the amorphous structure. In contrast, in crystals the optically active ions experienced nearly uniform environments as illustrated in Figure 1.2(a). The inhomogeneous broadening for crystals is much weaker than in glasses. Glasses often exhibit lower absorption and emission cross-sections due to the strong inhomogeneous broadening (Funabiki *et al.*, 2012).

Figure 1.2(b) displays the internal atomic arrangements of atoms or molecules in an amorphous and disordered network called glass in the absence of any periodicity. Glass structure is viewed as continuous non-periodic or irregular three-dimensional network without long range order. The short ranged order signifies more or less symmetrical array of atoms is in a local region generally less than 1.0 nm, but the lattice for each atom is not exactly uniform. The local short range order in oxide glasses mostly occurs around the elements of network former such as Te, Si, B, and P. Usually, the structural units having short ranged order are polyhedrons coordinated by strong covalent bonds and definite nearest ligands (Greenwood and Earnshaw, 1984).

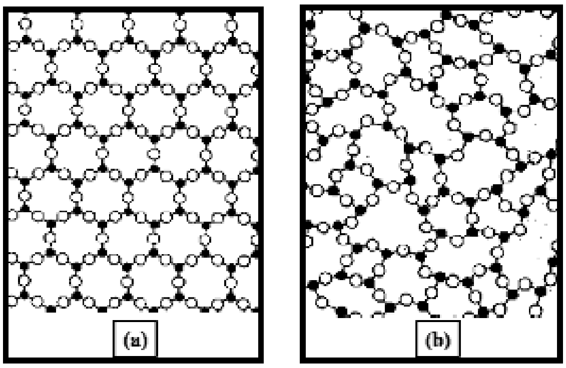

Figure 1.2: Schematic two-dimensional representation of atomic arrangements in a (a) crystal (regular) and (b) in glass (irregular).

It is customary to emphasize the choice of glass network former, modifier and RE dopants in achieving stable and efficient glass systems.

## 1.4 Common Glass Systems

The primary glass formers in commercial oxide glasses are silica ($SiO_2$), boron oxide ($B_2O_3$), and phosphorus pentoxide ($P_2O_5$), all of which readily form single component glasses (Kuzmany, 2009). Of these, other than silica, only boron oxide has some commercial importance and only when mixed with silica. Silica is the most important glass former and silicate glasses represent more than 95% of industrial glass production. Silica-based glass is technically important for its excellent chemical resistance (except HF and alkali) and small expansion coefficient which makes it a very good candidate for thermal shock resistance. Glass can be classified in different groups according to their intended usage or by their chemical composition (Shelby, 2005). The following sections describe the most common types of glass according to their chemical composition.

### 1.4.1 Soda-Lime Glass or Commercial Glass

Soda-lime glass is the most common commercial glass. It is comparatively inexpensive and amenable to recycling. The material Soda-lime glass is the glass of windows, bottles, and lightbulbs, used in vast quantities, the most common of them all. A typical composition of this glass is:

13-17% NaO (the “soda”), 5-10% CaO (the “lime”), and 70-75% SiO2

A small percentage of other reagents can be added for specific properties and application requirements. The principal addition in this type of glass, other than silica (SiO2), is sodium oxide or soda (Na2O). Even though sodium oxide contains oxygen atoms, it is held together by ionic rather than covalent bonds. The sodium atoms in the mixture donate electrons to the oxygen atom, producing a mixture of negatively charged oxygen ions and positively charged sodium ions. The oxygen atom with an extra electron binds to one silicon atom and does not form a bridge between pairs of silicon atoms. Therefore, the melting temperature of the mixture is considerably reduced. Relatively high amount of alkali content in the glass also causes an increase of the thermal expansion coefficient by about 20 times. Since sodium ions are so soluble in aqueous solution, calcium oxide (CaO) is added to the mixture to improve its insolubility (Shelby, 2005). Soda-lime glass is produced on a large scale and used for bottles, drinking glasses, and windows. Its light transmission properties, as well as low melting temperature, make it suitable for use as window glass. Its smooth and non-reactive surface makes it excellent as containers for food and drinks. Nowadays recycled glass, also known as cullet, is used to make green glass, which helps to save energy and reduce emissions. Soda-Lime glass has a low melting point, is easy to blow and mold, and is cheap. It is optically clear unless impure, when it is typically green or brown. Windows today have to be flat and that was not until 1950 easy to do; now the float-glass process, solidifying glass on a bed of liquid tin, makes “plate” glass cheaply and quickly.

**Composition:**
73% SiO2+1% Al2O3+17% Na2O+4% MgO+5% CaO

**General properties**

| | |
|---|---|
| Density | 2.440-2.490 kg/m$^3$ |
| Price | 0.8-1.7 USD/kg |

**Mechanical properties**

| | |
|---|---|
| Young’s modulus | 68-72 GPa |
| Yield strength (elastic limit) | 30-35 MPa |
| Tensile strength | 31-35 MPa |
| Elongation | 0 % |
| Hardness-Vickers | 439-484 HV |
| Fatigue strength at | 107 cycles 29.4-32.5 MPa |
| Fracture toughness | 0.55-0.7 MPa |

**Thermal properties**

| | |
|---|---|
| Maximum service temperature | 443-673 K |
| Thermal conductor or insulator | ? Poor insulator |
| Thermal conductivity | 0.7-1.3 W/m K |
| Specific heat capacity | 850-950 J/kg K |

**Electrical properties**

| | |
|---|---|
| Electrical conductor or insulator | Good insulator |
| Electrical resistivity | 7.943*$10^{17}$-7.943*$10^{18}$ μohm cm |
| Dielectric constant | 7-7.6 |
| Dissipation factor | 0.007-0.01 |
| Dielectric strength | 12-14 $10^{6}$ V/m |

**Eco properties: material**

| | |
|---|---|
| Global production, main component | 843*$10^{6}$ metric ton/yr |
| Reserves | 13*$10^{12}$ metric ton |

**Typical uses:** Windows, bottles, containers, tubing, lamp bulbs, lenses and mirrors, bells, glazes on pottery and tiles.

### 1.4.2 Lead Glass

Lead glass is similar to soda-lime glass where lime is replaced by a larger part of lead oxide (PbO). Lead glass typically contains 55– 65 wt% $SiO_2$, 18–38 wt% of PbO, and 13–15 wt% $Na_2O$ or $K_2O$. Lead glass is usually used for decorative glassware. It is also included in special optical glasses for their high refractive index. The networks in lead glass are more complete than those in soda-lime glass and thus they are stronger and have less internal friction. Lead oxide also makes the glass dense, hard, and X-ray absorbing, and therefore suitable for use in radiation shielding.

### 1.4.3 Aluminosilicate Glass

Aluminosilicate glasses are usually prepared from a ternary system with a typical composition 52–58 wt% $SiO_2$, 15–25 wt% of $Al_2O_3$, and 4–18 wt% CaO. With low thermal expansion and high softening temperature, this glass can tolerate high temperature better than soda-lime glass and is used in thermometers, combustion tubes, cookware, halogen lamps, furnaces, and fiberglass insulation.

### 1.4.4 Borosilicate Glass

Borosilicate glass contains substantial amounts of silica ($SiO_2$) and boron oxide ($B_2O_3$48%) as glass network formers, and are typically composed of 70–80 wt% $SiO_2$, 7–13 wt% of $B_2O_3$ 4–8 wt% $Na_2O$ or $K_2O$, and 2–8 wt% of $Al_2O_3$. Glass containing 7–13 wt% of $B_2O_3$ is known as low-borate borosilicate glass, and is mainly used to produce chemical apparatus, lamps, and tube envelopes. Glasses containing 15–25% $B_2O_3$, is known as high-borate borosilicate glass (Zachariasen, 1932). High-borate borosilicate glass is also known as leachable alkali-borosilicate glass with an optimum composition of 62.7 wt% $SiO_2$, 26.9 wt% of $B_2O_3$, 6.6 wt% $Na_2O$, and 3.5 wt% of $Al_2O_3$. This glass can be further processed to produce Controlled Pore Glass (CPG) which is widely used as a stationary media in chromatography, or alternatively, the pores can be closed up to yield a clear impervious glass known as Vycor 96% silica glass, commonly used in cookware. The increase of $B_2O_3$ content,with a very fine-scale secondary phase separation within the silica phase increases the chemical resistance, and in this aspect high-borate borosilicate glass differs greatly from low-borate (Shelby, 2005).

### 1.4.5 Silicon Dioxide ($SiO_2$)

Silicon dioxide is the glass former in borosilicate glass composition. Higher levels of silica increase the melting temperature as well as the working point, and reduces the coefficient of thermal expansion. With lower levels of silica, the resistance to acids deteriorates.

### 1.4.6 Boron trioxide ($B_2O_3$)

Boron trioxide reduces melting and working temperatures and improves hydrolytic stability when used below 13% by weight in the composition. Higher boron trioxide contents have an adverse effect on acid resistance and increases highly volatile alkali metal borates. On the other hand, lower borate contents increase the melting point of the glass by creating secure bonds with alkali metal ions. This helps to reduce the susceptibility to crystallization. Borate also play a major role in reducing the dielectric constant of glass (Zachariasen, 1932).

### 1.4.7 Alkali Metal Oxides

Sodium oxide ($Na_2O$) is widely used as a flux, especially in borosilicate glass composition, along with other alkali metal oxides like potassium dioxide ($K_2O$), lithium dioxide ($Li_2O$), and lead oxide (PbO). Alkali metal oxide reduces the working temperature and plays an important role in setting the thermal expansion. If the alkali metal oxides content is above a certain limit, glasses exhibit a high coefficient of thermal expansion. A higher level of alkali oxide also causes an adverse effect on hydrolytic stability. El-Malawany (2004) also discussed the role of alkali metal oxides on crystallization and suggested using at least two alkali metal oxides, even in small amounts, in order to have a positive effect on resisting unwanted crystallization. They also reported that beyond 1000 $^{o}$C, potassium borates evaporate more easily than sodium borates.

### 1.4.8 Alkali Earth Metal Oxides

Calcium oxide (CaO) is most commonly used as a property modifier component in glass composition. Small amounts of magnesium oxide (MgO), zinc oxide (ZnO), strontium oxide (SrO), and barium oxide (BaO) are also added separately based on application requirements. Calcium oxide can help greatly to accelerate the phase separation of borosilicate glasses. It also has a stabilizing effect on acid resistance. It has been found that limiting CaO to small amounts reduces the evaporation of highly volatile sodium and potassium borate compounds during hot forming (Rasmussen, 2012). If the amount of CaO exceeds certain limit, devitrification is likely to take place. Moreover, heat resistance and alkali resistance also deteriorate with high contents of CaO.

## 1.5 General Properties of Glass

1. Glass is hard and Brittleness It is a hard material as it has great impact resistance against applied load. However, at the same time, it is a brittle material as its breaks immediately when subjected to load.
2. Transparency The transparency is one such property of glass which creates a visual connect with the outside world
3. Refractive index of glass is probability the most common aptical property, is defined the ratio of the speed of light in a vacuum devised by speed of light in a medium
4. Absorption The next important property of glass is absorption and this is what is a key determinant of color in objects.
5. Reflection is an optical property that is seen when light flows from air to glass and a part of the incident light is reflected back from the glass surface.

6. Transmittance occurs when light is incident from air to glass and a part of the light gets transmitted through it. Optical glasses have excellent transmittance from the near UV and IR regions
7. The influence of visible and UV radiation (less than 380 nm wavelength) on glass is called solarization
8. Insulation It is an excellent insulator against heat, electricity and electromagnetic radiation because of its good insulating response against visible light transmission.
9. Color and shape varieties It can be blown, drawn and pressed to any colour, shape, and variety and is available in the market depending upon their use, dimensional requirements, and safety requirement.
10. Glass is 100% recyclable and one of the safest packaging materials due to its composition and properties.

# CHAPTER TWO

# EXPERIMENTAL PART

## 2.1 Absorption of Glass

Energy that is not transmitted through the glass or reflected off its surfaces is absorbed. Once glass has absorbed any radiant energy, the energy is transformed into heat, raising the glass temperature. Typical ¼-inch clear glass absorbs only about 7% of sunlight at a normal angle of incidence (also a 30-degree angle of incidence, as shown in the figure to the right). The absorptance of glass is increased by glass additives that absorb solar energy. If they absorb visible light, the glass appears dark. If they absorb ultraviolet radiation or near-infrared, there will be little or no change in visual appearance. Clear glass absorbs very little visible light, while dark-tinted glass absorbs a considerable amount. The absorbed energy is converted into heat, warming the glass. Thus, when "heat-absorbing" glass is exposed to the sun, it feels much hotter to the touch than clear glass. Tints are generally gray, bronze, or blue-green and were traditionally used to lower the solar heat gain coefficient and to control glare. Since they block some of the sun's energy, they reduce the cooling load placed on the building and its air-conditioning equipment. The effectiveness of heat-absorbing single glazing is significantly reduced if cool, conditioned air flows across the glass. Absorption is not the most efficient way to reduce cooling loads, as discussed later.

Absorption, in wave motion, the transfer of the energy of a wave to matter as the wave passes through it. The energy of an acoustic, electromagnetic, or other wave is proportional to the square of its amplitude, the maximum displacement or movement of a point on the wave; and, as the wave passes through a substance, its amplitude steadily decreases. If there is only a small fractional is said to be transparent to that particular radiation, but, if all the energy is lost, the medium is said to be opaque. All known transparent substances show absorption to same extent. For instance, the ocean appears to be transparent to sunlight near the surface, but it becomes opaque with depth.

As radiation passes through matter, it is absorbed to an extent depending on the nature of the substance and its thickness. A homogeneous substance of a given thickness may be thought of as consisting of a number of equally thin layers. Each layer will absorb the same fraction of the energy that reaches it. All glass and most plastics, however, are generally very absorptive of long-wave infrared energy. This property is best illustrated in the use of clear glass for greenhouses, where it allows the transmission of intense solar energy but blocks the retransmission of the low-temperature heat energy generated inside the greenhouse and radiated back to the glass.

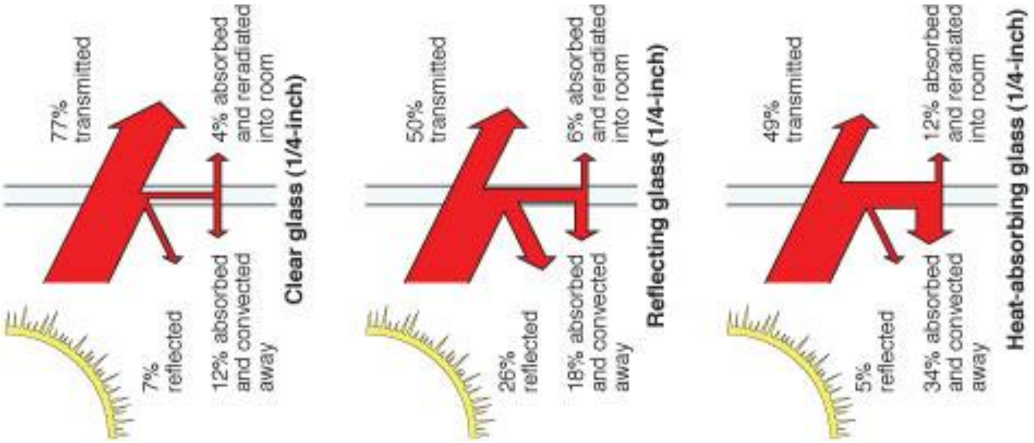

**Figure 2.1: Relation between absorption and thickness of the glass.**

Light is made up of photons. When a photon hits a material, it can emit energy that matches the amount required to excite an electron into a higher energy state. This will cause the photon to be absorbed by the material and not pass through it. When talking about glass specifically, we typically want as few photons as possible to be absorbed. As photons are absorbed, the intensity of the light on the other side of the glass is reduced. The absorbance factor of glass measures how much the intensity of the light decreases when it passes through the glass.

A material with high absorption, such as a neutral density filter for a camera, can dramatically decrease the intensity of the light passing through. This can be very useful in some situations, and very unwanted in others. If your application calls for as much light as possible to be let through, you will want a glass that features low absorption. If your application is being used to block light or reduce its intensity, you will want to select properties of glass to increase absorption.

When light travels through a glass, the intensity of the light is typically reduced. This absorption happens when the energy of a photon of light matches the energy needed to excite an electron within the glass to its higher energy state, and the photon is absorbed by the glass. The absorption spectrum of a glass varies by composition. Glasses with standard absorption peaks in their spectra, such as Kopp Glass filter plotted here, can be used to calibrate spectrophotometers. Large absorption peaks correspond to decreases in the transmission spectra. The absorbance of a glass, shown in the figure above as a function of wavelength, is often used to describe the decrease in intensity of light as it travels through the glass. It is defined as

$$A= -\log I/I_o$$

This value depends on the composition and thickness of the glass well as the wavelength of incident light.

## 2.2 Absorption Coefficient

The linear attenuation coefficient, attenuation coefficient, or narrow-beam attenuation coefficient characterizes how easily a volume of material can be penetrated by a beam of light, sound, particles, or other energy or matter. A large attenuation coefficient means that the beam is quickly “attenuated” (weakened) as it passes through the medium, and a small attenuation coefficient means that the medium is relatively transparent to the beam. The SI unit of attenuation coefficient is the reciprocal meter ($m^{-1}$). Extinction coefficient is an old term for this quantity but is still used in meteorology and climatology. Most commonly, the quantity measures the value of downward e-folding distance of the original intensity as the energy of the intensity passes through a unit (e.g. one meter) thickness of materials, so that an attenuation coefficient of 1 $m^{-1}$ means that after passing through 1 meter, the radiation will be reduced by a factor of e, and for material with a coefficient of 2 $m^{-1}$, it will be reduced twice by e, or $e^2$. Other measures may use a different factor than e, such as the decay attenuation coefficient below. The broad-beam attenuation coefficient counts forward-scattered radiation as transmitted rather than attenuated, and is more applicable to radiation shielding.

## 2.3 Experimental Part

Five samples of transparent soda-lime “clear” float glass were investigated using JASCO 770 UV-VIS-NIR spectrometer. The samples studied were 2 mm thick, the thickness measured with a caliper. The glass samples are cut into pieces of about 3 cm x 2 cm for detailed UV-VIS-NIR spectrometer analysis. Each sample exhibited a visual green tint easily observed by looking through the edge of the glass

## 2.4 Factors Change the Absorbance of Glass

There are three main factors that impact absorbance:

1. **Thickness:** Thickness is the easiest factor to understand and control. The more time it takes light to travel through glass, the more likely it is that a photon will excite an electron and be absorbed. By reducing the thickness of the material, you increase the amount of light that can pass through.
2. **Composition:** Glass reacts to light differently based on its chemical composition. Completely clear glass, for example, absorbs between 2-4% of

the light that passes through it, while prismatic glass absorbs between 5-10%. Different formulations of glass have different properties, and a glass chosen for its strength or impact resistance may not have the best optical clarity.

3. **Wavelength:** Certain wavelengths of light react with specific materials and increase their absorption. For example, take a green piece of glass. If a red light shines on green piece, it’s likely that almost no light would pass through. Shining a white light would cause a moderate amount of light to pass through. If you shine a green light onto the green glass, however, almost all of the light would pass through the material. When looking to block a certain wavelength of light as in many darkroom applications, for instance you would choose glass that has a high absorption of that specific wavelength.

### 2.5 UV-Vis-NIR Absorption Spectroscopy

The basic operational principle of UV-Vis-NIR spectroscopy is based on the measurement of light absorption due to electronic transitions in a sample. The typical UV-Vis-NIR spectrophotometer consists of a light source, a monochromator and a detector. The monochromator was used to spread out the beam of light into its certain wavelengths. A system of slit will focus the desired wavelength on the sample. The light that passes through the sample will reach the detector. The detector will then record the intensity of the transmitted light. The detector is generally a photomultiplier tube since light is reflected in different orders with overlapping wavelengths. Commonly, UV-Vis-NIR spectrophotometers utilize two light sources such as deuterium arc lamp for consistent intensity in the UV region and a tungsten-halogen lamp for light intensity in the visible and near infrared region. Some spectrophotometers use xenon flash lamps, which offer decent intensity over the UV, visible and near infrared regions. The mechanism of the spectrometer is comparatively easy and straightforward. A prism or diffraction grating separates the light beam from ultraviolet or visible light into different wavelength. Half mirrored device splits each monochromatic beam into two beams having equal intensity. These are called sample beam and reference beam. Filters are required since light is reflected in different orders with overlapping wavelengths. Dispersed light reaches a detector after passing through the sample of interest. The absorbance of a sample is determined by measuring the intensity ratios in the electronic detector without and with the sample. The incoming light will be converted into a current by the detector. The recorded intensity of the light is proportional to the detected current. The detector that normally used in UV-Vis-NIR spectroscopy is photomultiplier tube where it consists of a photoemissive cathode, several dynodes and an anode. Due to the photomultiplier is sensitive to UV and visible radiation, hence it has fast response time. However, it is limited to measure the low power radiation only as high intensity light will lead to the damage of the photomultiplier. The ultraviolet region scanned is normally from 200-400 nm and the visible portion is from 400-800 nm whereas near infrared scanning region from 800-1800nm.The basic components of an absorption spectrophotometer are illustrated in Fig. 2.2.

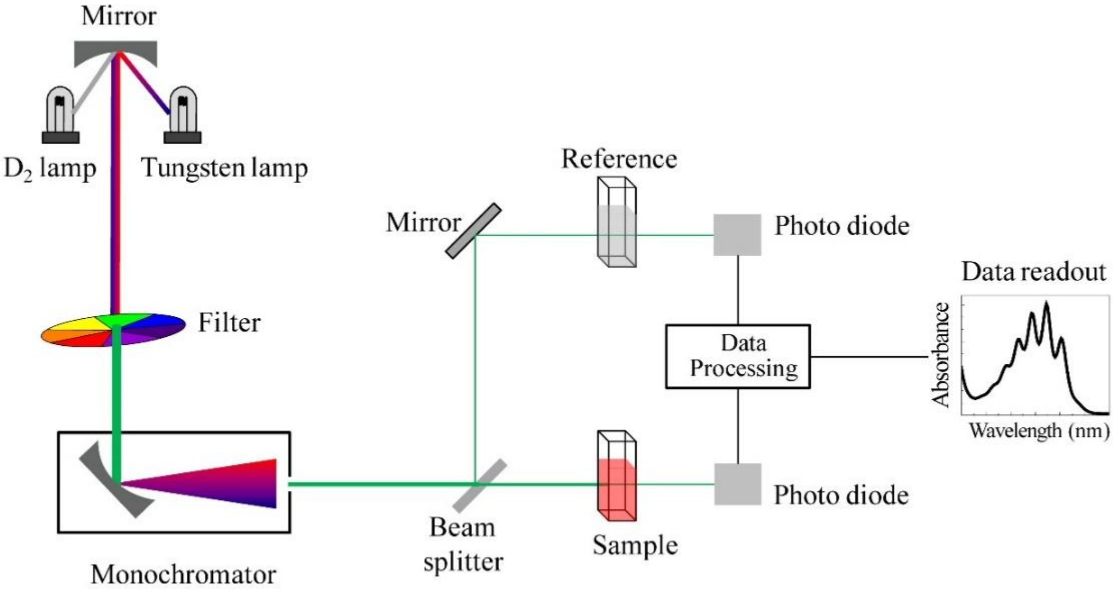

Fig. 2.2 Schematic diagram for UV-Vis-NIR spectroscopy.

## 2.6 Annealing Temperature

Annealing, a process of controlled cooling to relieve internal stresses and increase the stability of glass, can have several effects on the optical properties of glass. These effects can vary depending on the specific composition of the glass and the annealing conditions. Here are some of the key ways in which annealing can influence the optical properties of glass:

1. Reduction of Birefringence: Birefringence refers to the optical property of some materials, including glass, where light passing through the material splits into two polarized rays with different velocities. Internal stresses within glass can contribute to birefringence. Annealing helps to relieve these stresses, reducing birefringence and promoting optical clarity.
2. Minimization of Optical Distortion: Internal stresses in glass can also cause optical distortion, such as waviness or unevenness in the material. Annealing helps to minimize these distortions by promoting uniformity in the glass structure, resulting in improved optical clarity and consistency.
3. Enhancement of Transparency: Annealing can improve the transparency of glass by reducing the presence of microscopic imperfections, such as bubbles or inclusions, that can scatter or absorb light. By promoting a more uniform and homogeneous structure, annealing enhances the transmission of light through the glass, leading to improved optical properties.
4. Stabilization of Refractive Index: Annealing helps to stabilize the refractive index of glass by relieving internal stresses and promoting molecular rearrangement. This stabilization contributes to the consistency and predictability of the glass's optical behavior, particularly in applications where precise optical performance is required.
5. Reduction of Surface Defects: Annealing can also help to reduce surface defects, such as scratches or irregularities, that can affect the optical quality of glass. By promoting relaxation of surface stresses and promoting healing of

surface defects during the cooling process, annealing contributes to smoother, clearer glass surfaces.

Overall, annealing plays a crucial role in improving the optical properties of glass by relieving internal stresses, promoting structural uniformity, and minimizing defects. This results in glass with enhanced transparency, clarity, and optical performance, making it suitable for a wide range of optical applications, including lenses, windows, and display panels. In this project, the glass samples are annealed at 200, 300, 400, 500 $^{o}$C for 3 hours. The density and optical absorption spectra were investigated under these temperatures.

# CHAPTER THREE
# RESULTS & DISCUSSION

## 3.1 Results and Discussion

In this chapter, the results of different characterization analyses on commercial annealed Soda-Lime glass samples are presented. First, the density of the glass was discussed. It is then followed by structure and optical properties of the glass sample are presented.

## 3.2 Glass Density

Density is a reliable tool for evaluating the degree of compactness in glassy material. The densities of selected toughened Soda-Lime glasses are listed in Table 3.1.

**Table 3.1: Glass codes and Density**.

| **Density Calculation gm/cm$^3$** | | | | | | | | | | **Average Density gm/cm$^3$** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Glass Code** | **Weight in Air** | | | **Weight in Distilled Water** | | | **D1 gm/cm$^3$** | **D2 gm/cm$^3$** | **D3 gm/cm$^3$** | |
| | **A1** | **A2** | **A3** | **W1** | **W2** | **W3** | | | | |
| SL200 | 0.742 | 0.743 | 0.743 | 0.461 | 0.469 | 0.465 | 2.641 | 2.712 | 2.673 | 2.675 |
| SL300 | 0.861 | 0.864 | 0.861 | 0.539 | 0.512 | 0.521 | 2.674 | 2.461 | 2.538 | 2.558 |
| SL400 | 1.65 | 1.651 | 1.648 | 0.978 | 0.985 | 0.985 | 2.456 | 2.479 | 2.486 | 2.474 |

The variation of density with different type is presented in Fig. 3.1. It is clearly indicating an increase and decrease in the density by changing the annealing temperature from 200 to 400 °C for 3 hours annealing time. An increase in net molecular weight accompanies this increment and decrement. This reflects that a close-patched glass structure is obtained with the formation of a stable network structure (Xie et al., 2016).

The annealing process, typically used for soda lime glass, can affect the density of the glass. During the tempering process, the glass is rapidly heated and then cooled, creating internal stresses that increase the strength of the glass. This process can cause some changes in the density of the glass, though these changes are generally minimal (Rasmussen, 2012).

In most cases, the density of toughened soda lime glass remains relatively consistent with the density of untreated soda lime glass. However, there may be slight variations depending on factors such as the specific composition of the glass, the tempering process parameters, and any additional treatments applied.

In practice, the density of soda lime glass can vary within a small range around the typical density of soda lime glass, which is approximately 2.5 grams per cubic centimeter (g/cm³). The changes in density resulting from the toughening process are usually negligible and do not significantly affect the overall properties or performance of the glass (Rasmussen, 2012)..

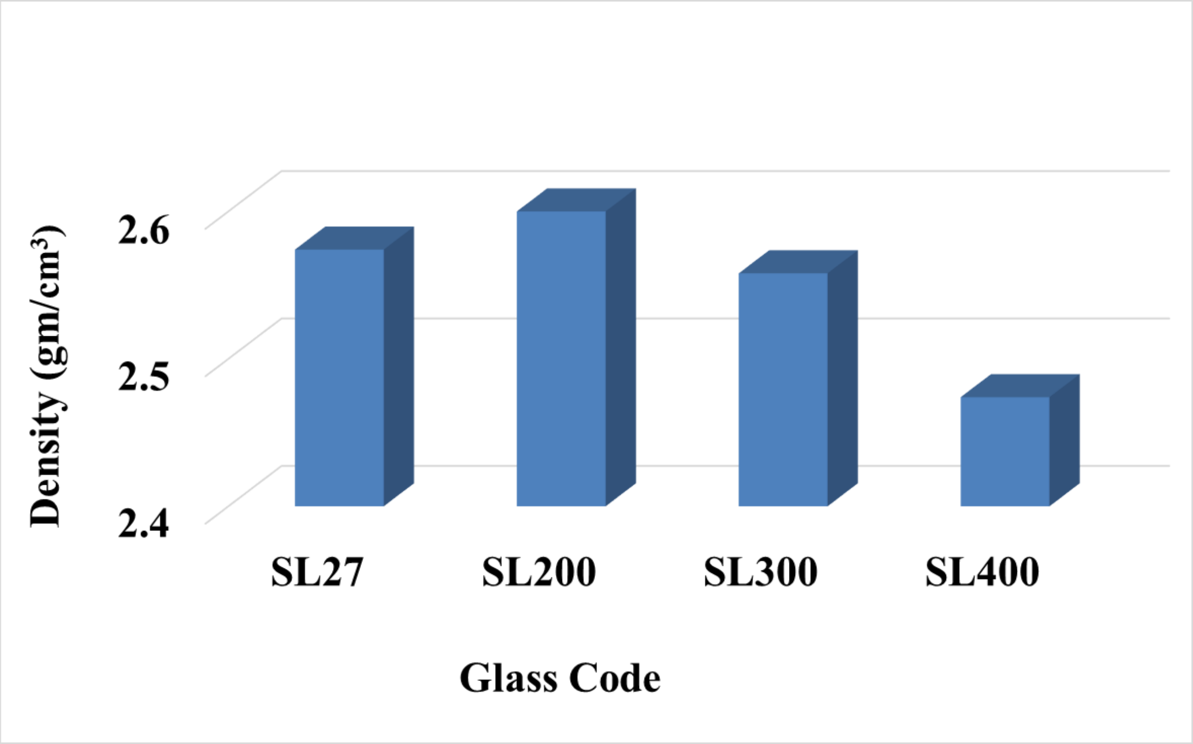

**Fig. 3.1: Density of different toughened soda lime glass.**

### 3.3 UV-Vis-NIR Spectra

A set of soda lime glass sample with different annealing temperature from 200 to 400 $^oC$ are characterized by using Jasco v770 UV-VIS-NIR spectrometer to determine the relationship between absorption and wavelength. When the glass annealing temperature was at 27 $^oC$ (room temperature), the wavelength in the horizontal axis and %Abs in the vertical axis that at the first absorption of light increase with the change in wave length until the wavelength approximately equal (350nm) and absorption is equal (%1.4), at wavelength of (850 to 1600) the absorption of light will remain, and the minimum wavelength of this sample (1600nm) at absorption of (%0.1) as shown figure 3.2:

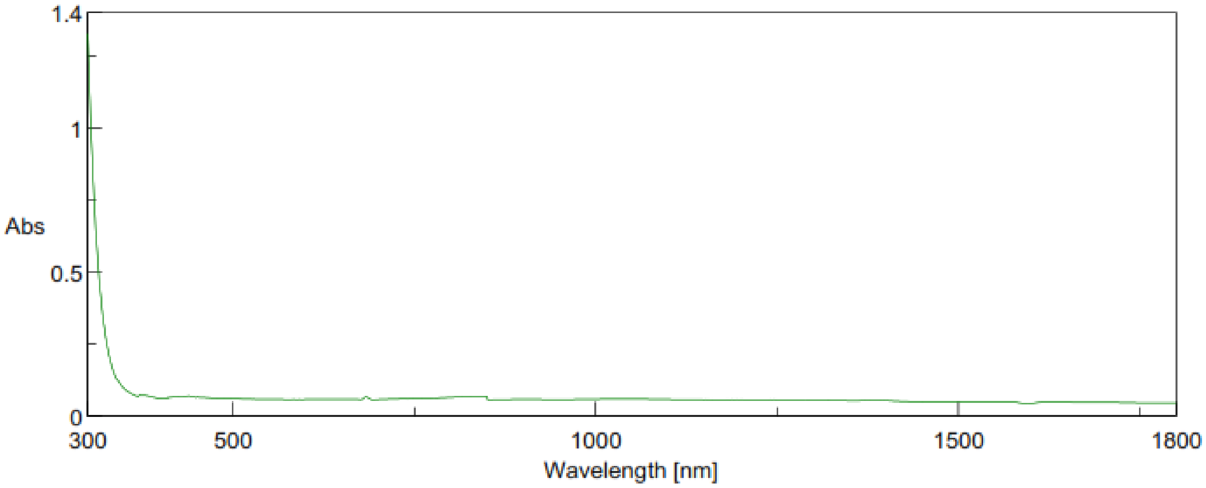

Figure 3.2: UV-VIS-NIR spectrum for glass sample SL27

For another glass sample, the annealing temperature was about 200 $^oC$, the spectra are shown in Figure 3.3. We can describe the relationship between wavelength and absorption by using Jasco v770 UV-VIS-NIR in the horizontal axis and %Abs in the vertical axis that, at the first, absorption of light increases with the change in wavelength until the wavelength is approximately equal (360nm) and absorption is equal (%2.5) (Zhang, 2009), at wave length of (800 to 1600nm) the absorption of light will remain, and the minimum wavelength of this sample (1500nm) at absorption of (%0.1) as shown Figure 3.3:

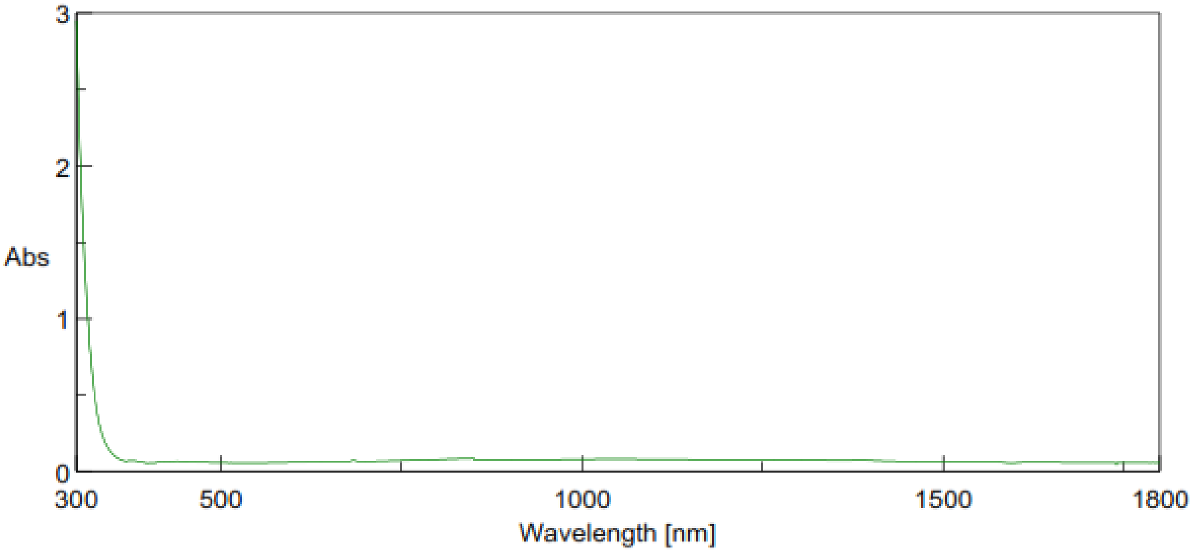

Figure 3.3: UV-VIS-NIR spectrum for glass sample SL200

For the third glass sample, the annealing temperature was about 300 $^{o}$C, as we see in Figure 3.4, the relationship between wavelength and absorption was studied by using Jasco v770 UV-VIS-NIR spectrometer and wavelength in the horizontal axis and absorption in the vertical axis in the first point (%0.05) the absorption is maximum also by increasing wavelength the absorption will be increasing in (400nm) and in (700 to 1300nm) approximately the absorption is constant, as shown in figure 3.4 (Zhang, 2009).

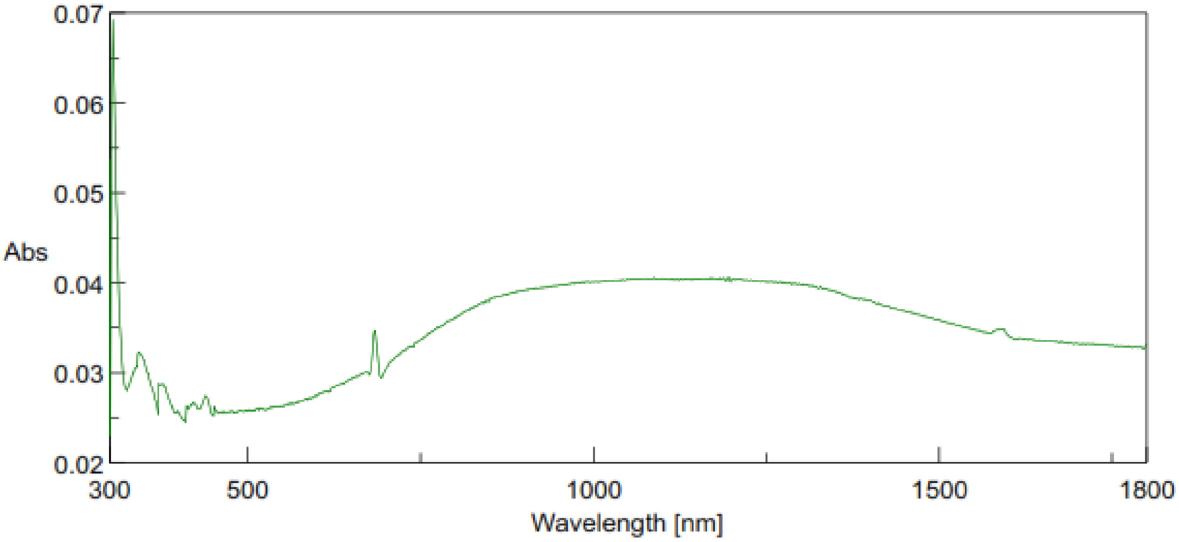

Figure 3.4: UV-VIS-NIR spectrum for glass sample SL300

For the fourth glass sample, the annealing temperature was about 400 °C; as we see in Figure 3.5, the relationship between wavelength in the horizontal axis and %Abs in the vertical axis, the minimum value of absorption is created in the first point (%0.009) with wavelength is equal to (300nm) and by increasing wavelength the absorption of light increased until (%0.029) again the increased value of wavelength and %Abs decrease and the peak is equal to (%0.026) in wavelength of (450 to 700nm) approximately is constant in (700nm) created another peak we have equal to (%0.028) in wavelength of (750 to 1800nm) the absorption of light in soda lime glass approximately remains, as shown in figure 3.5:

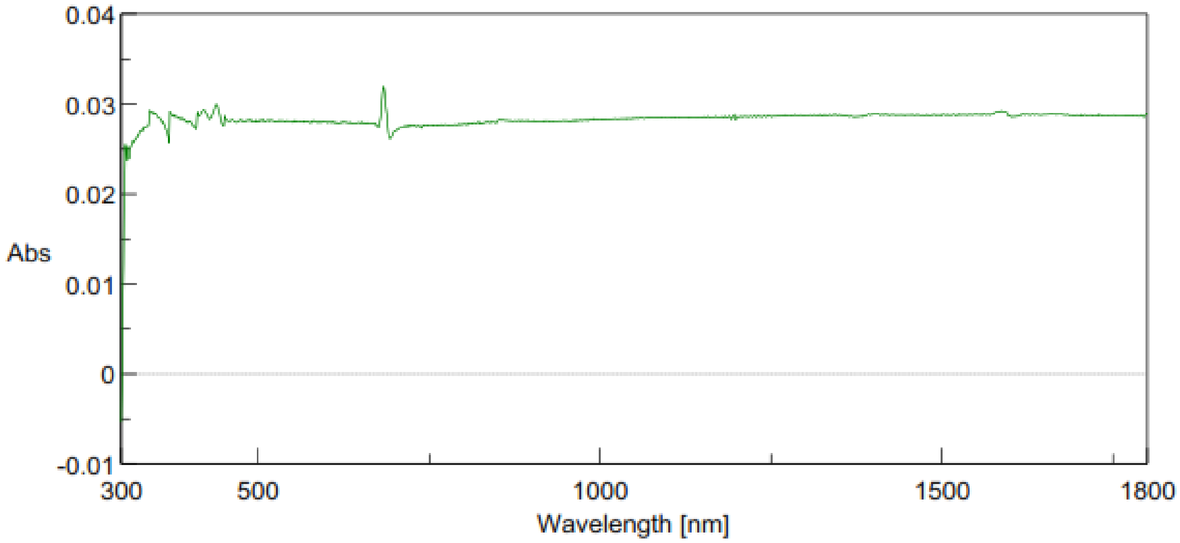

Figure 3.5: UV-VIS-NIR spectrum for glass sample SL400

The relation between sample thickness of soda lime glass that we use and minimum wave length with the absorption of light that we get it by using Jasco v770 UV-VIS-NIR spectrometer as shown in table 3.2:

Table 3.2: Wavelength and absorption % for different annealed glass.

| **Sample code** | **Wavelength(nm)** | **Absorption%** |
|---|---|---|
| SL27 | 300 | 1.2 |
| SL200 | 300 | 2.5 |
| SL300 | 300 | 0.07 |
| SL400 | 300 | 0.025 |

# CHAPTER FOUR

# CONCLUSIONS

## 4.1 Conclusions

Annealing temperature plays a significant role in determining the absorption characteristics of glass. Annealing is a process of controlled cooling to relieve internal stresses and prevent the glass from shattering. he higher density of soda-lime glass determined for the sample SL200 which is annealed at 200 $^{o}$C glass has a lower density around 2.675 g.cm$^{-3}$ while for SL400 glass sample, the lower density is obtained around 2.474 g.cm$^{-3}$. In summary, while there may be some indirect correlations between density and absorption in glass, the relationship is complex and depends on various factors such as atomic packing density, impurity content, crystallinity, and structural arrangement. Therefore, it is essential to consider multiple factors when studying the absorption properties of glass, rather than relying solely on density as a predictor of absorption. Generally, a higher density implies a more tightly packed structure with fewer void spaces between atoms. In such cases, there may be fewer opportunities for light to penetrate the material, leading to lower absorption. However, this relationship may not hold true for all glasses, especially those with complex compositions or structures. The relation between sample annealing temperature with absorption % of soda-lime glass studied by using Jasco v770 UV-IS-NIR spectrometer, the highest and lowest absorption % determined for glass samples SL200 and SL400 which was in the range 2.5 % and 0.05 % for the glass annealed at 200 and 400 $^{o}$C, respectively. In summary, the effect of annealing temperature on absorption in glass is complex and depends on various factors including structural changes, crystallization, defects and impurities, annealing stress, and chemical composition. Experimentation and analysis are often required to understand how annealing temperature specifically influences the absorption properties of a particular type of glass.

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