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A Study of the Optical Properties of Glass

دراسة الخصائص البصرية للزجاج

**A Thesis Submitted in Partial Fulfillment for the Requirement of
Master Degree in Physics**

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الآية

قال تعالى :

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(112) وَلَوْلَا فَضْلُ اللَّهِ عَلَيْكَ وَرَحْمَتُهُ لَهَمَّتْ طَائِفَةٌ مِّنْهُمْ أَنْ يُضِلُّوكَ وَمَا يُضِلُّونَ إِلَّا
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تَعْلَمُ ۚ وَكَانَ فَضْلُ اللَّهِ عَلَيْكَ عَظِيمًا (113)

صدق الله العظيم

سورة النساء

Dedication

I dedicate this work to

The soul of my Mother.....

The soul of My Father.....

My Brothers and Sisters.....

Everyone who taught me a letter.....

Acknowledgment

I would like to thank Allah for this grace to complete this work. I would also like to extend my thanks and graduated to the supervisors of Dr. Rawia Abd Elghani, for this encouragement and supervision over the course of this study. For her keenness to follow this study and for her indispensable help throughout this work.

Abstract

In this study, glass, its components, types and how it was manufactured were identified. The techniques of coloring the glass and the materials used for coloring the glass were also studied. Physical properties of glass such as corrosion and strength were studied. The optical characteristics of the glass were studied in detail. Characteristics of the transmission and absorption of ultraviolet and infrared radiation were investigated in the case of pure glass and the one which contains impurities. Dispersion of radiation by glass beside the index of refraction and dispersion of silica glass and oxide silica glass were studied. Either in the practical was studied absorption of visual radiation and ultra violet by uv-visible spectroscopy. It was found that the glass samples absorbed the ultraviolet radiation significantly, but the test strip showed that they did not absorb the radiation.

المستخلص

في هذه الدراسة تم التعرف على الزجاج و مكوناته و أنواعه و كيفية تصنيعه . أيضا تم التعرف على الطرق التي يتم بها تلوين الزجاج و المواد التي تستخدم لتلوين الزجاج . بعد ذلك تمت دراسة الخصائص الفيزيائية للزجاج مثل التآكل و قوة الشد و تمت دراسة الخصائص البصرية للزجاج بشكل تفصيلي , حيث تتمثل هذه الخصائص في الإنتقال و إمتصاص الأشعة فوق البنفسجية و تحت الحمراء في حالة الزجاج النقي و في حالة الزجاج الذي يحتوي على شوائب . ثانيا تمت دراسة تشتت الأشعة بواسطة الزجاج و دراسة معامل الإنكسار و التشتت لزجاج السيليكا و زجاج أكسيد السيليكا . عمليا تمت دراسة إمتصاص الأشعة المرئية و الأشعة فوق البنفسجية بواسطة جهاز مطيافية الأشعة فوق البنفسجية و المرئية , حيث أتضح أن عينات الزجاج تقوم بإمتصاص الأشعة فوق البنفسجية بدرجة كبيرة , اما شريحة الأختبار الطبي فقد أتضح أنها لا تقوم بإمتصاص الأشعة.

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Chapter One

Introduction

1.1 Glass

Glass is a non-crystalline amorphous solid that is often transparent and has widespread practical, technological, and decorative usage in, for example, window panes, tableware, and optoelectronics. The most familiar, and historically the oldest, types of glass are "silicate glasses" based on the chemical compound silica (silicon dioxide, or quartz), the primary constituent of sand. The term *glass*, in popular usage, is often used to refer only to this type of material, which is familiar from use as window glass and in glass bottles. Of the many silica-based glasses that exist, ordinary glazing and container glass is formed from a specific type called soda-lime glass, composed of approximately 75% silicon dioxide (SiO_2), sodium oxide (Na_2O) from sodium carbonate (Na_2CO_3), calcium oxide, also called lime (CaO), and several minor additives[1].

Many applications of silicate glasses derive from their optical transparency, giving rise to their primary use as window panes. Glass will transmit, reflect and refract light; these qualities can be enhanced by cutting and polishing to make optical lenses, prisms, fine glassware, and optical fibers for high speed data transmission by light. Glass can be coloured by adding metallic salts, and can also be painted and printed with vitreous enamels. These qualities have led to the extensive use of glass in the manufacture of art objects and in particular, stained glass windows. Although brittle, silicate glass is extremely durable, and many examples of glass fragments exist from early glass-making cultures. Because glass can be formed or molded into any shape, it has been traditionally used for vessels: bowls, vases, bottles, jars and drinking glasses. In its most solid forms it

has also been used for paperweights, marbles, and beads. When extruded as glass fiber and matted as glass wool in a way to trap air, it becomes a thermal insulating material, and when these glass fibers are embedded into an organic polymer plastic, they are a key structural reinforcement part of the composite material fiberglass. Some objects historically were so commonly made of silicate glass that they are simply called by the name of the material, such as drinking glasses and eyeglasses [1].

Scientifically, the term "glass" is often defined in a broader sense, encompassing every solid that possesses a non-crystalline (that is, amorphous) structure at the atomic scale and that exhibits a glass transition when heated towards the liquid state. Porcelains and many polymer thermoplastics familiar from everyday use are glasses. These sorts of glasses can be made of quite different kinds of materials than silica: metallic alloys, ionic melts, aqueous solutions, molecular liquids, and polymers. For many applications, like glass bottles or eyewear, polymer glasses (acrylic glass, polycarbonate or polyethylene terephthalate) are a lighter alternative than traditional glass[1].

1.2 Silicate glass

Naturally occurring glass, especially the volcanic glassobsidian, was used by many Stone Age societies across the globe for the production of sharp cutting tools and, due to its limited source areas, was extensively traded. But in general, archaeological evidence suggests that the first true glass was made in coastal north Syria, Mesopotamia or ancient Egypt. The earliest known glass objects, of the mid third millennium BCE, were beads, perhaps initially created as accidental by-products of metal-working (slags) or during the production of faience, a pre-glass vitreous material made by a process similar to glazing.

Glass remained a luxury material, and the disasters that overtook Late Bronze Age civilizations seem to have brought glass-making to a halt. Indigenous development of glass technology in South Asia may have begun in 1730 BCE. In ancient China, though, glassmaking seems to have a late start, compared to ceramics and metal work. The term *glass* developed in the late Roman Empire. It was in the Roman glassmaking center at Trier, now in modern Germany, that the late-Latin term *glesum* originated, probably from a Germanic word for a transparent, lustrous substance. Glass objects have been recovered across the Roman Empire in domestic, funerary, and industrial contexts. Examples of Roman glass have been found outside of the former Roman Empire in China, the Baltics, the Middle East and India.

Glass was used extensively during the middle Ages. Anglo-Saxon glass has been found across England during archaeological excavations of both settlement and cemetery sites. Glass in the Anglo-Saxon period was used in the manufacture of a range of objects including vessels, windows beads and was also used in jewelry. From the 10th-century onwards, glass was employed in stained glass windows of churches and cathedrals, with famous examples at Chartres Cathedral and the Basilica of Saint Denis. By the 14th-century, architects were designing buildings with walls of stained glass such as Sainte-Chappelle, Paris, (1203–1248) and the East end of Gloucester Cathedral. Stained glass had a major revival with Gothic Revival architecture in the 19th century. With the Renaissance, and a change in architectural style, the use of large stained glass windows became less prevalent. The use of domestic stained glass increased until most substantial houses had glass windows. These were initially small panes leaded together, but with the changes in technology, glass could be manufactured relatively cheaply in increasingly larger sheets. This led to larger window panes, and, in the 20th-

century, to much larger windows in ordinary domestic and commercial buildings [1].

In the 20th century, new types of glass such as laminated glass, reinforced glass and glass bricks increased the use of glass as a building material and resulted in new applications of glass. Multi-story buildings are frequently constructed with curtain walls made almost entirely of glass. Similarly, laminated glass has been widely applied to vehicles for windscreens. Optical glass for spectacles has been used since the middle Ages. The production of lenses has become increasingly proficient, aiding astronomers as well as having other application in medicine and science. Glass is also employed as the aperture cover in many solar energy collectors.

From the 19th century, there was a revival in many ancient glass-making techniques including cameo glass, achieved for the first time since the Roman Empire and initially mostly used for pieces in a neo-classical style. The Art Nouveau movement made great use of glass, with René Lalique, Émile Gallé, and Daum of Nancy producing colored vases and similar pieces, often in cameo glass, and also using luster techniques. Louis Comfort Tiffany in America specialized in stained glass, both secular and religious, and his famous lamps. The early 20th-century saw the large-scale factory production of glass art by firms such as Waterford and Lalique. From about 1960 onwards, there have been an increasing number of small studios hand-producing glass artworks, and glass artists began to class themselves as in effect sculptors working in glass, and their works as part fine arts [1].

In the 21st century, scientists observe the properties of ancient stained glass windows, in which suspended nanoparticles prevent UV light from causing

chemical reactions that change image colors, are developing photographic techniques that use similar stained glass to capture true color images of Mars for the 2019 ESA Mars Rover mission[1].

1.3Ingredients

Silica (SiO_2) is a common fundamental constituent of glass. In nature, vitrification of quartz occurs when lightning strikes sand, forming hollow, branching rootlike structures called fulgurites.

Fused quartz is a glass made from chemically-pure silica. It has excellent resistance to thermal shock, being able to survive immersion in water while red hot. However, its high melting temperature ($1723\text{ }^\circ\text{C}$) and viscosity make it difficult to work with. Normally, other substances are added to simplify processing. One is sodium carbonate (Na_2CO_3 , "soda"), which lowers the glass-transition temperature. The soda makes the glass water-soluble, which is usually undesirable, so lime (CaO , calcium oxide, generally obtained from limestone), some magnesium oxide (MgO) and aluminum oxide (Al_2O_3) are added to provide for a better chemical durability. The resulting glass contains about 70 to 74% silica by weight and is called a soda-lime glass. Soda-lime glasses account for about 90% of manufactured glass.

Most common glass contains other ingredients to change its properties. Lead glass or flint glass is more "brilliant" because the increased refractive index causes noticeably more specular reflection and increased optical dispersion. Adding barium also increases the refractive index. Thorium oxide gives glass a high refractive index and low dispersion and was formerly used in producing high-quality lenses, but due to its radioactivity has been replaced by lanthanum oxide in modern eyeglasses. Iron can be incorporated into glass to absorb

infrared radiation, for example in heat-absorbing filters for movie projectors, while cerium(IV) oxide can be used for glass that absorbs ultraviolet wavelengths[2].

1.4 The Aim of the Research

The main objective of this research after considering the method and material is to study the optical properties of glass.

1.5 Problem Statement

Glass is a very important material that is used in cars and buildings in the form of doors and windows. There were many problems faced by engineers when using glass, especially light penetration and absorption of radiation by glass. Also, glass is used in many medical devices, household appliances and utensils so it was necessary to study the glass and all its properties.

1.6 Thesis Layout

This thesis consist four chapters Chapter one introduction, chapter two physical properties, chapter three optical properties and chapter four material and method.

Chapter Two

Physical properties

2.1 Introduction

In the process of manufacture, silicate glass can be poured, formed, extruded and molded into forms ranging from flat sheets to highly intricate shapes. The finished product is brittle and will fracture, unless laminated or specially treated, but is extremely durable under most conditions. It erodes very slowly and can mostly withstand the action of water it is mostly resistant to chemical attack, does not react with foods, and is an ideal material for the manufacture of containers for foodstuffs and most chemicals. Glass is also a fairly inert substance.

2.2 Corrosion

Although glass is generally corrosion-resistant and more corrosion resistant than other materials, it still can be corroded. The materials that make up a particular glass composition have an effect on how quickly the glass corrodes. A glass containing a high proportion of Alkalis or alkali earths is less corrosion-resistant than other kinds of glasses [3].

2.3 Strength

Glass typically has a tensile strength of 7 megapascals (1,000 psi), however theoretically it can have a strength of 17 gigapascals (2,500,000 psi) due to glass's strong chemical bonds. Several factors such as imperfections like scratches and bubbles and the glass's chemical composition impact the tensile strength of glass. Several processes such as toughening can increase the strength of glass [4].

2.4 Contemporary production

Following the glass batch preparation and mixing, the raw materials are transported to the furnace. Soda-lime glass for mass production is melted in gas fired units. Smaller scale furnaces for specialty glasses include electric melters, pot furnaces, and day tanks. After melting, homogenization and refining (removal of bubbles), the glass is formed. Flat glass for windows and similar applications is formed by the float glass process, developed between 1953 and 1957 by Sir Alastair Pilkington and Kenneth Bickerstaff of the UK's Pilkington Brothers, who created a continuous ribbon of glass using a molten tin bath on which the molten glass flows unhindered under the influence of gravity. The top surface of the glass is subjected to nitrogen under pressure to obtain a polished finish. Container glass for common bottles and jars is formed by blowing and pressing methods. This glass is often slightly modified chemically (with more alumina and calcium oxide) for greater water resistance. Further glass forming techniques are summarized in the table Glass forming techniques.

Once the desired form is obtained, glass is usually annealed for the removal of stresses and to increase the glass's hardness and durability. Surface treatments, coatings or lamination may follow to improve the chemical durability (glass container coatings, glass container internal treatment), strength (toughened glass, bulletproof glass, windshields), or optical properties (insulated glazing, anti-reflective coating)[3].

2.5 Color

Color in glass may be obtained by addition of electrically charged ions (or color centers) that are homogeneously distributed, and by precipitation of finely dispersed particles (such as in photochromic glasses). Ordinary soda-lime glass appears colorless to the naked eye when it is thin, although iron (II) oxide (FeO) impurities of up to 0.1 wt% produce a green tint, which can be viewed in thick pieces or with the aid of scientific instruments. Further FeO and chromium (III) oxide (Cr₂O₃) additions may be used for the production of green bottles. Sulfur, together with carbon and iron salts, is used to form iron polysulfide and produce amber glass ranging from yellowish to almost black. A glass melt can also acquire an amber color from a reducing combustion atmosphere. Manganese dioxide can be added in small amounts to remove the green tint given by iron(II) oxide. Art glass and studio glass pieces are colored using closely guarded recipes that involve specific combinations of metal oxides, melting temperatures and "cook" times. Most colored glass used in the art market is manufactured in volume by vendors who serve this market, although there are some glassmakers with the ability to make their own color from raw materials [3].

2.6 Type of Glass

Fused quartz, also called fused-silica glass, vitreous-silica glass: silica (SiO₂) in vitreous, or glass, form (i.e., its molecules are disordered and random, without crystalline structure). It has very low thermal expansion, is very hard, and resists high temperatures (1000–1500 °C). It is also the most resistant against weathering (caused in other glasses by alkali ions leaching out of the glass, while staining it). Fused quartz is used for high-temperature applications such as furnace tubes, lighting tubes, melting crucibles, etc.

Soda-lime-silica glass, window glass: silica + sodium oxide (Na_2O) + lime (CaO) + magnesia (MgO) + alumina (Al_2O_3). Is transparent, easily formed and most suitable for window glass (see flat glass) It has a high thermal expansion and poor resistance to heat (500–600 °C). It is used for windows, some low-temperature incandescent light bulbs, and tableware. Container glass is a soda-lime glass that is a slight variation on flat glass, which uses more alumina and calcium, and less sodium and magnesium, which are more water-soluble. This makes it less susceptible to water erosion.

Sodium borosilicate glass, Pyrex: silica + boron trioxide (B_2O_3) + soda (Na_2O) + alumina (Al_2O_3). Stands heat expansion much better than window glass Used for chemical glassware, cooking glass, car head lamps, etc. Borosilicate glasses (e.g. Pyrex, Duran) have as main constituents silica and boron trioxide. They have fairly low coefficients of thermal expansion (7740 Pyrex CTE is $3.25 \times 10^{-6}/^\circ\text{C}$ as compared to about $9 \times 10^{-6}/^\circ\text{C}$ for a typical soda-lime glass), making them more dimensionally stable. The lower coefficient of thermal expansion (CTE) also makes them less subject to stress caused by thermal expansion, thus less vulnerable to cracking from thermal shock. They are commonly used for reagent bottles, optical components and household cookware [2].

Lead-oxide glass, crystal glass, lead glass: silica + lead oxide (PbO) + potassium oxide (K_2O) + soda (Na_2O) + zinc oxide (ZnO) + alumina. Because of its high density (resulting in a high electron density), it has a high refractive index, making the look of glassware more brilliant (called "crystal", though of course it is a glass and not a crystal). It also has a high elasticity, making glassware "ring". It is also more workable in the factory, but cannot stand heating very well. This kind of glass is also more fragile than other glasses and is easier to cut

Aluminosilicate glass: silica + alumina + lime + magnesia + barium oxide (BaO) + boric oxide (B_2O_3) Extensively used for fiberglass, used for making glass-reinforced plastics (boats, fishing rods, etc.) and for halogen bulb glass. Aluminosilicate glasses are also resistant to weathering and water erosion

Germanium-oxide glass: alumina + germanium dioxide (GeO_2). Extremely clear glass, used for fiber-optic waveguides in communication networks. Light loses only 5% of its intensity through 1 km of glass fiber [2] .

Another common glass ingredient is crushed alkali glass or 'cullet' ready for recycled glass. The recycled glass saves on raw materials and energy. Impurities in the cullet can lead to product and equipment failure. Fining agents such as sodium sulfate, sodium chloride, or antimony oxide may be added to reduce the number of air bubbles in the glass mixture. Glass batch calculation is the method by which the correct raw material mixture is determined to achieve the desired glass composition.

New chemical glass compositions or new treatment techniques can be initially investigated in small-scale laboratory experiments. The raw materials for laboratory-scale glass melts are often different from those used in mass production because the cost factor has a low priority. In the laboratory mostly pure chemicals are used. Care must be taken that the raw materials have not reacted with moisture or other chemicals in the environment (such as alkali or alkaline earth metal oxides and hydroxides, or boron oxide), or that the impurities are quantified (loss on ignition). Evaporation losses during glass melting should be considered during the selection of the raw materials, e.g., sodium selenite may be preferred over easily evaporating SeO_2 . Also, more readily reacting raw materials may be preferred over relatively inert ones, such

as $\text{Al}(\text{OH})_3$ over Al_2O_3 . Usually, the melts are carried out in platinum crucibles to reduce contamination from the crucible material. Glass homogeneity is achieved by homogenizing the raw materials mixture (glass batch), by stirring the melt, and by crushing and re-melting the first melt. The obtained glass is usually annealed to prevent breakage during processing [2].

2.7 Another Type of Glass

To make glass from materials with poor glass forming tendencies, novel techniques are used to increase cooling rate, or reduce crystal nucleation triggers. Examples of these techniques include aerodynamic levitation (cooling the melt whilst it floats on a gas stream), splat quenching (pressing the melt between two metal anvils) and roller quenching (pouring the melt through rollers).

1.Fiberglass

Fiberglass (also called glass-reinforced-plastic) is a composite material made up of glass fibers (also called fiberglass or glass filler embedded in a plastic resin. It is made by melting glass and stretching the glass into fibers. These fibers are woven together into a cloth and left to set in a plastic resin.

Fiberglass filaments are made through a pultrusion process in which the raw materials (sand, limestone, kaolin clay, fluorspar, colemanite, dolomite and other minerals) are melted in a large furnace into a liquid which is extruded through very small orifices (5–25 micrometres in diameter if the glass is E-glass and 9 micrometers if the glass is S-glass).

Fiberglass has the properties of being lightweight and corrosion resistant. Fiberglass is also a good insulator, allowing it to be used to insulate buildings.

Most fibreglasses are not alkali resistant. Fibreglass also has the property of becoming stronger as the glass ages [1].

2. Network glasses



Figure(2.1)A CD-RW (CD), Chalcogenide forms glass the basis of rewritable CD and DVD solid-state memory technology

Some types of glass that do not include silica as a major constituent may have physico-chemical properties useful for their application in fiber optics and other specialized technical applications. These include fluoride glass, aluminate and aluminosilicate glass, phosphate glass, borate glass, and chalcogenide glass.

There are three classes of components for oxide glass: network formers, intermediates, and modifiers. The network formers (silicon, boron, and germanium) form a highly cross-linked network of chemical bonds. The intermediates (titanium, aluminum, zirconium, beryllium, magnesium, zinc) can act as both network formers and modifiers, according to the glass composition. The modifiers (calcium, lead, lithium, sodium, potassium) alter the network structure; they are usually present as ions, compensated by nearby non-bridging oxygen atoms, bound by one covalent bond to the glass network and holding one negative charge to compensate for the positive ion nearby. Some elements can play multiple roles; e.g. lead can act both as a network former (Pb^{4+} replacing Si^{4+}), or as a modifier.

The presence of non-bridging oxygen's lowers the relative number of strong bonds in the material and disrupts the network, decreasing the viscosity of the melt and lowering the melting temperature [2].

The alkali metal ions are small and mobile; their presence in glass allows a degree of electrical conductivity, especially in molten state or at high temperature. Their mobility decreases the chemical resistance of the glass, allowing leaching by water and facilitating corrosion. Alkaline earth ions, with their two positive charges and requirement for two non-bridging oxygen ions to compensate for their charge, are much less mobile themselves and also hinder diffusion of other ions, especially the alkalis. The most common commercial glass types contain both alkali and alkaline earth ions (usually sodium and calcium), for easier processing and satisfying corrosion resistance. Corrosion resistance of glass can be increased by DE alkalization, removal of the alkali ions from the glass surface by reaction with sulfur or fluorine compounds. Presence of alkaline metal ions has also detrimental effect to the loss tangent of the glass, and to its electrical resistance; glass manufactured for electronics (sealing, vacuum tubes, lamps ...) have to take this in account.

Addition of lead(II) oxide lowers melting point, lowers viscosity of the melt, and increases refractive index. Lead oxide also facilitates solubility of other metal oxides and is used in colored glass. The viscosity decrease of lead glass melt is very significant (roughly 100 times in comparison with soda glass); this allows easier removal of bubbles and working at lower temperatures, hence its frequent use as an additive in vitreous enamels and glass solders. The high ionic radius of the Pb^{2+} ion renders it highly immobile in the matrix and hinders the movement of other ions; lead glasses therefore have high electrical resistance, about two

orders of magnitude higher than soda-lime glass ($10^{8.5}$ vs $10^{6.5}$ $\Omega\cdot\text{cm}$, DC at 250 °C). For more details, see lead glass.

Addition of fluorine lowers the dielectric constant of glass. Fluorine is highly electronegative and attracts the electrons in the lattice, lowering the polarizability of the material. Such silicon dioxide-fluoride is used in manufacture of integrated circuits as an insulator. High levels of fluorine doping lead to formation of volatile SiF_2O and such glass is then thermally unstable. Stable layers were achieved with dielectric constant down to about 3.5–3.7[2].

3. Colloidal glasses

Concentrated colloidal suspensions may exhibit a distinct glass transition as function of particle concentration or density.

In cell biology, there is recent evidence suggesting that the cytoplasm behaves like a colloidal glass approaching the liquid-glass transition. During periods of low metabolic activity, as in dormancy, the cytoplasm vitrifies and prohibits the movement to larger cytoplasmic particles while allowing the diffusion of smaller ones throughout the cell.

4. Glass-ceramics



Figure (2.2) a high-strength glass-ceramic cooktop with negligible thermal expansion

Glass-ceramic materials share many properties with both non-crystalline glass and crystalline ceramics. They are formed as a glass, and then partially crystallized by heat treatment. For example, the microstructure of whiteware ceramics frequently contains both amorphous and crystalline phases. Crystalline grains are often embedded within a non-crystalline intergranular phase of grain boundaries. When applied to whiteware ceramics, vitreous means the material has an extremely low permeability to liquids, often but not always water, when determined by a specified test regime.

The term mainly refers to a mix of lithium and aluminosilicates that yields an array of materials with interesting thermomechanical properties. The most commercially important of these have the distinction of being impervious to thermal shock. Thus, glass-ceramics have become extremely useful for countertop cooking. The negative thermal expansion coefficient (CTE) of the crystalline ceramic phase can be balanced with the positive CTE of the glassy phase. At a certain point (~70% crystalline) the glass-ceramic has a net CTE near zero. This type of glass-ceramic exhibits excellent mechanical properties and can sustain repeated and quick temperature changes up to 1000 °C [1].

2.8 Structure

As in other amorphous solids, the atomic structure of a glass lacks the long-range periodicity observed in crystalline solids. Due to chemical bonding characteristics, glasses do possess a high degree of short-range order with respect to local atomic polyhedral.

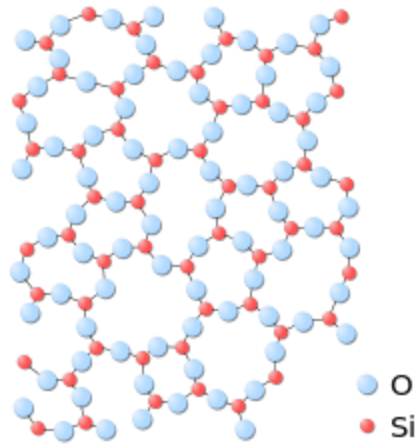


Figure (2.3) the amorphous structure of glassy silica (SiO_2) in two dimensions. No long-range order is present, although there is local ordering with respect to the tetrahedral arrangement of oxygen (O) atoms around the silicon (Si) atoms [2].

2.8.1 Formation from a super cooled liquid

In physics, the standard definition of a glass (or vitreous solid) is a solid formed by rapid melt quenching, although the term glass is often used to describe any amorphous solid that exhibits a glass transition temperature T_g . For melt quenching, if the cooling is sufficiently rapid (relative to the characteristic crystallization time) then crystallization is prevented and instead the disordered atomic configuration of the supercooled liquid is frozen into the solid state at T_g . The tendency for a material to form a glass while quenched is called glass-forming ability. This ability can be predicted by the rigidity theory. Generally, a glass exists in a structurally metastable state with respect to its crystalline form, although in certain circumstances, for example in atactic polymers, there is no crystalline analogue of the amorphous phase [2].

Glass is sometimes considered to be a liquid due to its lack of a first-order phase transition where certain thermodynamic variables such as volume, entropy and enthalpy are discontinuous through the glass transition range. The glass transition may be described as analogous to a second-order phase transition where the intensive thermodynamic variables such as the thermal expansivity and heat capacity are discontinuous. Nonetheless, the equilibrium theory of phase transformations does not entirely hold for glass, and hence the glass transition cannot be classed as one of the classical equilibrium phase transformations in solids [2].

Glass is an amorphous solid. It exhibits an atomic structure close to that observed in the supercooled liquid phase but displays all the mechanical properties of a solid. The notion that glass flows to an appreciable extent over extended periods of time is not supported by empirical research or theoretical analysis (see viscosity of amorphous materials). Laboratory measurements of room temperature glass flow do show a motion consistent with a material viscosity on the order of 10^{17} – 10^{18} Pa s.

Although the atomic structure of glass shares characteristics of the structure in a supercooled liquid, glass tends to behave as a solid below its glass transition temperature. A supercooled liquid behaves as a liquid, but it is below the freezing point of the material, and in some cases will crystallize almost instantly if a crystal is added as a core. The change in heat capacity at a glass transition and a melting transition of comparable materials are typically of the same order of magnitude, indicating that the change in active degrees of freedom is comparable as well. Both in a glass and in a crystal it is mostly only the vibrational degrees of freedom that remain active, whereas rotational and

translational motion is arrested. This helps to explain why both crystalline and non-crystalline solids exhibit rigidity on most experimental time scales [2].

2.9 Behavior of Antique Glass

The observation that old windows are sometimes found to be thicker at the bottom than at the top is often offered as supporting evidence for the view that glass flows over a timescale of centuries, the assumption being that the glass has exhibited the liquid property of flowing from one shape to another. This assumption is incorrect, as once solidified, glass stops flowing. The reason for the observation is that in the past, when panes of glass were commonly made by glassblowers, the technique used was to spin molten glass so as to create a round, mostly flat and even plate (the crown glass process, described above). This plate was then cut to fit a window. The pieces were not absolutely flat; the edges of the disk became a different thickness as the glass spun. When installed in a window frame, the glass would be placed with the thicker side down both for the sake of stability and to prevent water accumulating in the lead comes at the bottom of the window. Occasionally, such glass has been found installed with the thicker side at the top, left or right.

Mass production of glass window panes in the early twentieth century caused a similar effect. In glass factories, molten glass was poured onto a large cooling table and allowed to spread. The resulting glass is thicker at the location of the pour, located at the center of the large sheet. These sheets were cut into smaller window panes with nonuniform thickness, typically with the location of the pour centered in one of the panes (known as "bull's-eyes") for decorative effect. Modern glass intended for windows is produced as float glass and is very uniform in thickness.

Chapter Three

Optical Properties

3.1 Transmission of silica glass

Silica glass is the only material whose ultimate optical loss released in optical fiber fabricated using an elaborate technique based on a vapor phase reaction. The optical absorption of silica glass has been extensively over a wide range of wavelength although transition metal and *OH* impurity absorption bands have been virtually eliminated from fiber, bands related to gaseous species and defects are apparent. Recent applications such as fiber Bragg grating devices and UV lithography on the other hand the Kramers-Kronig (K-K) analysis, which is used to examine the absorption properties through a complex index N (where $N = n - ik$, n is the refractive index and k is the extinction coefficient), has been shown to be useful for investigating glass structure. K-K analysis is also used for describing the IR absorption tail determining theoretical loss in fibers. This Datareview provides a brief overview of optical absorption of silica glass [5].

Glass is in widespread use largely due to the production of glass compositions that are transparent to visible light. In contrast, polycrystalline materials do not generally transmit visible light. The individual crystallites may be transparent, but their facets (grain boundaries) reflect or scatter light resulting in diffuse reflection. Glass does not contain the internal subdivisions associated with grain boundaries in polycrystals and hence does not scatter light in the same manner as a polycrystalline material. The surface of a glass is often smooth since during glass formation the molecules of the supercooled liquid are not forced to dispose in rigid crystal geometries and can follow surface tension, which imposes a

microscopically smooth surface. These properties, which give glass its clearness, can be retained even if glass is partially light-absorbing—i.e., colored

Glass has the ability to refract, reflect, and transmit light following geometrical optics,¹ without scattering it (due to the absence of grain boundaries). It is used in the manufacture of lenses and windows. Common glass has a refraction index around 1.5. This may be modified by adding low-density materials such as boron, which lowers the index of refraction (see crown glass), or increased (to as much as 1.8) with high-density materials such as (classically) lead oxide (see flint glass and lead glass), or in modern uses, less toxic oxides of zirconium, titanium, or barium. These high-index glasses (inaccurately known as “crystal” when used in glass vessels causes more chromatic dispersion of light, and are prized for their diamond-like optical properties.

According to Fresnel equations, the reflectivity of a sheet of glass is about 4% per surface (at normal incidence in air), and the transmissivity of one element (two surfaces) is about 90%. Glass with high germanium oxide content also finds application in optoelectronics e.g., for light-transmitting optical fibers[5].

3.1.1 Fundamental (UV/IR) Absorption

The fundamental optical absorption bands in silica glass appear in a **UV** region of $0.1 \mu m$ (10 eV) due to electronic transitions and in an **IR** region of $10 \mu m$ (0.1 eV) due to molecular vibrations in (SiO_4) tetrahedral molecules, the absorption diminishes in the region between this UV and IR regions. Additional bands appear in this transparent region. Absorption due to defect centers and the Urbach tail appears in the UV-visible region, while impurity absorption due to transition metal and *OH* ions appear in a region from **UV** to **IR**.

The UV absorption beaks are located at 10.2, 11.7, 14.3 and 17.2 eV and are understood as electronic transitions from various valence bands conduction of O_{2p} electrons. The 10.2 eV beak strongest and has an absorption coefficient α with the magnitude of the order of 10^6 cm^{-1} based on K-K analysis, inn which $\alpha = 4\pi k/\lambda$ (where λ is the wavelength).

The **IR** absorption peaks appear at 9.1, 12.5 and $21 \mu\text{m}$ and are assigned to molecular vibrations as symmetric bond stretching vibration(ν_3),symmetric bond stretching vibration ($\nu_1 = 2\nu_4$) and bond bending vibration(ν_4), respectively. The $9.1 \mu\text{m}$ (1100 cm^{-1}) peak is the main one and its α value has magnitude of the order of 10^4 cm^{-1} . Overtone and combination modes appear in the shorter wavelength region, summarized in Table 1.they form an IR absorption tail together with fundamental modes. This tail measured for silica specimens with various lengths in the 3-6 μm regions [5].

Table (3.1) Peak positions and intensities of IR absorption bands in silica glass [H].

Wavelength (μm)	Intensity (dB/km)
21.3	5×10^9
12.5	2×10^9
9.1	1×10^{10}
6.2	8×10^7
5.3	1×10^8
5.1	6×10^7
4.5	4×10^6
4.2	1×10^6
3.8	6×10^5
3.2	6×10^4
3.0	5×10^4

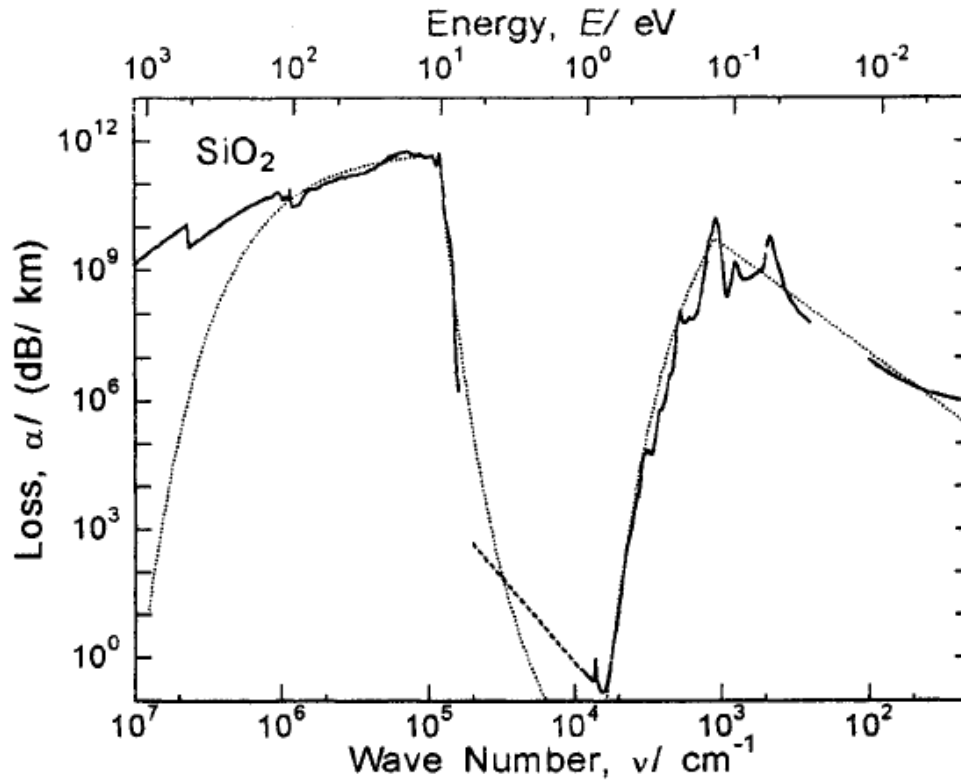


Figure (3.1) Absorption spectra of silica glass

Fig (3.1) shows the absorption properties of silica glass and the pure silica fiber. Model absorption curves derived by K-K analysis are also shown, assuming that the courses are given by an empirical form. This curves can be calculated reproduces the measured reflective index, using the K-K relation, as

$$\begin{aligned}
n(\nu_i) &= 1 + \frac{1}{\pi} \int_0^{\infty} \frac{\nu k(\nu)}{\nu^2 - \nu_i^2} d\nu \\
&= 1 + \frac{1}{2\pi^2} \int_0^{\infty} \frac{\alpha(\nu)}{\nu^2 - \nu_i^2} d\nu
\end{aligned} \tag{3.1}$$

$$k(\nu_i) = \frac{2\nu_i}{\pi} \int_0^{\infty} \frac{n(\nu)}{\nu_i^2 - \nu^2} d\nu \tag{3.2}$$

Where ν is a wave number $1/\lambda$, giving $\alpha = 4\pi\nu k$. This method is useful for determining the IR absorption tail, because it avoids the effects of *OH* impurities.

Batted curves: model absorption spectra calculated to reproduce

The measured refractive index curve; solid curves: measured absorption spectra;

broken line: Rayleigh scattering and loss spectrum of a low loss pure silica core single-mode fiber

3.1.2 Absorption Due to Defect Centers

Silica glass contains disordered bonding structures such as oxygen deficient centers (**ODC**) and peroxy linkages. They can be turned into electronic defects by irradiation by high energy photons and particles such as γ rays and neutrons. Typical defects are *Si - E'* centres (electron trapped *Si*), non-bridging oxygen hole centers (NBOHC, hole trapped non-bridging *O*) and peroxy radicals (**POR**). Absorption bands which appear at 7.6, 5.8, 5.0 and 4.8 eV are correlated to the defects, as summarized in Table 3.2

Table 3.2 Correlation between absorption bands and defects in silica glass

Absorption band (eV)	Defect	Remark
7.6	ODC	$\equiv\text{Si-Si}\equiv^1$
5.8	E' centre	$\equiv\text{Si}\bullet^2$
5.0	Unrelaxed ODC E' centre Silicon lone pair centre	$\equiv\text{Si}\dots\text{Si}\equiv$ $\equiv\text{Si}\bullet$ $\equiv\text{Si}:$
4.8	NBOHC POR Ozone molecule	$\equiv\text{Si-O}\bullet$ $\equiv\text{Si-O-O}\bullet$ O_3
3.8	Peroxy linkage	$\equiv\text{Si-O-O-Si}\equiv$
2.0	NBOHC POR Ozone molecule	$\equiv\text{Si-O}\bullet$ $\equiv\text{Si-O-O}\bullet$ O_3

¹ \equiv represents bonding to 3 oxygen atoms; ² \bullet denotes unpaired electron.

Defects are formed in silica fibers during drawing, in which disordered structures initiated at high temperatures above 2000°C are quenched in the fibers at extreme rates of above 10³ °C/s. A drawing induced band appears at 2.0 eV (0.62 μm) in high purity silica fibers. Although this band is correlated to NBOHC, it has also been suggested that it is related to **ODC** or O_3 .

Defects initiated by irradiation with excimer lasers such as **KrF** (248 nm) and **ArF** (193 nm) lasers induce bands in the UV region. The photo-induced bands have a substantial effect on silica glass used as lens and photomask for UV lithography. The laser irradiation increases the E' and NBOHC concentrations and such increases are correlated to bands of 7.6 and 5.8 eV. The induced band tends to be small in silica glass with high OH content.

Fiber Bragg grating devices are attracting increasing attention because they offer a variety of light manipulating functions based on Bragg reflection. The Bragg grating is written in $Ge:SiO_2$ fibres by modulated laser irradiation. This irradiation causes a refractive index increase and the modulated index profile forms the grating. The index increase is understood to result

From the increased absorption due to the increase in defects such as $Ge - E'$ through the K-K relation, the formation of electric dipoles at defects

Through the Pockels effect, and the increased density of glass through the Lorentz-Lorentz law, Photo-induced $Ge - E'$, which exhibits an absorption band at 5 eV similar to that of Si- E' , dominates the index increase. The index increase in Ge: SiO_2 fibers are enhanced to 10^3 by H_2 loading, compared with IQ-4 for unloaded fibers [5].

3.1.3 Absorption Due to Impurities

Common impurities in silica glass are transition metal ions such as Fe, Co, V, Cu and Cr and OH groups. Absorption bands due to these ions appear over a wide range from UV to near IR because of the complex transition process of 3d electrons, and the bands depend on their valence states in glass, Although the amount of each transition metal impurity must be reduced to a few ppb, these impurities are completely removed from the fibers based on the difference between the vapour pressures of $SiCl_4$ and impurity chlorides [5].

OH Groups in silica glass induce fundamental absorption at $2.7 \mu m$. The OH groups exist in silica as isolated (free) and hydrogen bonded states. The isolated OH induces a sharp peak at $3672 cm^{-1}$ and the hydrogen bonded OH induces a broad peak at $3608 cm^{-1}$. Absorption due to water molecules appears at 1611

cm^{-1} . The typical *OH* induced losses in the fibres appear at 1.38, 1.24 and 0.95 μm due to the overtone and combination modes of isolated *Si – OH*. The 1.38 μm loss is the most intense and its absorbance corresponds to 60 $dB/(km ppm)$ as summarized in TABLE 3. *OH* groups in the fibres are removed by dehydration in a Cl_2 atmosphere [5].

Table 3.3 Peak positions and intensities of *OH* absorption bands in silica glass

Wavelength (μm)	Intensity ($dB/km ppm$)	Identification
2.72	10000	ν_3
2.21	201	$\nu_3 + \nu_1$
1.38	62.7	$2\nu_3$
1.25	2.7	$2\nu_3 + \nu_1$
1.14	0.07	$2\nu_3 + 2\nu_1$
0.94	1.6	$3\nu_3$
0.88	0.08	$3\nu_3 + \nu_1$
0.72	0.08	$4\nu_3$

3.1.4 Absorption Due to Dissolved Gaseous Species

Absorption due to gaseous species such as O_2 and Cl_2 has been apparent in recent high purity silica glass. The dissolved O_2 exhibits absorption in the UV region above 7.5 eV, O_2 is turned into O_3 by ArF laser irradiation and the initiation of O_3 is correlated to the 4.8 and 2.0 eV bands. Absorption due to Cl_2 appears at 3.8 eV.

Dissolved H_2 molecules have special importance in relation to the optical absorption of the fibre. H_2 Loading is a key technique for fabricating fibre Bragg grating devices as noted above. The dissolved H_2 caused serious problems in terms of the long-term reliability of fibre cables installed for commercial use more than a decade ago. The H_2 induced loss in $Ge:SiO_2$ fibre appears over a

wide region of 1 - 2 μm . When the dissolved H_2 molecules react with the glass network over a long period of time or by heating, they form $Ge - OH$ and $Si - OH$, resulting in OH loss increase. $Ge -$ and $Si - E'$ centres are suggested as the reaction sites. When SiH is present, it induces absorption at 1.53 μm in the fiber [5].

The application of silica glass in the optoelectronics field in recent decades has demanded a further understanding of its absorption properties. K-K analysis is useful for understanding not only glass structure but also the **IR** absorption tail which is needed for attempts to realize further reduction in optical loss in the fibers. Absorption bands induced by defect centers and dissolved gaseous species are utilized in forming fiber Bragg grating devices and in managing photo-induced bands in UV lithography. Further investigation into fabrication methods must be undertaken to expedite silica glass application [5].

3.2 Intrinsic scattering losses of silica glass

Intrinsic scattering loss, which determines transmission loss of optical fibers along with the infrared absorption tail, is composed of Rayleigh, Raman and Brillouin components, and the Rayleigh scattering is dominant. The slope of the transmission loss versus λ^{-4} plot, where λ is the wavelength, is accepted as the Rayleigh scattering loss a_R of the fibers. Although the a_R value depends on the fabrication process, an a_R value of around 0.76 (dB/km) μm^4 is obtained with good reproducibility for pure silica core fibers. By contrast, various magnitudes of scattering intensity have been measured for bulk silica glass. Recent investigations confirm that the Rayleigh scattering intensity varies in proportion to the fictive temperature (T_f) of the glass specimen. This Data review offers a brief overview of scattering loss in silica glass and fibers [5].

3.2.1 Measurement

The intrinsic scattering loss in glass materials, composed of Rayleigh, Raman and Brillouin components, exhibits a λ^{-4} dependence and the Rayleigh scattering contributes more than 85%. Rayleigh scattering is induced by local structural fluctuations such as density and concentration fluctuations. The scattering due to density fluctuations occurs in a single component glass such as silica. Raman and Brillouin scattering losses are induced by the interaction between the incident light and optical and acoustic phonons, respectively [5].

The scattering intensity in bulk silica glass is measured from two standpoints: scattering by small particles and scattering by thermodynamic fluctuations.

Scattering by small particles is formulated as the Rayleigh-Gans theory for small particles (relative to wavelength) and the Mie theory for large particles. The Rayleigh scattering intensity is evaluated using the Rayleigh ratio R , and the scattering loss is given as $\alpha = 7.3 R_{90}$ dB/km, where R_{90} is the scattered light intensity at a right angle in a unit of $\times 10^6 \text{ cm}^{-1}$. The scattered light in this measurement generally includes Raman and Brillouin components.

When scattering is considered in terms of the local fluctuation of the electric susceptibility, the Rayleigh ratio is evaluated using the temperature correlation of thermodynamic parameters such as density, entropy and pressure. Since these parameters have a time-dependent nature, the scattered light has spectral components of Brillouin doublets. The scattering is described with the Landau-Placzek ratio, Ru^* ($= IC/2IB$, where I_c is the central Rayleigh intensity and IB is the Brillouin intensity). The Rayleigh scattering loss can be derived from the Rayleigh-Brillouin spectrum through RLP and the Brillouin scattering loss.

Raman scattering is usually used, along with infrared absorption, for examining glass structure. Although the Raman scattering loss has been evaluated theoretically, there seems to be no effective experimental method for determining the absolute intensity.

The intrinsic scattering loss in optical fibers appears as the slope of the loss versus λ^{-4} plot. This λ^{-4} dependent loss is generally accepted as the Rayleigh scattering loss for optical fibers although it also includes the Raman and Brillouin scattering losses. α_R Derived by this plot has practical meaning as an inherent measure for determining the loss property of the fibers. Additional scattering loss may arise depending on the fabrication conditions. Such loss is generally λ independent and is induced by an imperfection at the core/cladding interface, microbending or residual stress.

When the input power to silica fibers becomes large, stimulated Raman and Brillouin scattering phenomena are induced due to the non-linear effect. The former phenomenon is used for Raman amplification in the 1.3 μm band, while the latter limits the input power to the fibers [5].

In addition, the Rayleigh scattering intensity of fiber preform glasses can be changed by heat treatment. The scattering intensity of reheated preform glass increases to 5 -10% higher than that of annealed preform glass.

A theoretical evaluation of the scattering loss in alkali-doped silica glasses suggests that the intensity can be reduced for elements such as **Na**, **K** and **Rb** when the concentration is very small, that is less than 2 mol %. The scattering loss for these alkali-doped silica glasses can be reduced to up to 20% lower than that of pure silica. In addition, when F is co-doped with alkali, the alkali

concentration extends further. Similarly, it has been shown that the scattering of Na-implanted silica decreases even though the concentration is 10 ppm [5].

3.2.2 Bulk Silica Glass

Various magnitudes of Rayleigh scattering loss were reported for pure silica glasses in the early 1970s and they range from 0.3 to 0.8 (dB/km) μm^4 . This variation seems to be a result of the uncontrolled quality of the silica specimen itself an investigation has shown that the scattering intensity obtained from recent silica glass varies depending on the fabrication method and that such dependence can be related to the glass transition temperature of the specimen.

This temperature dependence of Rayleigh scattering in silica glass has been examined in relation to T_f . The result, based on R_{LP} measurements, reveals a linear relationship between α_R and T_f , by which α_R increases from 0.5 to 0.9 (dB/km) μm^4 for a T_f range of 830 to 12300C. This linear relation is confirmed by a measurement of the scattered light intensity for silica samples whose T_f is changed by heat treatment, in which the relative intensity increases proportionally with increasing T_f . Since the glass structure is solidified at T_f , equilibrium structural fluctuation at temperatures just above T_f is frozen. Structural fluctuations such as density fluctuations depend on T_f . although the refractive index and the isothermal compressibility, which affect the Rayleigh scattering, also change with T_f their effects are small. Thus, the Rayleigh scattering primarily exhibits a proportional dependence on T_f . Therefore, the variation in scattering intensity can be understood as the effect of T_f which is a resultant temperature of thermal history. Scattering loss values obtained from silica glass and silica fibers are summarized in Table(3.4).

On the other hand, T_f values of around 16000C are obtained from pure silica core single-mode and multimode fibers. If the linear $T_f - \alpha_R$ relation is valid for this temperature range, this suggests that a further reduction may be expected in the transmission loss in silica fibers by reducing the T_f of the fibers [5].

Table3.4 Scattering loss in silica glass and silica fibres.

Sample	Scattering loss (dB/km) μm^4 or relative value	Measurement*
Silica fibres		
pure silica	0.76	s
doped silica P:SiO ₂	0.66	s
Ge, F:SiO ₂	1.5 ~ 4.0	s
Silica glass		
pure silica	0.3 ~ 0.8	ls, lp
heat treatment	0.5 ~ 0.9	lp
heat treatment	20% low	ls
alkali-doped (<2 mol%)	20% low	th
Na-implanted (10 ppmw)	13% low	ls

* s: the slope of the loss versus λ^{-4} plot; ls: total scattered light measurement; lp: R_{LP} measurement; th: theoretical estimation.

A Rayleigh scattering coefficient of around 0.76 (dB/km) μm^4 is typical of current pure silica glass. For doped silica fibers other than P:SiO₂ fibre, α_R tends to increase with dopant concentration and becomes more sensitive to the drawing conditions. A recent investigation of the Rayleigh scattering loss in silica glass confirms that the scattering loss increases in proportion to T_f . This result suggests that a further reduction can be expected in the scattering loss of pure silica core fibres if T_f is reduced [5].

3.3 Refractive index and dispersion of silica glass

The refractive index and its variation with wavelength, called dispersion, are the fundamental parameters of the optical materials including silica. Silica glasses have been used to make fibers for the optical communication network and optical imaging for the last three decades. The refractive indices of silica are measured at specific wavelengths lying within the transmission region, with sufficient accuracy. It is worthwhile to relate these measured refractive indices with a suitable empirical or mathematical

Expression having physical meaning and being more accurate than experiment. The evaluated optical constants of silica can be used to compute dispersion throughout the transmission region. A brief review of various relations between refractive indices and wavelengths is presented in Section **B**. The measured up-to-date data for refractive indices have been analyzed in a physically meaningful model using the Sellmeier equation as described in Section C. The dispersion characteristic is computed from the **UV** to

The near **IR** and is described in Section D. Section **E** presents the concluding remarks [5].

3.3.1 Sellmeier Equation

To relate the measured refractive indices with wavelength for fused silica, Malitson used a three-pole Sellmeier equation. The same type of Sellmeier equation was also used by Matsuoka et al for the wavelength dispersion of silica glass in the **UV** and visible region. Tatian also used the same form of Sellmeier equation for several optical materials. Kitamura et al represented the refractive

indices of densified silica glass in a modified form of three-pole Sellmeier equation. Recently, the three-pole

Sellmeier equations have been used in many optical glasses including silica glass. The three-pole Sellmeier equation is of the following form:

$$n^2 = 1 + A\lambda^2/(\lambda^2 - B) + C\lambda^2/(\lambda^2 - D) + E\lambda^2/(\lambda^2 - F) \quad (3.3)$$

In this three-pole Sellmeier equation, two poles are lying in the **VUV/UV** region, whereas the remaining pole is lying in the **IR** region of the optical materials. However, in practice, it is very difficult to know precisely all the absorption peaks. Therefore, it is scientifically useful and physically acceptable to use an average electronic absorption bandgap and also an average lattice absorption bandgap. The two-pole Sellmeier equation can be written as:

$$n^2 = A + B\lambda^2(\lambda^2 - C) + D\lambda^2(\lambda^2 - E) \quad (3.4)$$

Where A , is the wavelength in μm . The first and second terms represent, respectively, the contributions to refractive indices due to higher-energy and lower-energy bandgaps of electronic absorption, and the last term accounts for the decrease in refractive indices due to lattice absorption. The optical constants A, B, C, D, E and F are called Sellmeier coefficients of the optical materials [5].

3.3.2 Derivation of the Sellmeier Coefficients

The refractive indices of silica have been measured in the **UV**, visible and near **IR** regions. The measurement accuracy is within five to six decimal places. At present, there are two-pole and three-pole Sellmeier equations for silica. However, the fitting accuracy should be the dominant consideration in choosing a dispersion formula having fewer optical parameters. Recently I have analyzed the

refractive indices of the various optical materials including silica glass in the above two-pole Sellmeier equation (EQN (2)). This is the most accurate of the dispersion equations, and can fit index data to accuracy consistent with the measurements and the accuracy needed for most optoelectronic applications. The Sellmeier coefficients are evaluated by the least squares analysis. The normal approach is to first find the initial values of the parameters and then to add corrections by an iterative process so as to minimize the deviation between the measured and the computed values. The Sellmeier coefficients A, B, C and D are evaluated by taking beforehand a reasonably estimated value for E , the lattice absorption frequency. The choice of the value for E is not critical since the materials stop transmitting long before the lattice absorption frequency is reached. It is possible to estimate the average electronic absorption bandgap from the evaluated Sellmeier coefficient C by the following equation:

$$E_{ag} = 1.2398/\sqrt{C} \quad (3.5)$$

The room temperature values of refractive indices for silica are used to compute the Sellmeier coefficients A, B, C, D and E from different sources. Some of these Sellmeier coefficients are already cited in .It is worthwhile to compare the estimated values of the average electronic absorption bandgaps (11.8 ~ 11.9 eV) with the experimental values of 11.6 eV and 11.8 eV Therefore, the present two-pole model Sellmeier equation not only expresses the refractive indices with sufficient accuracy but also provides us with the estimated value of the average electronic absorption bandgap. The refractive indices vary with change of ambient temperature. These variations in silica and other optical materials have been analyzed satisfactorily for the first time in a physical model [5].

3.3.4 Dispersion of Refractive Indices

The group velocity dispersion (GVD) is an important parameter of the silica glass. It plays a vital role in optical fiber communication systems. Since the refractive indices are fitted using a physically meaningful Sellmeier equation, it is possible to satisfactorily calculate the GVD, $M(\lambda)$, from the Sellmeier equation using the following relation:

$$M(\lambda) = -\lambda/c [d^2n(\lambda)/d\lambda^2] \quad (3.6)$$

$$M(\lambda) = l/(cn) [-4/\lambda^5 \{ BC^2 / (1 - C/\lambda^2)^3 + DE^2 / (1 - E/\lambda^2)^3 \} + \lambda(dn/d\lambda)^2 + 3n(dn/d\lambda)] \quad (3.7)$$

Where

$$dn/d\lambda = -l/(n\lambda^3) [BC / \left(1 - \frac{C}{\lambda^2}\right)^2 + DE / \left(1 - \frac{E}{\lambda^2}\right)^2] \quad (3.8)$$

And c is the speed of light.

The chromatic dispersion characteristics are computed throughout the transmission region of silica and are shown in FIGURE 1 from the optical constants cited in TABLE 1. The behavior is not linear. The values of $M(\lambda)$ are shown in table 3.5 at the three optical windows, i.e. at 0.85, 1.33 and 1.55 μm .

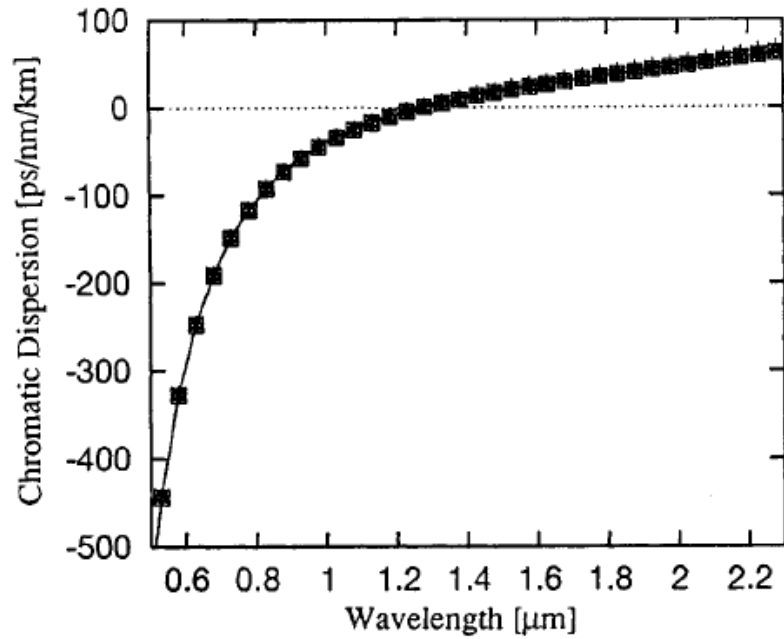


Figure 3.2 Dispersion behaviour of silica at room temperature from 0.5 to 2.3 μm .

Table 3.5 Chromatic dispersion and zero-dispersion wavelength of silica at room temperature.

Sellmeier	Abbé number	Chromatic dispersion (ps/nm/km) at			Zero-dispersion wavelength (μm)
		0.85 (μm)	1.33 (μm)	1.55 (μm)	
[1]	67.9813	-83.4100	5.6530	22.0900	1.2700
[2]	67.5492	-81.7321	8.3875	25.4154	1.2455
[4]	67.8694	-83.8650	5.4032	21.8461	1.2725
[6]	68.1185	-82.9667	5.9416	22.3860	1.2670
[10]	68.0049	-83.6540	5.3557	21.7358	1.2728
Average [except 2]	67.9935	-83.4739	5.5884	22.0145	1.2706

The zero-dispersion wavelengths are also evaluated and the average value is $1.2706\mu\text{m}$. Here, the material dispersion dominates over the waveguide dispersion of optical fibers made of silica glass. The values of refractive index are available only from $0.238\mu\text{m}$ to $0.546\mu\text{m}$ in fused silica. Therefore, the extrapolated refractive indices gave a value of the zero-dispersion wavelength accurate to only one decimal point. The variation of the zero-dispersion wavelength with temperature is $0.025\text{ nm}/^\circ\text{C}$ in silica. Interested readers may

consult for the temperature-dependent characteristics of refractive indices and dispersion of silica and other important optical materials.

The up-to-date values of the refractive indices of silica have been fitted satisfactorily using a two-pole physically meaningful model of the Sellmeier equation. The estimated average electronic absorption bandgap has agreed well with the experimental value. The behavior of chromatic dispersion has been analyzed and it is confirmed here that the material dispersion of silica glass dominates over the waveguide dispersion of the optical fiber [5].

3.4 Transmission of oxide glass

Glasses are materials which do not crystallize when the melt is cooled down. The viscosity increases so fast that the atoms cannot reach their prescribed distances. Their atomic network has deviations from the exact crystal position order. The deviations are mainly dependent on the chemical

Composition of the glass and (to a small degree) on the melting and cooling process, a special group of oxides - called glassformers - is responsible for this behavior. Examples of network formers are SiO_2 , B_2O_3 , P_2O_5 , GeO_2 , As_2O_3 and Sb_2O_3 .

Other types of oxides such as alkali oxides and alkaline earth oxides cause interruptions of the network and thus variations of the physical and chemical properties like density, refractive index, thermal expansion and temperature dependence of the viscosity. For fibers with high numerical aperture, glasses with higher refractive index are needed.

Due to the many possible variations of the chemical composition there are many chances to adjust several properties, for instance the refractive index. Also the light transmission is defined by the chemical composition (and to a lower degree by the melting and cooling process) [5].

3.4.1 Intrinsic Optical Losses

3.4.1.1 Electronic Transitions

Transitions of electrons of the atomic shells cause absorption in the ultraviolet spectral region. The distribution and intensity of the absorption is influenced by the chemical composition of the glass. In the case of fused silica the electronic transitions cause strong and broad absorption bands in the ultraviolet with maxima at 109 and 121 nm. By addition of network modifiers these bands are broadened and shifted to longer Wavelengths. In FIGURE 3.3 it is shown how the ultraviolet transmission edge of fused silica is shifted to longer wavelengths by adding small amounts of Na_2O . This modification is caused by non-bridging oxygen. In FIGURE 3.4 the spectral absorption of binary alkali silicate glasses is shown. We see the influence of the different alkali types. The heavier the alkali type the greater is the shift of the ultraviolet absorption edge to longer wavelengths [5].

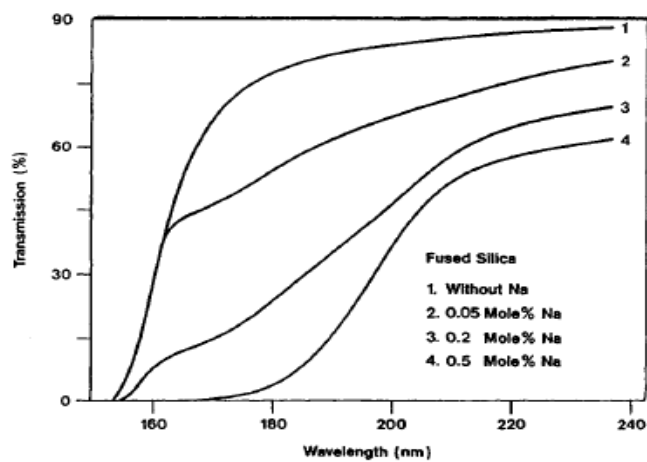


Figure 3.3 Ultraviolet transmission of fused silica with small amounts of Na_2O ; sample thickness 1 mm

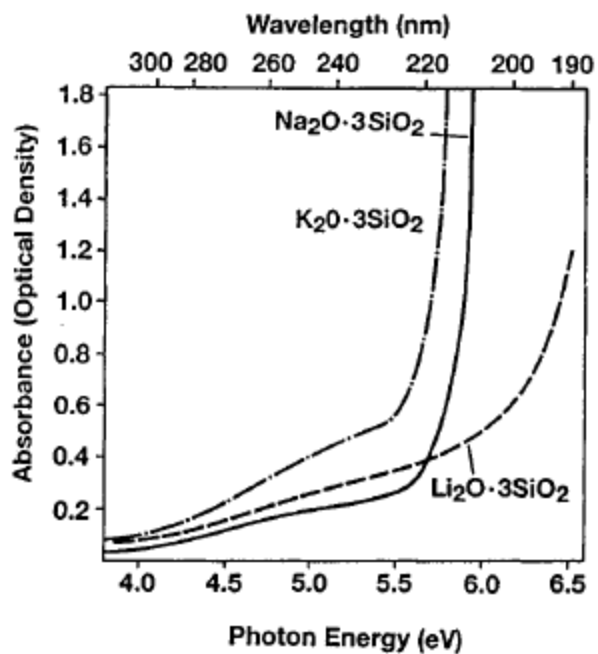


Figure 3.4 Ultraviolet absorption of alkali silicate glasses with different alkali types; sample thickness 2 mm

3.4.1.2 Molecular Vibrations

Molecular vibrations (for instance $Si - O$, $B - O$ or $P - O$) cause strong absorption in the middle infrared region. In FIGURE 3 the infrared absorption edge of oxide glasses with different network forming cations is given. The heavier the network forming cation the more the infrared absorption edge is shifted to longer wavelengths.

Mostly the glasses contain OH groups which cause absorption bands in the region 2.5 to 6.5 microns. If glasses with good infrared transmission are wanted one has to reduce or to eliminate the OH-content [5].

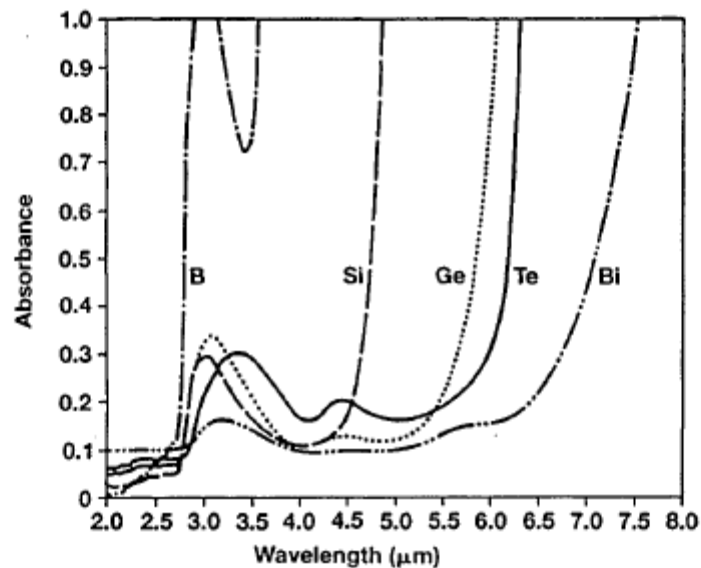


Figure 3.5 Infrared absorption edge of oxide glasses with different network forming cations; sample thickness 1.85 mm, except Bi: 2.00 mm

3.4.1.3 Scattering

Another source of intrinsic loss is light scattering. The Brownian movement of the molecules in the melt causes density fluctuations in the glass melt, which are frozen-in when the melt is cooled down. The density fluctuations cause fluctuations of the refractive index. The consequence is light scattering.

The intensity of the scattering increases with the refractive index of the glass, another source of scattering can be phase separation of the glass. A third source of scattering may be undissolved particles (contaminants, metals, crystals) or bubbles. This scattering loss is caused by the melting technique. It is not an intrinsic loss [5].

3.5 Intrinsic scattering losses of oxide glass

Oxides with low scattering compositions are being investigated extensively because of the recent interest in realizing low loss oxide fibers. The intrinsic scattering of light is classified as either elastic (Rayleigh scattering) or inelastic (Brillouin and Raman scattering). Of these, Rayleigh scattering normally has the highest intensity. This Datareview provides an overview of these three kinds of scattering in oxide glasses and supplies related references [5].

3.5.1 Raylight Scattering

Light scattering by particles smaller than the wavelength of light is called Rayleigh scattering. The 'particles' in glass media consist of frozen-in fluctuations of density and concentration. Since concentration fluctuation is related to diffusion, the temperature at which it is frozen in the glass [5].

3.5.1.1 Density Scattering

The magnitude of the scattering due to density fluctuation is described, by using classical electromagnetic theory and thermodynamics, as follows:

$$A_{dens} = \frac{8\pi}{3\lambda^4} \left(\rho \frac{\partial \varepsilon}{\partial p} \right) k T_F K_T(T_F) = \frac{8\pi^3}{3\lambda^4} n^8 p^2 k T_F k_T(T_F) \quad (3.7)$$

Where ρ is the density, ε the permittivity, k Boltzmann's constant, $K_T(T_F)$ the isothermal compressibility at T_F , n the refractive index and p Pockel's photoelastic constant. This equation shows that the scattering decreases as T_F decreases. It is difficult to discuss the compositional dependence of A_{dens} qualitatively for multicomponent oxide glasses because these parameters are not independent of each other and p and K_T are only available in a limited number of compositions [5].

Lines defined parameter Λ , which is a measure of the density dependence of bond polarisability (x), to obtain $n^8 p^2 = (n^2 - 1)^2 (1 - \Lambda)^2$, and discussed the conditions under which this term is expected to approach zero. $Na_2O - Al_2O_3 - SiO_2$ and $CaO - Al_2O_3$ Glasses are thought to show low density scattering since their glass network frame is 'stuffed' with network modifier ions without accompanying any nonbridging oxygen's (see M_2 in FIGURE 3.6).

3.5.1.2 Concentration Scattering

Concentration scattering appears when the glass consists of more than one component. Its magnitude is related to the mixing enthalpy of the components, or the activities of each component in the glass, which are both very hard to determine. Thus, concentration scattering is often evaluated from the difference between the experimentally determined scattering coefficient and the

theoretically calculated density scattering, i.e. $A'_{conc} = A_{Ray1} - A_{dens}$. Spierings compared A'_{conc} and A_{conc} for $K_2O - MgO - PbOSiO_2$ glass[5]. The latter is theoretically derived under the assumption that the glass is an ideal

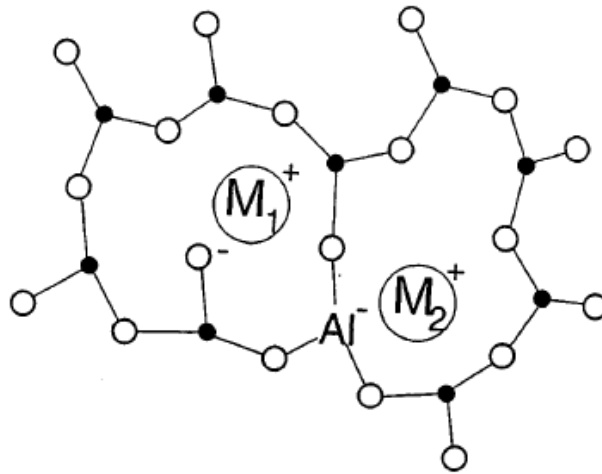


Figure 3.6 A schematic model of the glass network structure. M_1, M_2 : network modifier ions accompanied by and without non-bridging oxygen, respectively; large open circle: O; filled circle: tetrahedral network former ions - their fourth bonds project upward or downward from the plane of the drawing.

Mixturesome gaps still remain between them. Lines calculated the compositional dependence of these two scattering coefficients for ternary silicate glasses ($SiO_2 - Na_2O.3SiO_2 - NaAlO_2.3SiO_2$ system which is treated as a regular mixture).

The scattering intensities of commercial optical glasses are known to be larger than that of silica glass. Since they usually comprise many components, their concentration scattering becomes large.

Scattering properties of glasses are closely related to the thermodynamics in an amorphous state. However, it is difficult to separate density scattering from concentration scattering qualitatively as they include fictive temperature and mixing enthalpy. To achieve this requires the systematic measurement of Pockel's coefficient and isothermal compressibility data for various glasses [5].

3.6 Refractive index and dispersion of oxide glass

Multi-component oxide glasses, which typically consist of glass formers such as SiO_2 and B_2O_3 and modifiers such as Na_2O and CaO , have been studied as alternative materials for low-loss optical fibres for telecommunications. Laser emission of rare-earth ions, especially Nd^{3+} and Er^{3+} ions, has been demonstrated in silicate, phosphate and telluride glass fibers. Tellurite glass fiber is currently considered as an Er^{3+} -doped fibre amplifier with a broad bandwidth for wavelength-division multiplexing (WDM) systems. Refractive index and its dispersion gives us useful information for designing core/clad structure for optical fibers; it also determines the material dispersion, the wavelength dependence of the light wave velocity in transmission. As for laser materials, refractive index dispersion is related to the radiative transition probabilities of active ions and third-order optical non-linearity. This Data review provides information on refractive index and its dispersion characteristics in multi-component oxide glasses for optical fibers. A good selection of refractive index data for glass in general can be found in [5].

Chapter Four

Material and Method

4.1 UV-Visible spectroscopy

Spectroscopy is the study of interaction between matter and electromagnetic radiation. Spectroscopy means study of the interaction between matter and radiated energy and it used to refer to the measurement of radiation intensity as a function of wavelength. Spectroscopy is basically an experimental subject and is concerned with the absorption, emission or scattering of electromagnetic radiation by atoms or molecules [7].

UV-Vis spectroscopy is absorption spectroscopy or reflectance spectroscopy in the ultraviolet-visible spectral region. This means it uses light in the visible and adjacent (near-UV and near-infrared [NIR]) ranges. The absorption or reflectance in the visible range directly affects the perceived color of the chemicals involved. In this region of the electromagnetic spectrum, molecules undergo electronic transitions. This technique is complementary to fluorescence spectroscopy, in that fluorescence deals with transitions from the excited state to the ground state, while absorption measures transitions from the ground state to the excited state [7].

A hydrogen, deuterium or discharge lamp covers the ultraviolet range, and a tungsten filament (usually tungsten \halogen lamp) covers the visible range. The radiation is separated according to its frequency\wavelength by a diffraction grating followed by a narrow slit. The slit ensures that the radiation is of a very narrow waveband it is monochromatic.

The cells in the spectrometer must be made of pure silica. Detection of the radiation passing through the sample or reference cell can be achieved by either photomultiplier or photo diode, that converts photons of radiation into tiny electrical currents; or semiconducting cell (that emits electrons when radiation is incident on it) followed by an electron multiplier similar to those used in mass spectrometers. The spectrum is produced by comparing the currents generated by the sample and the reference beams [8].

4.1.1 Basic components UV-Visible:

1. Light source Sample.
2. Sample cell.
3. Uniform wave length(Monochromatic).
4. Scout (detector).

Optical sources are two types of photovoltaic sources: a tungsten bulb (Lamp Tungsten) for the measurement of visible rays (Visible) in the range (350 - 800). The light source is a deuterium bulb (Lamp D2) It is a light bulb. Seeing it with the naked eye because it can cause temporary blindness due to the strength of its radiation, this for the measurement of ultraviolet radiation in the range (200 - 350).

The sample cells are either to be made from Glass or quartz (figure. (2.4)), and quartz are best made because the cell is made of glass. Among its components is sodium synthesis which is absorbed in the field UV. Therefore, it is preferable to use cells made of quartz. These cells are not among the components made by sodium and the prices of cells Quartz between 300 - 1000 SR depending on the quality of the cell and its thickness.



Figure (4.1) Sample cell

Uniform wave length(Monochromatic) is a glass publication and this publication was used in old machines Currently, in the modern instruments of spectroscopy, there is a so-called reserve and function It scans the sample to determine the wavelength at which the highest catch occurred when it was shed Light whether the light of the tungsten bulb to measure the visible rays or from the deuterium bulb to measure The ultraviolet rays produce a uniform wavelength of many beams of light based Monochromatic The reception of the beam whose angle of fall is appropriate on the uniform wavelength and then The wavelength uniformly reverses the ray of radiation on it and directs it to a filter This filter selects the appropriate package very accurately and then continues to move The packet to a reflective mirror sends the fallen optical beam to the sample cell and then To the Scouts [9].

Scouts(Detector) that shows the amount of light coming out of the sample cell and explains what the quantity is The light outside the sample cell is equal to the amount of light inside the sample if it happens The amount of light inside the sample is equal to the amount of light outside the sample that did not absorb And therefore to get only a straight line does not have any absorption. If the opposite happened the light outside the sample cell is less than the light inside the sample.

Diffraction grating is an optical component with a periodic structure, which splits and diffracts light into several beams travelling in different directions. The emerging coloration is a form of structural coloration. The directions of these beams depend on the spacing of the grating and the wavelength of the light so that the grating acts as the dispersive element. Because of this, gratings are commonly used in monochromatic and spectrometers. For practical applications, gratings generally have ridges or rulings on their surface rather than dark lines. Such gratings can be either transmissive or reflective. Gratings which modulate the phase rather than the amplitude of the incident light are also produced, frequently using holography.

The principles of diffraction gratings were discovered by James Gregory, about a year after Newton's prism experiments, initially with items such as bird feathers. The first man-made diffraction grating was made around 1785 by Philadelphia inventor David Rittenhouse, who strung hairs between two finely threaded screws. This was similar to notable German physicist Joseph von Fraunhofer's wire diffraction grating in 1821.

4.1.2 Applications of UV-Vis spectroscopy:

UV-VIS spectroscopy is routinely used in analytical chemistry for the quantities determination of different analyses, such a transition metal ions, highly conjugated organic compounds, and biological macromolecules. Spectroscopic analysis is commonly carried out in solutions but solids and gases may also be studied.

Solutions of transition metal ions can be colored (i.e. absorb visible light) because electrons within the metal atoms can be excited from one electronic state to another. The color of metal ion solutions is strongly affected by the presence

of other species, such as certain anions or ligands. For instance, the color of a dilute solution of copper sulfate is a very light blue; adding ammonia intensifies the color and changes the wavelength of maximum absorption (λ_{\max}).

4.2 Material and Method

In this study was used four samples of glass were used, with the same dimensions as length 3 cm, and width 1cm, and the thickness of 3mm, and also different colors are white, blue and brown and the last sample is test strip. The device used in this experiment was uv/visibile spectroscopy.

4.3 Results

When the first sample was inserted into the device and after it was turned on, the sample worked on the absorption of the radiation and the result was in the following figure



Figure (4.2)absorption of brown glass [$\lambda_{\max} = 385.0$ nm]

When the second sample was inserted into the device and after it was turned on, the sample worked on the absorption of the radiation and the result was in the following figure

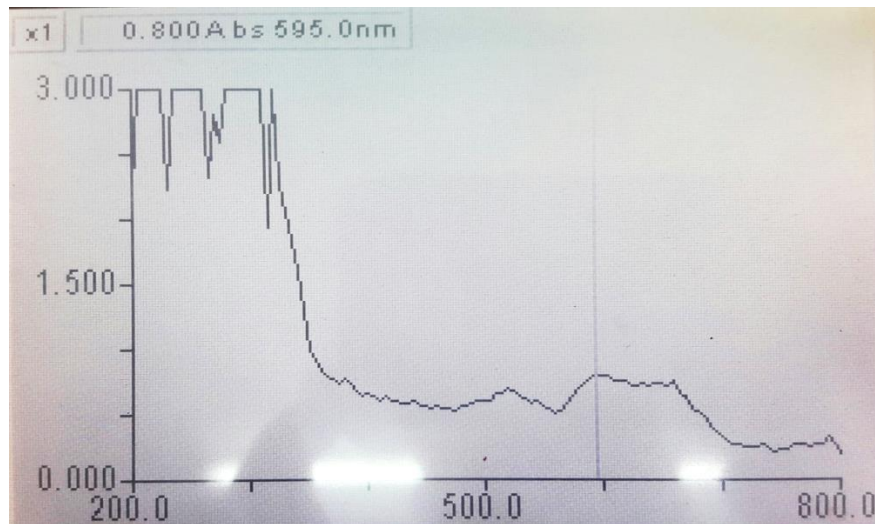


Figure (4.3) absorption of blue glass [$\lambda_{\max}=595.0$ nm]

When the third sample was inserted into the device and after it was turned on, the sample worked on the absorption of the radiation and the result was in the following figure



Figure (4.4) absorption of white glass [$\lambda_{\max}=570.0$ nm]

When the fourth sample was inserted into the device and after it was turned on, the sample worked on the absorption of the radiation and the result was in the following figure

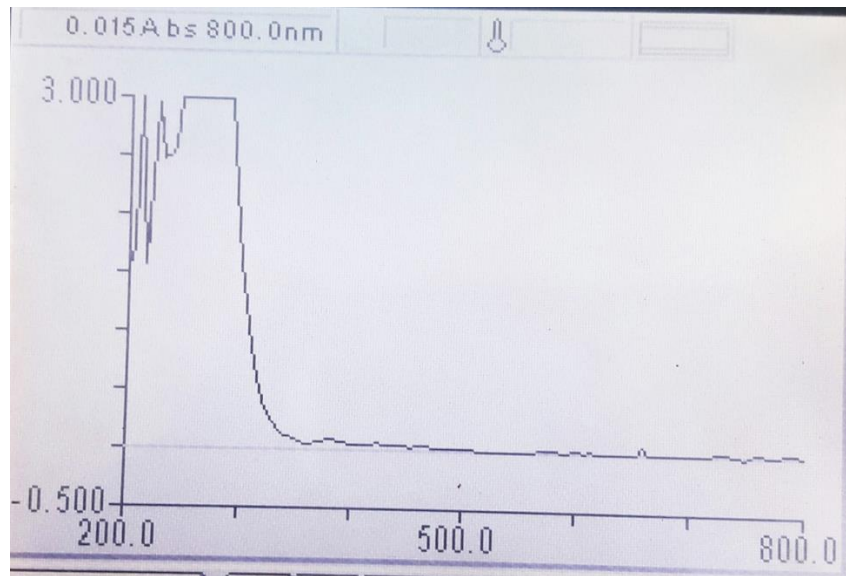


Figure (4.5) absorption of test strip [$\lambda_{\max}=0.0$ nm]

4.4 Discussion

After experimenting with the four samples, it was observed that in the case of brown glass, the wavelength of absorption was average range. In the case of blue glass, the wavelength was greater. In the case of the white glass, the wavelength was large indicating that the beam falling on the white glass it performs easily without any resistance.

In the case of the sample of the test strip, the absorption was non-existent, so this is used in test strip.

4.5 Conclusion

The up-to-date values of the refractive indices of silica have been fitted satisfactorily using a two-pole physically meaningful model of the Sellmeier equation. The estimated average electronic absorption bandgap has agreed well with the experimental value. The behavior of chromatic dispersion has been analyzed and it is confirmed here that the material dispersion of silica glass dominates over the waveguide dispersion of the optical fiber.

Scattering properties of glasses are closely related to the thermodynamics in an amorphous state. However, it is difficult to separate density scattering from concentration scattering qualitatively as they include fictive temperature and mixing enthalpy. To achieve this requires the systematic measurement of Pockel's coefficient and isothermal compressibility data for various glasses.

4.6 Recommendation

Use of carbon dioxide vanadium in the glass industry so that the nature of this material change when it reach a certain temperature and prevent the light into force within the infrared, a range that leads to the feeling of heat associated with the light of the sun as this stuff at normal temperatures impermeable to light, but At 70 ° C, a change is made to the material so that its electrons come in a different pattern, turning from a semi-conductor to a metal that prevents infrared access.

So that this new glass will solve a problem faced by architects in the design of buildings with glass facades and will reduce the costs of air conditioning that peak in the summer.

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