Effect of tri-Potassium citrate on the Structure of Sucrose and Maltose in Solutions at Different Temperatures: Volumetric and Ultrasonic Studies

By

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science (M.Sc) in Chemistry

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Declaration

This is to certify that the thesis work entitled "**Effect of tri-Potassium citrate on the Structure of Sucrose and Maltose in Solutions at Different Temperatures: Volumetric and Ultrasonic Studies**" has been carried out by Subhas Chandra Sarkar in the Department of Chemistry, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work has not been submitted anywhere for the award of any degree or diploma.

Subhas
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ABSTRACT

A volumetric and sound velocity method was used for the analysis of effect of tri-Potassium citrate (TPC) on the structure of sucrose and maltose. Densities and sound velocities of sucrose and maltose in water and in aqueous 0.05 $mol.kg^{-1}$, 0.20 $mol.kg^{-1}$, 0.35 $mol.kg^{-1}$ and 0.5 $mol.kg^{-1}$ (TPC) solutions have been studied at 293.15K to 313.15K with an interval of 5K. From density values, various parameters such as apparent molar volume (φ_v), limiting apparent molar volume (φ_v^0), limiting apparent molar volume transfer ($\Delta_{tr}\varphi_v^0$), apparent molar expansibilities $(\delta\varphi_v^0/\delta T)_p$ and Hepler's constant have been calculated. The acoustic properties such as adiabatic compressibility (β_s), apparent molar adiabatic compressibility (φ_k), limiting apparent molar adiabatic compressibility (φ_k^0), apparent molar adiabatic compressibility of transfer ($\Delta_{tr}\varphi_k^0$), acoustic impedance (Z) and hydration number (n_H) have been calculated by densities sound velocities data.

The densities increase with the increase of concentration of sucrose and maltose. Densities of sucrose and maltose in aqueous TPC solutions are higher than that of sucrose and maltose in pure water solution. The apparent molar volume varies upon the disaccharides (sucrose and maltose) concentration as well as on the temperature. The smaller values of experimental slope (S_v) as compared to limiting apparent molar volume (φ_v^0) values suggest the dominance of solute-solvent interaction over the solute-solute interaction. The true volume (φ_v^0) of disaccharides are found to be order of: maltose > sucrose.

The limiting apparent molar volume transfer ($\Delta_{tr}\varphi_v^0$) values of sucrose and maltose are positive which suggest the dominance of ion-hydrophilic and hydrophilic-hydrophilic interactions over the hydrophobic-hydrophobic and ion-hydrophobic interactions. The $\Delta_{tr}\varphi_v^0$ values increase with an increase in concentration of the TPC which indicates the presence of strong ion-hydrophilic interactions in the mixtures. The values of limiting apparent molar volume expansion $(\delta\varphi_v^0/\delta T)_p$ are positive. Hepler's constant values are positive or small negative for all studied disaccharides in binary and ternary system suggest the studied systems act as structure maker. The values of partial molar volumes ($\bar{V}_2$) increase with increasing of concentration of sucrose and maltose for the studied systems.

The sound velocity increases with the increase of concentration of sucrose and maltose. Sound velocities of disaccharides in aqueous TPC solutions are higher than that of disaccharides in pure water solution. This indicate that the increase of compactness of the medium with the increase in disaccharides and TPC concentration. The adiabatic compressibility (β_s) decreases with the increase of concentration of disaccharides. This indicates the water molecules around the disaccharides are less compressible than the water molecules in the bulk solution. The negative φ_k values indicate the greater loss of structural compressibility of water. The positive $\Delta_{tr}\varphi_k^0$ values for all the saccharides indicate the presence of ionic-hydrophilic and hydrophilic-hydrophilic interactions. The small S_k values also indicates the dominating of solute- solvent interactions over solute-solute interaction.

The acoustic impedance, Z increases with the increase of concentration of disaccharides indicates the presence of effective solute-solvent interactions. The hydration number (n_H) decrease with the increase of concentration and temperature for both binary and ternary systems. The positive hydration number (n_H) values indicate an appreciable solvation of solutes. Hydration capacity of maltose is higher than sucrose in water and in aqueous TPC solution.

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Nomenclature

φ_v	The apparent molar volume
ρ_0	Density of solvent
ρ	Density of solution
u_0	Sound velocity of solvent
u	Sound velocity of solution
$\bar{V}_2$	Partial molar volume
m	Molality
M	Molecular mass
n_1	Number of moles of solvent
n_2	Number of moles of solute
n_H	Hydration number
R_A	Relative association
Z	Acoustic impedance
β_s	Adiabatic compressibility of solution
$\beta s,o$	Adiabatic compressibility of solvent
h	Plank’s constant
N	Avogadro’s number
R	Universal gas constant
A,B,C	Constants related with temperature effects

CHAPTER I

Introduction

1.1 General

The study of the intermolecular interactions in solution has a huge contribution in the development of molecular science. There are various type of interactions which exist in solutions. Of these, solute-solvent interactions appear to be most important. With the help of these interactions we can understand the nature of the solute and solvent, in terms of the structure of the solvent. The nature of solute-solvent, solute-solute interactions has been deduced mainly from thermodynamic and the transport properties. The volumetric and viscosity behaviour of solutes in solution provide information regarding solute-solvent and solute-solute interactions [1-4]. The volumetric properties of disaccharides in aqueous and non-aqueous solvent are played an important role for understanding their behavior. Ultrasonic technique has been found to be more accurate and comprehensive in understanding solute-solvent interactions and understanding the role played by the biological molecules in living organism [5, 6].

Carbohydrates are very important for some physiological process. They are not only basic material but also plays significant role in the configuration of biological molecules. When non-polar solutes dissolve in water. They increase the mutual ordering of water molecules around them as shown by thermodynamic studies [7, 8]. Thus the idea of "ice bergs" being formed around non polar solutes was born, and such solutes have been called structure formers [9]. Many physico-chemical phenomena, like solubilities of electrolytes, rates of chemical reactions, phase separation technique are strongly influenced by the selective solvation of ions in mixed solvents [10, 11].

Many researchers have presented thermodynamic properties of aqueous mixtures of saccharides with various compounds [12-25] such as electrolytes, disaccharides, etc. Some studies have been found in the literature on mixtures of disaccharides [26-28] and electrolytes [29] with citrate salts. Citrate salts likes potassium citrate and sodium citrate contain biodegradable and nontoxic citrates, and it can be discharged to biological wastewater treatment plants. The medicinal properties of Potassium citrate is to prevent of gout and kidney stones and is also used to make urine less acidic.

1.2 Physical and chemical properties of constituents in solution

The studies of disaccharides with biologically important citrate salts will lead to new interesting sets of mixtures. Also, it can provide useful information regarding conformational stability and interaction in the ternary system, it is inevitable to find out the size and the shape of the molecules and the geometry of the arrangement of their constituent atoms. For this Purpose, the important parameters are bond lengths or interatomic distance and bond angles. The type of atomic and other motions as well as the distribution of electrons around the nuclei must also be ascertained; even for a diatomic molecule a theoretical approach for such information would be complicated. However the chemical analysis and molecular weight determination would reveal the composition of the molecules, and the study of its chemical properties would unable one to ascertain the group or sequence of atoms in a molecule. But this cannot help us to find out the structures of molecules, as bond length, bond angles, internal atomic and molecular motions, polarity etc. cannot be ascertained precisely.

For such information it is indispensable to study the typical physical properties, such as absorption or emission of radiations, refractivity, light scattering, electrical polarization, magnetic susceptibility, optical rotations etc. The measurement of bulk properties like density, surface tension, viscosity etc. are also have gained increased importance during the recent years, because not only of their great usefulness in elucidating the composition and structure of molecules, but also the molecular interaction in binary and ternary systems.

The various physical properties based upon the measurement of density, viscosity, surface tension, refractive index, dielectric constant etc., have been found to fall into the following four categories [30].

(i) Purely additive properties: An additive property is one, which for a given system is the sum of the corresponding properties of the constituents. The only strictly additive property is mass, for the mass of a molecule is exactly equal to the sum of the masses of its constituent atoms, and similarly the mass of a mixture is the sum of the separate masses of the constituent parts. There are other molecular properties like molar volume, radioactivity etc. are large additive in nature.

(ii) Purely constitutive properties: The property, which depends entirely upon the arrangement of the atoms in the molecule and not on their number is said to be a purely constitutive property. For example, the optical activity is the property of the asymmetry of the molecule and occurs in all compounds having an overall asymmetry.

(iii) Constitutive and additive properties: These are additive properties, but the additive character is modified by the way in which the atom or constituent parts of a system are linked together. Thus, atomic volume of oxygen in hydroxyl group (OH) is 7.8 while in kenotic group (=CO) it is 12.2. The parachor, molar refraction, molecular viscosity etc. are the other example of this type.

(iv) Colligative properties: A colligative property is one which depends primarily on the number of molecules concerned and not on their nature and magnitude. These properties are chiefly encountered in the study of dilute solutions. Lowering of vapor pressure, elevation of boiling point, depression of freezing point and osmotic pressure of dilute solutions on the addition of non-volatile solute molecules are such properties.

1.3 Properties of solute in solvent

In the basis of chemistry, a homogeneous solution mixture is composed of two or more substances. In this mixture, a solute substance dissolved in another substance, known as a solvent. The solution more or less takes on the characteristics of the solvent. The concentration measurement of a solute in a solution indicates how much of that solute is dissolved in the solvent, regarding the amount of solvent is present.

The physicochemical properties including solute-solvent interactions in mixed solvents have raised over the past decade on the basis of their greater complication in comparison with pure solvents [31, 32]. The combined effects of preferential solvation of the solute by one of the components in the mixture and of solvent-solvent interactions makes this exhausting behavior results [33]. This solvation occurs when the polar solute has in its microenvironment more of one solvent than the other, in comparison with the bulk composition. These phenomena may help in the elucidation of kinetic, spectroscopic and thermodynamic events that occur in solution.

Basically, solute-solvent interactions mean the properties of solutions can be computed from the properties of the individual components. But in the liquid state creates innate difficulties and the properties of solution cannot understand properly. The theoretical treatments, which assume some model (e.g., lattice model, cell model etc.) for the structure of the components and their solution. On the other hand, it is considered suitable and useful to determine experimentally the values of certain macroscopic properties of solutions for proper understanding of the structure of the solution. Some experimentally determined macroscopic properties are: density, sound velocity, thermodynamic properties, surface tension, etc., which are readily measurable.

Physical properties like density, sound velocity, surface tension, conductivity, dielectric constant, refractive index etc. provide an instruction about the molecular structure as well as the molecular interactions that occur when solute and solvent are mixed together. Two fundamental physico-chemical properties are density and sound velocity which are easy, simple, inexpensive and precise tools, by which one can get the valuable information about the molecular interactions in solid and liquid mixture correlated with equilibrium and transport properties. Quantitative conclusion can be drawn about the molecular interactions even in simple liquids or their mixtures from the above designated properties. Our present investigation is based on the methods of physico-chemical analysis, which is a useful tool in getting sound information about the structure of some aqueous TPC with disaccharides in studying the solute-solvent and solvent-solvent interactions in ternary systems.

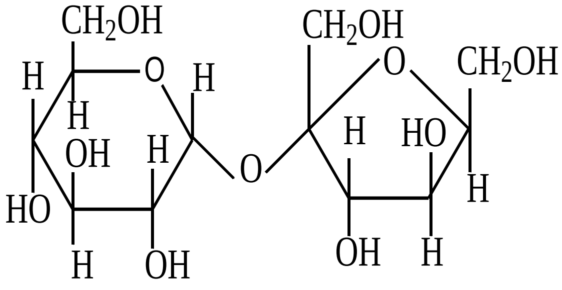
1.4 Carbohydrates

A carbohydrate is a biomolecule which contain carbon (C), hydrogen(H) and oxygen (O) atoms, where hydrogen–oxygen atom ratio is 2:1 (as in water); in other words, with the molecular formula $C_m(H_2O)_n$ (where m may be different from n). In biochemistry, The term is very common which has a synonym of 'saccharide', a group that indicates sugars, starch and cellulose. The saccharides are classified into four chemical groups: monosaccharides, disaccharides, oligosaccharides and polysaccharides. The smallest or lower molecular weight carbohydrates, are monosaccharides and disaccharides commonly referred to as sugars [34]. The word saccharide comes from the Greek word (sákkharon), meaning "sugar"[35].

Among main types of nutrients carbohydrates is one of them. In human body these are the most important source of energy. Carbohydrates changes into glucose known as blood sugar by digestion. This sugar supply energy in our body cells, tissues and organs. This energy stored in liver and muscles for further used when it is needed. According to their chemical structure carbohydrates are called simple or complex. Sugars which found naturally in foods such as fruits, vegetables, milk and milk products known as simple carbohydrates. Carbohydrates found in whole grain breads, cereals, starchy vegetables and legumes are known as complex carbohydrates. Fiber are the good sources of many complex carbohydrates.

1.5 Properties of Sucrose

Sucrose is known as common table sugar. This disaccharide occurred in naturally, and this molecule is produced by the combination of two monosaccharides glucose and fructose. Sucrose is stayed in all plants. The molecular formula of sucrose is $C_{12}H_{22}O_{11}$. Sucrose is extracted from either sugar cane or sugar beet and finally refined for human consumption. The modern sugar refinement processes named bleaching is used to remove residual color, and for making crystal. Crystallization is the process of purification in which other substances are removed, and produces crystals of pure sucrose. Then the sucrose which is found are clear, odorless, and have a sweet taste. The sugar crystals are white in colour. All over the world sucrose is used as an ingredient in food production and food recipes. Sucrose is obtained by the elimination of a water molecule from the glucose and fructose glycosidic hydroxyl groups combination [36]. Sucrose may hydrolysis to TPC so that analytical use of reduction of TPC can be made in determination of sucrose [37].

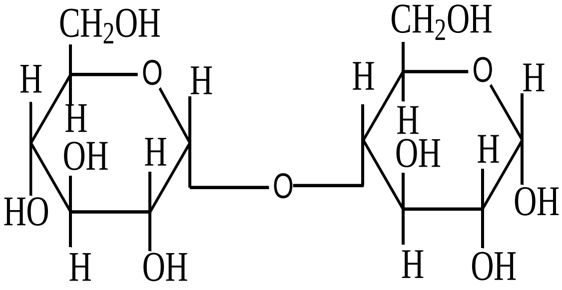


Glucose Fructose

Figure 1.1: Structure of Sucrose

1.6 Properties of Maltose

Maltose which is known as maltobiose or malt sugar, is a disaccharide obtained from the joining of two glucose units of an α(1→4) bond. But when two glucose molecules are joined with an α(1→6) bond the maltose which is found known as isomer isomaltose. It is a two-unit member of the amylose homologous series and the key structural unit of starch. Beta-amylase breaks down in starch and it removes two glucose units at a time and produce maltose. For example germinating seeds is found in this reaction [38].



Glucose Glucose

Figure 1.2: Structure of Maltose

1.7 Properties of TPC

Potassium citrate (also known as tri-Potassium citrate) is a potassium salt of citric acid which molecular formula is $K_3C_6H_5O_7$. It is a hygroscopic crystalline powder in white colour. It has no odor and it taste is saline. It contains 38.28% potassium by mass. It monohydrate form is highly hygroscopic and deliquescent. Potassium citrate is used as a food additive as well as to regulate acidity. It is used in medicinally to control kidney stones by the deriven from either uric acid or cystine. This weak acid is synthesized inside Krebs' cycle. Further it can be used as an oral alkalinizing agent [39].

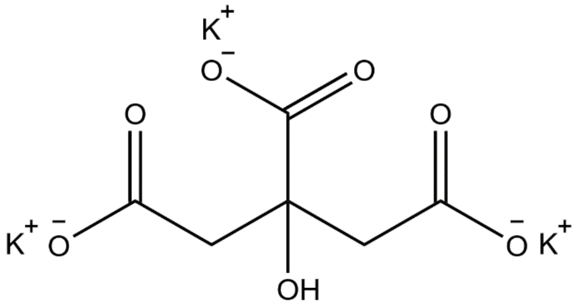


Figure 1.3: Structure of TPC

1.8 Properties of water

The molecular structure of water is very simple. The molecular structure of water causes a specific electrochemical properties. The hydrogen side of the water molecule has a slight positive charge. A negative charge exists on the other side of the molecule. This structure causes polarity in water and make it a powerful solvent as well as strong surface tension.

When water molecules organize themselves in distinctly different patterns makes a physical phase change. The molecular arrangement of ice (the solid form of the water molecule) increase it volume and decrease it density. This extension of the water molecule in ice causes floating on top of liquid water.

1.9 Structure of water

Water is an ‘anomalous’ liquid and many of its properties is differ basically from normal liquids of simple structures. The deviations from regularity indicate some kind of association of water molecules. The physical properties exhibited by liquid water are unique [40] : i) negative volume of melting ii) density maximum in normal liquid range (at 4^{0}C) iii) isothermal compressibility minimum in the normal liquid range at (46^{0}C) iv) numerous crystalline polymorphs v) high dielectric constant vi) abnormally high melting, boiling and critical temperatures for such a low molecular weight substance that is neither ionic nor metallic vii) increasing liquid fluidity with increasing pressure and viii) high mobility transport for $H^{+}$and OH^{-} ions pure water has a unique molecular structure [41]. The O-H bond length is 0.096 nm and the H-O-H angle 104.5^{0}. The chemist have pondered over the possible structural arrangements that may be responsible for imparting very unusual properties to water. The most fundamental problem in solution chemistry is to understand the solute water interaction and the knowledge of water structure should be prerequisite. The physico-chemical properties of aqueous solution in most of the cares are explained in terms of the structural change produced by solute molecules. To study the role of water in biological systems it is necessary to understand the structural changes in the solvent.

To describe the properties of water various structural models have been developed. These model generally be grouped into two categories, namely the continumm model and the mixture models. The continumm models [42, 43] treat liquid water as a uniform dielectric medium, and when averaged over a large number of molecules the environment about a particular molecules is considered to be the same as about any other molecules that is the behavior of all the molecules is equivalent.

The mixture model theories [44] depict the water as being a mixture of short lived liquid clusters of varying extents consisting of highly hydrogen bonded molecules which are mixed with and which alternates role with non bonded monomers.

The flickering cluster of Frank and Wen [45], later developed by Nemethy and Scherage among the mixture models, [42] are commonly adopted in solution chemistry. The properties of dilute aqueous solutions in terms of structural changes brought about by the solutes can be explained more satisfactorily using this model than any other model. On the basis of this model the tetrahedraly hydrogen bonded clusters, referred to as bulky water $(H_2O)_b$, are in dynamic equilibrium with the monomers, referred to as dense water, $(H_2O)_d$ as represented by.

$$(H_2O)_b \rightleftharpoons (H_2O)_d$$

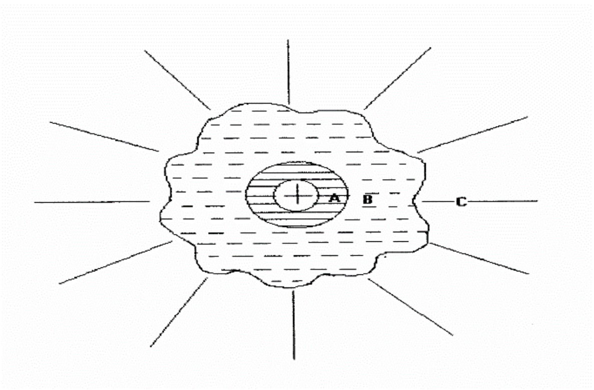


Fig 1.4: Frank and Wen model for the structure modification produce by an ion

The hydrogen bonding in the clusters is postulated [46] to be cooperative phenomenon. So that when one bond forms several others also come into existence. In terms of solvent-solvent, solvent-solute and solute-solute interaction the properties of solution can be accounted. The concentration dependence of a given property in terms of thermodynamics, extrapolated to the limit of infinite dilution provides a measure of solute-solvent interactions. Solute-water interaction or hydration phenomenon can be classified into three basic types:

i. Hydrophilic hydration
ii. Ionic hydration
iii. Hydrophobic hydration

The introduction of a solute into liquid water creates changes in the properties of the solvent which are similar to these brought about by temperature or pressure. The solute that shifts the equilibrium to the left and increase the average half-life of the clusters is termed as structure maker on the other hand which has an effect in the opposite direction is called 'Structure breaker'.

The experimental result on various macroscopic properties provides useful information for proper understanding of specific interactions between the components and the structure of the solution. The thermodynamic and transport properties are sensitive to the solute-solvent, solute-solute, and solvent-solvent interaction. These three types of interaction are possible in solution systems but solute-solute interaction are negligible at dilute solutions. The concentration dependence thermodynamic properties are a measure of solute-solute interaction and in infinite dilutions these parameters serve as a measure of solute-solvent interactions. The solute causes changes in water structure also result in a change in solution viscosity.

1.10 Hydrophilic hydration

Solvation occurs as the result of solute-solvent interactions different from those between solvent molecules themselves. The solubility of a solute molecule in water is distinguished by changes in the water structure that depend on the nature of the solute. When dissolution is occured in any solute will create a hydration shell around the solute molecule and disrupt the arrangement of water molecules in the liquid state. For the ionic solute species, the hydration shell is characterized to extend from an inner layer where water molecules near the charge species are strongly polarized and oriented by the electrostatic field, the region where water molecules are significantly polarized but not strongly oriented, the water molecules are only slightly polarized by the electric field of the ion to an outer solvent region of bulk water [47].

1.11 Hydrophobic hydration and hydrophobic interaction

The hydrophobic effect refers to the combined phenomena of low solubility and the entropy dominated character of the solvation energy of non polar substances in aqueous media [48]. Anomalous behavior in other thermodynamic properties, such as the partial molar enthalpies, heat capacities and volumes of the nonpolar solutes in water is also reflected by it. Between the nonpolar solutes merged in water than their Vander Waals interaction in free space this effect originated from much stronger attractive interaction energy [49]. Hydrophobic interaction is denoted as the tendency of relativity nonpolar molecules to “stick together” in aqueous solution [50] and the results comes from hydrophobic hydration of a nonpolar molecule. Hydrophobic hydration plays an important role in facilitating amphiphiles to aggregates in the aqueous bulk phase and to absorb, excessively, at the aqueous solution/air interface, it has been an uninterrupted objective of chemists working in these areas to examine a clearer understanding of the molecular nature behind the hydration phenomenon occurring between nonpolar solutes and water. Hydrophobic hydration which is essential to the rationalization of the results obtained in this work is given at this point is a brief but detailed account of the general aspects.

1.12 Disaccharides-solvent systems

The experimental data on volumetric and ultrasonic properties provide valuable information for proper understanding the nature of interaction between the components of the solution. The study of volumetric and sound velocity of solution containing disaccharides and TPC are interesting. The correlation between solute-solvent interactions is complex. The environment of the solute affects the volumetric and sound velocity properties; it is of interesting to study the effect of the media changing from water- TPC with disaccharides on the thermodynamic properties.

1.13 Aim of the present work

The developments in solution theory are still far from being adequate to account for the properties of the constituent molecules. Accordingly, it is the experimental data on various volumetric and ultrasonic properties, which provide useful information for proper understanding of specific interaction between the components and structure of the solution. The experimental approach of measurements of various macroscopic properties is also useful in providing guidance to theoretical approaches, since the experimentally determined values of solution properties may bring to light certain inadequacies in the proposed model on which theoretical treatments may be based. Volumetric and ultrasonic studies on ternary solutions have attracted a great deal of attention and experimental data on a good number of systems are available in a number of review articles [51]. Since there has to be the same origin, namely, the characteristic intermolecular interactions, it is natural to seek functional relationships among the volumetric properties, ultrasonic properties and thermodynamic properties.

Besides the theoretical importance, the knowledge of physicochemical properties of multicomponent mixtures is indispensable for many chemical process industries. For instance, in petroleum, petrochemical and related industries the above mentioned processes are commonly used to handle the mixture of hydrocarbons, alcohols, aldehydes, ketones etc., which exhibit ideal to non-ideal behavior. For accurate design of equipment required for these processes, it is necessary to have information regarding the interactions between the components. Similarly, knowledge of the sound velocity of liquids/mixtures is indispensable. Sound velocity and density data yield a lot of information on the nature of intermolecular interaction and mass transport.

The experimental data on volumetric and ultrasonic properties such as apparent molar volumes, partial molar volumes, apparent molar adiabatic compressibility and hydration number often provide valuable information for the understanding of the nature of homo and hetero-molecular interactions. The knowledge of the main factors involved in the solute-solvent and solvent-solvent interactions of liquid mixtures is fundamental for a better understanding of apparent molar volumes and ultrasonic properties.

The thermo-physical properties of liquid systems like density and sound velocity are strictly related to the molecular interactions taking place in the system [52]. The studies of disaccharides express the interaction of dipolar ions with other functions and components in the biological system [53]. There are different types of interactions such as ionic or covalent, charge transfer, hydrogen bonding, ion-dipole and hydrophobic interactions. There are various papers appeared recently which use volumetric and ultrasonic method to access physiochemical parameters of biological molecule and interpreted the solute-solvent interactions [54, 55]. Therefore we decided to study the density and sound velocities properties of disaccharides in mixed solvent system.

In the present investigations, (i) densities, apparent molar volumes, partial molar volumes, apparent molar expansibilities (ii) sound velocities, apparent molar adiabatic compressibility, hydration number, acoustic impedance, relative association parameters of aqueous TPC with carbohydrates at six different temperatures (293.15-313.15K) have been determined.

Few studies have been reported on volumetric and acoustic behavior of D(+)-glucose and D(−)-fructose in aqueous trisodium citrate solutions at different temperatures and solute solvent interactions of mono saccharides D(−)-ribose and D(+)-xylose in aqueous trisodium citrate solutions at different temperatures [56]. To the best of our knowledge, no data on density, sound velocity, apparent molar volume, partial molar volume, adiabatic compression and isobaric expansion of sucrose and maltose in aqueous TPC solutions at different temperatures under atmospheric pressure has previously been reported. So we believe that this work will be significant to understand the molecular interactions of sucrose and maltose in aqueous TPC solutions at different temperatures.

The specific aims are:

i) to measure the density and sound velocity of sucrose and maltose with aqueous TPC solution at different temperature.
ii) to examine the apparent molar volume, limiting apparent molar volume, apparent molar volume transfer, partial molar volume, molar volume expansibilities, isentropic compression, hydration number, acoustic impedance of the studied systems at different temperature.
iii) to understand the effect of TPC on the structure of sucrose and maltose in solution.
iv) to predict about the structure making or breaking mechanism of sucrose, maltose in aqueous and aqueous TPC systems.

v) to enrich the available data on physico-chemical properties of the system.

CHAPTER II

Literature review

A literature review is a text of a paper and this text contain the current knowledge including substantive findings. Theoretical and methodological contributions in a particular topic are known by this text. In every academic field literature reviews used as basis for research. Saccharides perform important biological functions such as cell-cell recognition, antifreeze agents, protein or enzyme stability, etc. They are important components of formulations in the pharmaceutical and biotechnological industries. It is well known that among biological macromolecules the modulation of the cryprotectant action of saccharides occurred by the salt. It is known as the thermodynamic effects which changes in saccharide hydration, viscosity, diffusion and crystallization kinetics. Thus, experimental behaviour of thermodynamic and transport properties of saccharide-salt aqueous mixtures is important for basic research as well as for applications in the biochemical and biotechnological fields. Phosphate-based inorganic salts have salting-out and stabilizing effects on macromolecules and proteins. Several biophysical mechanisms have been used to explain the protective action of disaccharides.

Shahidi *et al.* studied the partial molar volumes of mono-, di-, tri-, tetra-, penta-, hexa-, hepta-, and polysaccharides and their derivatives in water at 25 ºC. The experimental values can be calculated from the van der Waals volumes of the molecules if account is taken of the shrinkage in volume caused by hydrogen-bonding of solvent molecules to the hydroxyl groups of the sugars [57].

Paljk *et al.* also reported the densities of some D-pentoses and D-hexoses in aqueous solutions over the temperature range (293.15 to 318.15) K. They discussed the results in terms of molar volumes of the solutions were found to be linearly dependent on the mole fraction of the solute. Thus, the partial molar volumes of solvent and solute, respectively, are concentration-independent. They also investigated, the dependence of the partial molar volumes of the solute on temperature [58].

Fucaloro *et al.* performed the partial molar volumes and refractions of fructose, glucose, mannose and sucrose at (15, 20 and 25) ºC. They proposed a model to explain the deviations of the partial molar volumes at higher concentrations from those at infinite-dilution. In addition, the partial molar volumes of the sugars at infinite dilution were fit to quadratic relations in temperature [59].

Bernal *et al*. studied the molar volumes, expansion coefficients and isentropic compressibilities of aqueous solutions of various saccharides and their deuterated isomers and rationalized the property values by using a specific hydration model. Results suggest that hydration depends not only on the conformation of the solute molecules, but also on the solvent which reorients according to the solute conformation [60].

Hoiland *et al*. reported the partial molal volumes and isentropic compressibilities of some di- and tri-saccharides at 25 ºC. They interpreted the results in terms of the stereochemistry of the solute and how the solute molecule fits in the water structure [61].

Chalikian has studied the partial molar volumes and adiabatic compressibilities for several monosaccharides in aqueous solution at 18, 25, 40, and 55 °C. The experimental data were used for the estimation of the solvent contraction, caused by the polar groups of monosaccharides. The volume and compressibility data suggested a similar hydration of the polar groups of pentoses and hexoses [62].

Shiio performed the ultrasonic velocities of various saccharides using ultrasonic interferometer at 25 ºC. From the values of bound water obtained, it was found that (0.5-0.9) water molecules were hydrated to one –OH radical of each saccharide and the enthalpy difference between hydrated water and non-hydrated was found to be about (12 to 13) kcal mol^{-1}[63].

Barone *et al.* used calorimetry to measure the heats of dilution of D-xylose, D-fructose, D-galactose, D-mannose, lactose and raffinose in water at 25 ºC. The excess functions were calculated and compared with the spectroscopic properties [64].

Sargent *et al.* reported the apparent molar volumes and heat capacities for disaccharide at various temperatures and at pressure 0.35 MPa. They compared their results with those of D-glucose and D-galactose solutions [65].

Brown *et al.* studied the apparent molar volumes and heat capacities of aqueous solutions of D(+)-cellobiose, D(+)-maltose and sucrose at (278.15 to 393.15) K and at pressure 0.35 MPa. The values for the disaccharides were discussed relative to those of the component monosaccharide [66].

M. G Azam perfomed the volumetric and sound velocity of L-proline and L-lysine in aqueous nicotinamide solution at different temperatures. These measurements have been performed to evaluate some important parameters viz. apparent molar volume (φ_v), limiting apparent molar volume (φ_v^0), limiting apparent molar volume transfer ($\Delta_{tr}\varphi_v^0$), apparent molar expansibilities (E_φ^0) and Hepler's constant ($(\delta E^0\varphi/\delta T)_p$). The results have been discussed in terms of solute-solvent interactions [67].

Samanta *et al.* studied the densities and viscosities of glucose in aqueous urea solutions at (298.15, 303.15, 308.15 and 313.15) K and calculated the apparent molar volumes, limiting partial molar volume, and relative viscosity. The solute acts as water structure maker and provides strong solute-solvent interaction [68].

Dhondge *et al.* reported the apparent molal volume of solute and the Jones Dole viscosity B- and D-coefficients for glucose, fructose, sucrose, and lactose in aqueous urea solutions from density and viscosity measurements, respectively, and have discussed the results on the basis of interactions among solute and solvent molecules [69].

Parke *et al.* studied the density and sound velocity of sweeteners; sucrose, maltitol, acesulfame K, aspartame, sodium cyclamate and sodium saccharin at 20 °C and determined various thermodynamic parameters. These solution properties were used to explain the mechanism of sweet chemoreception [70].

M. Tariquzzaman reported the volumetric and ultrasonic properties of L-lysine, L-ornithine and glycine in aqueous fructose solution at different temperatures. Using these experimental values, the acoustical parameters such as adiabatic compressibility, apparent molal compressibility, apparent molal volume, limiting apparent molal compressibility, limiting apparent molal volume were calculated for all the systems. The results suggest the interaction of ion-hydrophilic and hydrophilic-hydrophilic interactions [71].

Parfenyuk *et al.* also carried out the same studies on D-maltose and sucrose with some amino acids (glycine, DL-alanine, DL-leucine, and L-serine) at 298.15 K. The results were analysed in terms of the nature of solutes, their specific conformations and hydration [72].

Cardoso *et al*. reported the solubilities of various mono-, di-, tri and cyclic saccharides in H_2O and in D_2O at various temperatures. The Vant' Hoff equation was used to calculate the solution enthalpies for the saccharides in these two solvents [73].

Kumar *et al*. reported the partial molar volumes and isentropic compressibilities from density and sound velocity data of various saccharides in aqueous leucine at different temperatures and interpreted the results in view of the molecular interactions [74].

M. Islam studied the volumetric and sound velocity studies of L-serine, L-asparagine and L-glutamine in aqueous vitamin B6 solution at different temperatures. experimental data have been used to estimate adiabatic compressibility (β_s), apparent molar adiabatic compressibility (φ_k), limiting apparent molar adiabatic compressibility (φ_k^0), apparent molar adiabatic compressibility of transfer ($\Delta_{tr}\varphi_k^0$) which indicates solute-solvent interaction [75].

To the best of our knowledge volumetric and ultrasonic properties of sucrose and maltose in aqueous TPC solution at different temperatures were not reported previously. The literature survey suggests that volumetric and ultrasonic properties of systems consist of biologically important compounds remain a fruitful field of investigation. Literature survey also clearly shows the importance of the effects of added electrolytes to the molecular interactions thereby changing the volumetric and ultrasonic properties. In this context, the objective of the present set of studies was framed to investigate in detail, the volumetric and ultrasonic properties of biologically important compounds such as carbohydrates and TPC.

CHAPTER III

Experimental

The following systems have been carried for the investigation of molecular interactions of sucrose and maltose in water and in aqueous solution of tri-Potassium citrate (TPC).

1. sucrose + water
2. maltose + water
3. sucrose + water + 0.05 mol.kg^{-1} TPC
4. sucrose + water + 0.20 mol.kg^{-1} TPC
5. sucrose + water + 0.35 mol.kg^{-1} TPC
6. sucrose + water + 0.50 mol.kg^{-1} TPC
7. maltose + water + 0.05 mol.kg^{-1} TPC
8. maltose + water + 0.20 mol.kg^{-1} TPC
9. maltose + water + 0.35 mol.kg^{-1} TPC
10. maltose + water + 0.50 mol.kg^{-1} TPC

All experiments have been carried out at five equidistant temperatures as 293.15K, 298.15K, 303.15K, 308.15K and 313.15K. The details of various information have been described in the following sections.

3.1 Materials

The chemicals used for study were sucrose, maltose and tri-Potassium citrate. All chemicals were of analytical reagent (A.R) grade. Specifications and structural formula for all of them are given below:

Chemicals	Molecular formula	Molar mass (g.mol^{-1})	Reported purity	Producer
tri-Potassium citrate	$C_6H_5K_3O_7.H_2O$	324.41	Extra Pure	LOBA Chemical, India
Sucrose	$C_{12}H_{22}O_{11}$	342.29	99.5%	MERCK (India)
Maltose	$C_{12}H_{22}O_{11}.\ H_2O$	360.32	99.0%	MERCK (India)

3.2 Apparatus

A HR-200 electronic balance with an accuracy of ± 0.0001g was used for the mass determination. Densities and speeds of sound was measured by an Anton Paar DSA 5000M model high precision vibrating tube digital density meter and speed of sound measuring device, with automatic viscosity corrections.

3.3 Preparation of solution

The solutions were prepared immediately before the measurement. The binary solutions were prepared by mixing appropriate mass of the components. The amount of each component was later converted into the molality. The molalities of the samples are controlled to ± 0.00005 mol.kg^{-1}. Precautions were taken to prevent the introduction of moisture into the experimental example. Each time, the solution was prepared immediately before the density measurement.

3.4 Density and sound velocity measurements

The density of liquid may be define as the mass per unit volume of the liquid, the unit of volume being the cubic centimeter (cm^3) or millimeter . Since the millimeter is defined to be the volume occupied by one gram of water at temperature in g mL^{-1} is unity and the density of water at any other temperature is expressed relative to that of water at 4^{0}c. The absolute density of a certain substance at temperature t^0 C is equal to the relative density multiplied by the density of water at the temperature. Density and sound velocity of pure liquid and liquid-liquid mixtures was measured using high precession vibrating tube digital densitometer (Anton Paar DSA 5000 M, Austria). The density and sound velocity values have been found with an error of ± 0.000006 g cm^{-3} and ± 0.05 ms^{-1} respectively. The method is based on the principle of time lapse measurement for certain member of oscillations of a vibrating U-shaped sample tube fill with the sample liquid. At constant temperature, the natural vibrational period of the U- tube is related to density of liquid filling the tube. In the latest version of Anton Paar digital density meter (DSA 5000 M), the natural vibration period is automatically converted into the density value and display directly on the LC display monitor of the decimeter. The DSA 5000 M density measuring cell consists of a cell consists of a U-shaped oscillator glass cylinder. The temperature of the sample tube is controlled by two integrated in-built Pt 100 platinum thermometers to a level of highest accuracy and traceable to national standard. The temperature of the sample tube is controlled to ± 0.001K. The design of the cell ensures identical volumes to be used for the measurement on different samples. Using a polyethylene syringe the sample was continuously and slowly injected from the upper part of U-tube until the excess fluid flowed out of the lower part. This ensured that the inner surface of the cell was completely wet and there are no micro bubbles inside the U-tube. The syringe was kept as such in plugged. After the measurement the sample was removed and air was passed, by built in pump, through the tube to remove excess liquid. The tube was then rinsed several times with the solution of higher concentration and finally the solution was injected for the measurement. Measuring the density of water supplied with the densitometer checked the working of the densitometer. All measurements were made starting from the lowest to the highest solute concentration.

3.5 Density

The density of a liquid may be defined as the mass per unit volume of the liquid unit of volume being the cubic centimeter (cm^3) or milliliter (mL). Since the milliliter is defined to be the volume occupied by one gram of water at temperature of maximum density (i.e., at 4^0C), the density of water at this temperature in gmL^{-1} is unity and the density of water at any other temperature is expressed relative to that of water at 4^0C and expressed by (d^{10}_4).

The relative density of a substance is the ratio of the weight of a given volume of the substance to the weight of an equal volume of water at the same temperature (d^{10}_4). The absolute density of a certain substance temperature t^{0}C is equal to the relative density multiplied by the density of water at the temperature. The density of a liquid may be determined either by weighing a known volume of the liquid in a density bottle or picnometer or by buoyancy method based on "Archimedes principle".

In our present investigation, the densities of the pure components and the mixture were determined by density and sound velocity meter.

3.6 Density and temperature

An increase in temperature of a liquid slightly increases the volume of the liquid, thus decreasing its density to some extent. The temperature increase brings about an increase in molecular velocity. These energetic molecules then fly apart causing more holes in the bulk of the liquid. This causes the expansion of the liquid, thereby decreasing the number of molecules per unit volume and hence the density.

3.7 Molarity

Molarity (C) is defined as the number of moles of solute per litre of solution. If n_2 is number of moles of solute and V liters is the volume of the solution then,

$$Molarity(\mathrm{C}) = \frac{\text{Number of moles of solute}}{\text{Volume of solution}}$$

Or, $C = \frac{n_2}{V}$ …………………………………………………………………..…….(3.1)

For one mole of solute dissolved in one liter of solution, C = l i.e. molarity is one. Such a solution is called 1 molar. A solution containing two moles of solute in one liter is 2 molar and so on. As evident from expression (3.1), unit of molarity is molL^{-1} [76].

3.8 Molar volume of mixtures

The volume in mL occupied by one gram of any substance is called its specific volume and the volume occupied by 1 mole is called the molar volume of the substance. Therefore, if ρ is the density and M be the molar mass, we have the molality (m) of a solution is defined as the number of moles of the solute per 1000 g of solvent [76]. Mathematically,

$$Molality(\mathrm{m}) = \frac{\text{Number of moles of solute}}{\text{Weight of solvent in gram}} \times 1000$$

$$\text{or, } \mathrm{m} = \frac{\frac{\mathrm{a}}{\mathrm{M_2}} \times 1000}{\text{Volume of solvent in mL} \times \text{Density of solvent in g cm}^{-3}}$$

$$\text{or, } \mathrm{m} = \frac{\frac{\mathrm{a}}{\mathrm{M_2}} \times 1000}{\mathrm{V_1} \times \rho_0}$$

$$\text{or, } \mathrm{m} = \frac{\mathrm{a}}{\mathrm{M_2}} \times \frac{1000}{\mathrm{V_1} \times \rho_0} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.2)$$

Where,

a = Weight of solute in gram

M_2 = Molecular weight of solute in gram

V_1 = Volume of solvent in mL

ρ_0 = Density of solvent in g cm^{-3}

$$\text{Specific volume, (V)} = \frac{1}{\rho} mLg^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

$$\text{And Molar volume, (V}_\mathrm{m}\text{)} = \frac{M}{\rho} mLmol^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

When two components are mixed together, there may be either a positive or a negative deviation in volume. The positive deviation in volume i.e. volume expansion has been explained by the breakdown of the mode of association through H-bonding of the associated liquids. The negative deviation in molar volume i.e. volume contraction has been thought of by many observers, as arising from the i) compound formation through association, ii) decrease in the intermolecular distance between the interacting molecules, iii) interstitial accommodation of smaller species in the structural network of the larger species and (iv) change in the bulk structure of either of the substance forming the mixture.

3.9 Apparent/ partial molar volume measurements

The apparent molar volumes of the solution for binary and ternary systems were determined from density measurement using the following equation [76, 77]:

$$\varphi_v = \frac{1}{\rho}\left\{M_2 - \frac{1}{m}\left(\frac{\rho-\rho_0}{\rho_0}\right)\right\}$$

or, $$\varphi_v = \frac{1}{m\rho\rho_0}\left(\rho_0 - \rho\right) + \frac{M_2}{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.5)$$

Where, ρ is the density of the experimental solution, M_2 and m are the molar mass and molality of the electrolyte respectively and ρ_0 is the density of the solvent. The molality 'm' of a solution was calculated from mole fraction of solute and solvent

$$m = \frac{X_2 \times 1000}{X_1 M_1}$$

Where, M_1 and M_2 = the molecular weight of solvent and solute

And also from molarity C,

$$m = \frac{1}{\left(\frac{\rho}{C} - \left(\frac{M_2}{1000}\right)\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

Where, C is the molarity, M_2 is the solute molecular weight and ρ is the density of the solution respectively.

The molarity 'C' of a solution was calculated from the following equation:

$$C = \frac{1}{M_2} \times \frac{a}{\text{vol. of solution in liter}} \quad \text{……………………..………………..……………. (3.7)}$$

Where, a = weight of the solute in gm. M_2 = solute molecular weight.

Molar volume of solvent (pure water) at experimental temperature was calculated using the following equation [77].

$$\overline{V}_1^0 = \frac{\text{Molecular masses of solvent}}{\text{Density of solvent (at expt. temp.)}} \quad \text{……………..…………………………….(3.8)}$$

The partial molar volumes of the solute and solvent can be obtained from density measurement using the following equation.

$$\overline{V_2} = \varphi_v + \frac{\sqrt{m}}{2}\left(\frac{\delta\varphi_v}{\delta\sqrt{m}}\right) = \varphi^0{}_v + \frac{3\sqrt{m}}{2}\left(\frac{\delta\varphi_v}{\delta\sqrt{m}}\right) \quad \text{……………………….…………………(3.9)}$$

Where, $\varphi^0{}_v$ = apparent molar volumes at zero concentration.

And $$\overline{V_1} = V_1^0 - \frac{M_1 m^{3/2}}{2000}\left(\frac{\delta\varphi_v}{\delta\sqrt{m}}\right) \quad \text{……………..…………………………….(3.10)}$$

The values of $\frac{\delta\varphi_v}{\delta\sqrt{m}}$ were obtained from the slope of the plot of φ_v against $\sqrt{C}$ by the use of Masson (50) equation and the apparent molar volume of solutes at infinite dilution ($\varphi_v^0 \approx \overline{V}_2{}^0$) were determined from the intercept of the plot, at C equal to zero.

3.10 Limiting apparent molar volume of transfer

Limiting apparent molar volume of transfer can be obtained from using the following equation,

$\Delta\varphi_v^0 = \varphi_v^0$ (in aq. TPC solution) - φ_v^0 (in water) …..…..………………………….(3.11)

Where, φ_v^0 is limiting apparent molar volume.

3.11 Temperature dependent limiting apparent molar volume

At infinite dilution, the variation of limiting apparent molar volumes i.e. (φ_v^0) with the temperature can be expressed by the general polynomial equation as follows:

$$\varphi_v^0 = A + B\,(T-T_m) + C\,(T-T_m)^2 \quad \ldots\ldots(3.12)$$

Where T is the temperature in Kelvin, T_m is the average temperature A, B, and C are the empirical constants.

The limiting apparent molar expansibilities are calculated as follows:

$$E_\varphi^0 = (\delta\varphi_v^0/\delta T)_p = B + 2C\,(T-T_m) \quad \ldots\ldots (3.13)$$

Hepler developed the general thermo-dynamic expression to determine the capacity of solute as a structure maker or structure breaker in mixed solvent system using general thermodynamic expression [78]:

$$(\delta E_\varphi^0/\delta T)_p = (\delta^2\varphi_v^0/\delta T^2)_p = 2C \quad \ldots\ldots(3.14)$$

Where $(\delta^2\varphi_v^0/\delta T^2)_p$ is Hepler's constant.

3.12 Theory of ultrasonic velocity

Sound is propagated through a medium by longitudinal waves. A longitudinal wave is a type of periodic motion in which the displacement of the particles in the medium occurs in the same direction as the wave itself. A schematic diagram of a longitudinal sound wave is shown in Figure 3.1. For simplicity a one-dimensional wave is depicted, one can imagine that sound generated by an oscillating boundary at the left, is traveling to the right through a medium. The motion of the sound wave is a function of both time and space. The figure can be viewed as a density contour map of the medium. The darker areas have higher density; these are periodic compressions (C). The lighter areas have lower density these are periodic expansions, or refractions (R). The density of the fluid ahead of the wave front is the undisturbed bulk density (ρ), which is intermediate between the local densities of the medium C and R.

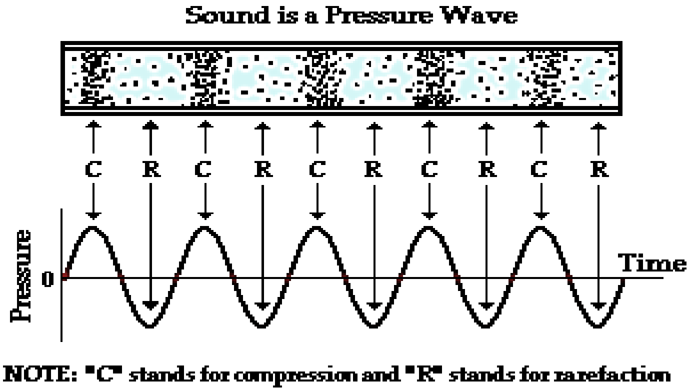


Figure 3.1: Schematic diagram of a longitudinal standing wave C and R show positions of medium compressions and refractions (high and low densities) respectively.

When a layer of fluid medium is compressed or rarefied during the passage of a sound wave, the pressure in the layer changes from the equilibrium pressure. The amount of pressure changed is defined as the excess pressure or sound pressure or acoustic pressure. Considering the acoustic pressure an equation for sound wave [79] or sound velocity can be derived, which is expressed as,

$$u = \left(\frac{1}{\rho\beta}\right)^{½} \qquad \text{………………………………………..…................. (3.15)}$$

Where, ρ is the equilibrium density and β is the compressibility, which is the reciprocal of bulk modulus, k, of medium, given by

$$\beta = k^{-1} = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right) \qquad \text{……………………………………………………………......}$$

(3.16)

Where, ∂V = volume changed during the passage of sound

∂P = acoustic pressure

V = volume of medium at equilibrium

An important aspect of sound propagation as the fact that if the frequency of the sound being generated by high enough i.e., audio frequencies which are between 10^3 and 10^4 Hz (oscillations per second), the compressions and refractions are established very rapidly as the sound way moves through the medium. This condition means that heat transport between the compressed and rarefied regions of the medium and the surroundings is slow relative to the creations of the compressions and refractions. Thus, on a local basis, the compressions and refractions are carried out adiabatically. At much lower sound frequencies, on the other hand, it is possible to imagine that heat transport between the medium and the surroundings is fast enough to allow the medium to be compressed and expanded isothermally (if the thermal mass of the surroundings is large enough). Accordingly, the compressibility β can be described under constant-temperature or constant-energy conditions, and one can thus distinguish between isothermal and adiabatic compressibility's of a substance, β_{T}, and β_{S} respectively. Since audio frequencies are used in this experiment, we must use the adiabatic (or isentropic), which can be explicitly written as,

$$\beta_s = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_s \text{.. (3.17)}$$

Writing β_s instead of β in equation (3.16) gives the Newton-La place equation of the form

$$u = \left(\frac{1}{\rho\beta_S}\right)^{½} \text{.. (3.18)}$$

Various attempts [80-85] have been made to calculate theoretically ultrasonic sound velocity through binary mixtures.

3.13 Adiabatic Compressibility measurements

The adiabatic compressibility, β_s of the solution for binary and ternary systems were determined from density and sound velocity data using the following equation,

$$\beta_s = \frac{1}{\rho u^2} \quad \text{... (3.19)}$$

Where, ρ is the density of the experimental solution and u is the sound velocity of the solution.

3.14 Apparent molar Adiabatic Compressibility measurements

The apparent molar adiabatic compressibility, β_s of the solution for binary and ternary systems were determined from density and sound velocity data using the following equation,

$$\varphi_K = \frac{M\beta_s}{\rho} + \left(\frac{\beta_{s,o}\rho - \beta_s\rho}{m\rho\rho_o}\right) \ldots\ldots (3.20)$$

Where, ρ and ρ_o are the density of the experimental solution and solvent, m is the molarity of the solution and β_s and $\beta_{s,o}$ are the adiabatic compressibility of the experimental solution and solvent.

3.15 Acoustic Impedance measurements

The acoustic impedance, Z is of the solution for binary and ternary systems were determined from density and sound velocity data using the following equation,

$$Z = u\rho \quad \ldots\ldots (3.21)$$

Where, ρ is the density of the experimental solution and u is the sound velocity of the solution.

3.16 Hydration number

The hydration number, n_H of the solution for binary and ternary systems were determined from density and sound velocity data using the following equation,

$$n_H = \frac{n_1}{n_2}\left(1 - \frac{\beta_s}{\beta_{s,o}}\right) \ldots\ldots (3.23)$$

Where n_H denotes the hydration number. β_s, $\beta_{s,o}$ are adiabatic compressibilities of solution and solvent respectively and n_1 and n_2 are number of moles of solvent and solute respectively.

CHAPTER IV

Results and Discussion

Carbohydrates are important class of biological molecules. In food and biological industries the thermodynamic data of aqueous solutions of saccharides is very important. Potassium citrate has some medicinal properties and it is used for the prevention of gout and kidney stones and its another application is to make urine less acidic. For the development of molecular science intermolecular interactions studies has a huge contribution. The interaction of sucrose and maltose with TPC in terms of volumetric and sound velocity measurement has been carried out. The experimental results and the properties derived from experimental data are presented in this chapter. The studied systems are:

1. sucrose + water
2. maltose + water
3. sucrose + water + 0.05 mol.kg^{-1} TPC
4. sucrose + water + 0.20 mol.kg^{-1} TPC
5. sucrose + water + 0.35 mol.kg^{-1} TPC
6. sucrose + water + 0.50 mol.kg^{-1} TPC
7. maltose + water + 0.05 mol.kg^{-1} TPC
8. maltose + water + 0.20 mol.kg^{-1} TPC
9. maltose + water + 0.35 mol.kg^{-1} TPC
10. maltose + water + 0.50 mol.kg^{-1} TPC

The above-mentioned systems have been studied precisely at five equidistant temperatures ranging from 293.15K to 313.15K at interval of 5K by density and sound velocity methods. The volumetric properties such as apparent molar volume (φ_v), partial molar volume ($\bar{V}_2$), limiting apparent molar volume (φ_v^0), limiting apparent molar volume transfer ($\Delta_{tr}\varphi_v^0$), limiting apparent molar expansibilities ($(\delta\varphi_v^0/\delta T)_p$) and Hepler's constant have been determined from density data. The ultrasonic properties like adiabatic compressibility (β_s), apparent molar adiabatic compressibility (φ_k), limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k), apparent molar adiabatic compressibility of transfer ($\Delta_{tr}\varphi_k^0$), acoustic impedance (Z) and hydration number (n_H) have been determined from sound velocity data. The obtained information of these systems have presented in various sections.

4.1 Volumetric properties

The densities, ρ of disaccharides in water systems have been determined at temperatures ranging from (293.15K, 298.15K, 303.15K, 308.15K and 313.15K) with an interval of 5K over the concentration ranging from 0.05 $mol.kg^{-1}$ to 0.40 $mol.kg^{-1}$. The densities of sucrose and maltose in water have been shown in tables 4.1-4.2 and figures are graphically shown in 4.1-4.2 at different temperatures. Figures 4.1-4.2 show that the densities of sucrose and maltose increase with the increase of concentration. These are due to the increase in number of particles in given region which leads to shrinkage in volume of solution [86-87]. The densities decrease with the increase of temperature. Because the solution is heated, the thermal energy of molecules increases and accordingly the intermolecular distance increases, which leads to the decrease of the density.

The densities, ρ of ternary systems such as sucrose and maltose in 0.05 $mol.kg^{-1}$, 0.20 $mol.kg^{-1}$, 0.35 $mol.kg^{-1}$ and 0.50 $mol.kg^{-1}$ aqueous TPC solutions are listed in tables 4.3-4.10 and figures are graphically shown in 4.3-4.10. The values of densities of sucrose and maltose in aqueous TPC systems has been found to be in the order of disaccharides in aqueous 0.50 $mol.kg^{-1}$ TPC > disaccharides in aqueous 0.35 $mol.kg^{-1}$ TPC > disaccharides in aqueous 0.20 $mol.kg^{-1}$ TPC > disaccharides in aqueous 0.05 $mol.kg^{-1}$ TPC. It is seen that the density increase with the increasing of TPC concentration at a fixed disaccharides concentration. The increase of density with concentration of TPC can be attributed to solute-solvent interaction. For ternary systems the densities also decrease with the increase of temperature. Because the solution is heated, the thermal energy of molecules increases and accordingly the intermolecular distance increases, which leads to the decrease of the density [88]. Densities of disaccharides in aqueous TPC system are higher than that of disaccharides in water systems.

The apparent molar volumes (φ_v) of sucrose and maltose in water are calculated from density data. The value of apparent molar volume of sucrose and maltose in water at different temperatures (293.15, 298.15, 303.15, 308.15, 313.15) K are given in tables 4.11-

4.12 and the variation of φ_v with molality of sucrose and maltose are graphically represented in figures 4.11-4.12. It appears from the figure that apparent molar volume is dependent upon the disaccharides concentration as well as on the temperature. Plots of φ_v vs. molality (m) of disaccharides show linear relationship in water system. The values of apparent molar volume (φ_v) of aqueous disaccharides are positive and linearly increase with the increase of concentration of disaccharides.

The values of apparent molar volume (φ_v) of aqueous sucrose and maltose solutions increase in the order of maltose > sucrose which due to the increasing of number of carbon in cyclic ring present in sucrose and maltose at all temperatures and concentrations, so that increase in surface of solute to interact with solvent. The value of φ_v increases with increase in temperature because of thermal agitation, which leads to the bond breaking.

The value of apparent molar volume of sucrose and maltose in aqueous TPC solutions (0.05 mol.kg^{-1}, 0.20 mol.kg^{-1}, 0.35 mol.kg^{-1} and 0.50 mol.kg^{-1}) at different temperatures (293.15, 298.15, 303.15, 308.15, 313.15) K are given in tables 4.13-4.20 and figures 4.13-4.20 show the plots of apparent molar volume as a function of molality of sucrose and maltose at different temperatures. Plots of φ_v vs. molality of disaccharides show linear relationship in aqueous TPC system. For sucrose and maltose in aqueous TPC solutions systems, the values of apparent molar volume (φ_v) are also positive and linearly increase with the increase of concentration of sucrose and maltose. It has been also found that apparent molar volumes for sucrose and maltose increase with the increase of TPC concentration (0.05 mol.kg^{-1}, 0.20 mol.kg^{-1}, 0.35 mol.kg^{-1} and 0.50 mol.kg^{-1}). At a fixed TPC concentration and temperature, the increase of φ_v with the concentration of added disaccharides may be due to the cluster formation or aggregation. Also, the apparent molar volumes increase with an increase in the number of carbon in cyclic ring present in disaccharides (i.e. from maltose and sucrose) at all temperatures and concentrations of tri-potassium citrate, due to the increase in surface of solute to interact with solvent [89].

Comparatively lower apparent molar volume, φ_v of sucrose in aqueous TPC solutions than maltose in aqueous TPC was found. This indicates that the sucrose in aqueous TPC solution is more compressed than maltose in aqueous TPC solution. The apparent molar volume, φ_v of sucrose and maltose in aqueous TPC solution is higher than sucrose and maltose in water solution. This indicates that the sucrose and maltose is less compressed in aqueous TPC solution than aqueous solution.

The limiting apparent molar volume (φ_v^0) which is also called the standard partial molar volume of aqueous sucrose and maltose at 293.15, 298.15, 303.15, 308.15 and 313.15K are reported in tables 4.21-4.22. The limiting apparent molar volumes (φ_v^0) of disaccharides reflect the true volume of the solute. However, limiting apparent molar volumes at infinite dilution (φ_v^0) of the solute can represent further information regarding solute-solvent interactions. The apparent molar volumes (φ_v) was observed to correlate linearly with solution molality (m) at all experimental temperatures, hence standard partial molar volumes (φ_v^0) was obtained from Masson equation [90]. Tables 4.21-4.22 show that values of limiting apparent molar volume (φ_v^0) are positive. At each temperature, the φ_v^0 values increase with size of carbon chain. Furthermore, the values of φ_v^0 also increase with an increase in the molar mass and size of the disaccharides, that is, higher values of φ_v^0 are obtained for maltose as compared to sucrose. These trends in limiting apparent molar volumes (φ_v^0) indicate the presence of strong solute-solvent interactions. The increase in φ_v^0 values with increase in temperature for all disaccharides may be explained as release of some solvent molecules from the loose solvation layers of the solutes in solution.

The values of limiting apparent molar volume (φ_v^0) for sucrose and maltose in ternary solution at the studied temperatures are presented in tables 4.23-4.30. These tables show that values of limiting apparent molar volume (φ_v^0) are positive and increase with an increase in the TPC concentration. Furthermore, the values of φ_v^0 also increase with an increase in the molar mass and size of the disaccharides, that is, higher values of φ_v^0 is obtained for maltose as compared to sucrose in aqueous TPC solutions. The increase in φ_v^0 values with the increase in temperature for the studied systems may be explained as release of some solvent molecules from the loose solvation layers of the solutes in solution.

The values of experimental slope (S_V) for disaccharides in water and disaccharides in aquous TPC solution at the experimental temperatures are reported in tables 4.21-4.30. The values of experimental slope (S_V) are positive for all the concentration of disaccharides. The non-zero values of S_V indicate the presence of solute-solute interactions in solutions of disaccharides. Since there is no regular trend in the values of S_V, this clearly indicates that solute-solute interaction is also influenced by other factors. The smaller values of S_V as compared to φ_v^0 suggest the dominance of solute-solvent interaction over the solute-solute interaction [91].

The values of limiting apparent molar volume transfer of disaccharides from water to aqueous TPC solutions at infinite dilution was calculated by using the equation,

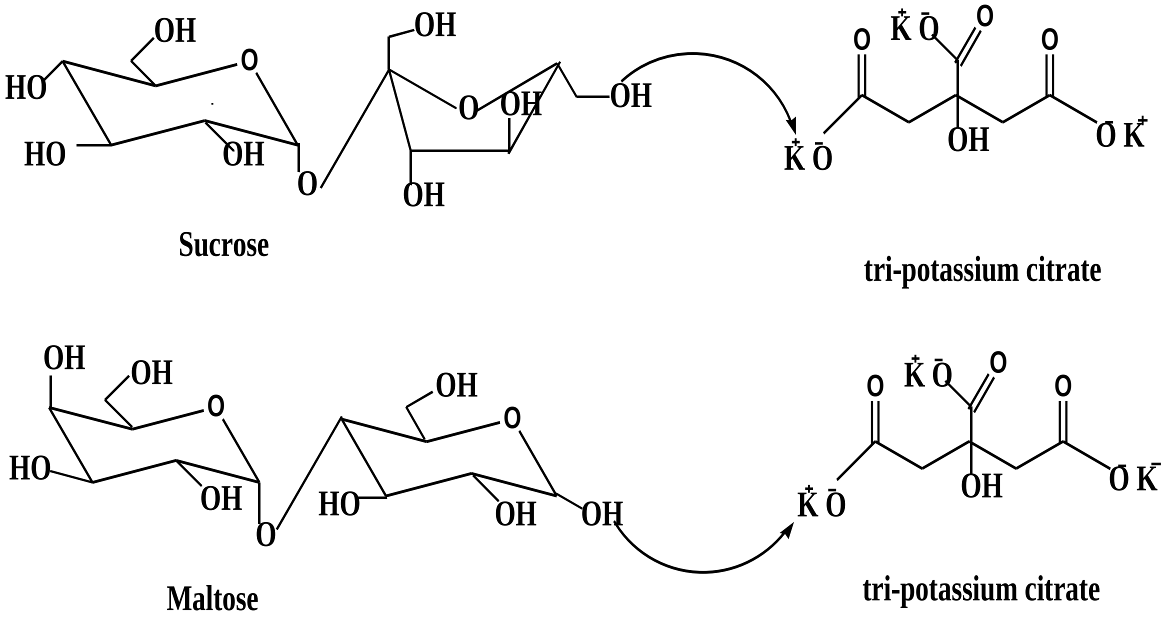
$$\Delta_{tr}\varphi_v^0 = \varphi_v^0\,(\text{TPC}) - \varphi_v^0\,(\text{in water}).$$

The values of limiting apparent molar volume transfer ($\Delta_{tr}\varphi_v^0$) of sucrose and maltose in aqueous TPC solutions have been reported in tables 4.23-4.30. The $\Delta_{tr}\varphi_v^0$ values of sucrose and maltose in aqueous TPC solutions are positive. The observed positive values of $\Delta_{tr}\varphi_v^0$ suggest strong ion-hydrophilic or hydrophilic-hydrophilic interactions of disaccharides with tri-potassium citrate. The interactions that may be possible between disaccharide and TPC molecules are

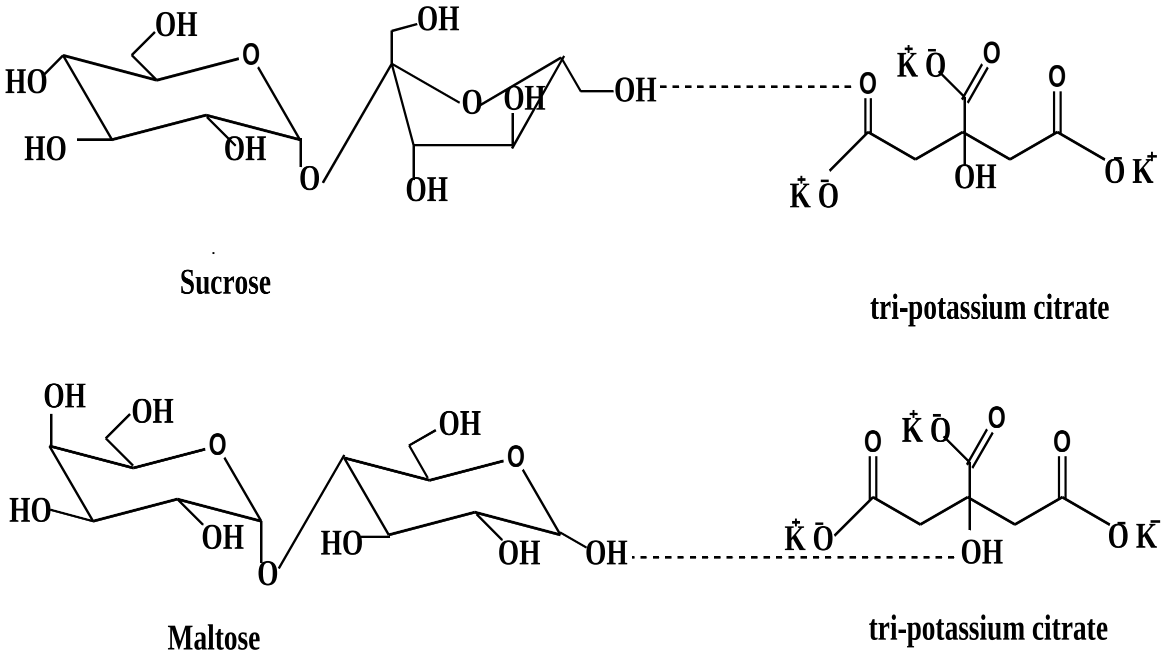
(i) interaction between -OH and -O- of the sucrose and maltose; and K^+ and $C_6H_5O_7^{3-}$ ions of the tri-Potassium citrate. In Scheme - 1, -OH of the sucrose and maltose interact with K^+ ions of the TPC and in Scheme – 2, -OH of the sucrose and maltose interact with -O- of the TPC.

(ii) interaction between the hydrophobic part of the saccharides and the ions of the tri-Potassium citrate.

The type (i) interactions are hydrophilic interactions which may be dominating over type (ii) for the system. Interactions of type (i) result in positive $\Delta_{tr}\varphi_v^0$ values and the positive $\Delta_{tr}\varphi_v^0$ values for all the disaccharides indicate the presence of hydrophilic-ionic and hydrophilic-hydrophilic interactions. The $\Delta_{tr}\varphi_v^0$ values increase with an increase in concentration of the TPC which indicates the presence of strong ion-hydrophilic interactions in the mixtures.



Scheme 1: Possible hydrophilic-ionic interaction



Scheme 2: Possible hydrophilic-hydrophilic interaction

The values of limiting apparent molar volume expansibilities $E_\varphi{}^0$ and $(\delta E_\varphi{}^0/\delta T)_P$ of aqueous sucrose and maltose are reported in tables 4.21-4.22. The $E_\varphi{}^0$ values are found to be positive at all temperatures and concentrations of disaccharides. The positive values of $E_\varphi{}^0$ suggest that the presence of solute-solvent interactions in these systems, as already indicated by apparent molar volume data. The sign of $(\delta E_\varphi{}^0/\delta T)_P$ determines the tendency of a dissolved solute as a structure maker or structure breaker in a solvent. The small negative or positive $(\delta E_\varphi{}^0/\delta T)_P$ values are observed for both sucrose and maltose having structure making capacity. The values of limiting apparent molar volume expansibilities $E_\varphi{}^0$ and $(\delta E_\varphi{}^0/\delta T)_P$ of sucrose and maltose aqueous TPC solutions are reported in tables 4.23-4.30. The $E_\varphi{}^0$ values are found to be positive at all temperatures and concentrations of disaccharides in TPC solution which is similar with the binary systems. The positive values of $E_\varphi{}^0$ suggest that the presence of solute-solvent interactions in these systems. The positive and small negative values of $(\delta E_\varphi{}^0/\delta T)_P$ for studied systems show the structure making ability of disaccharides in aqueous TPC solutions $(\delta E_\varphi{}^0/\delta T)_P$ [92-96].

The values of Partial molar volume ($\bar{V}_2$) of aqueous disaccharides and disaccharides in aqueous TPC solutions are shown in tables 4.31-4.40. Figures 4.21-4.30 show the plots of partial molar volume as a function of concentration of aqueous disaccharides and disaccharides in aqueous solution of tri-potassium citrate. The value of partial molar volume ($\bar{V}_2$) increases with the increase of concentration of disaccharides. This suggests that solute-solvent interactions increase with the increase of concentration of disaccharides.

4.2 Ultrasonic properties

Ultrasonic velocity of a liquid is fundamentally related to binding forces between the atoms and molecules. The measurements of ultrasonic velocity have been adequately employed in understanding the nature of molecular interaction in pure liquids, binary and ternary systems [97-99]. It provides qualitative information about the physical nature and strength of molecular interaction in the liquid mixtures [100].

The sound velocities, u of sucrose and maltose in water and in aqueous TPC systems have been determined at temperatures ranging from (293.15K to 313.15K) with an interval of 5K over the concentration ranging from 0.05 $mol.kg^{-1}$ to 0.40 $mol.kg^{-1}$. The sound velocities of sucrose and maltose in water and in aqueous TPC solution have been shown in tables 4.41-4.50 at different temperatures. Figures 4.31-4.40 show the plots of sound velocities as a function of molality of sucrose and maltose in water and in aqueous TPC solution. These figures show that the sound velocity increases with the increase of concentration of sucrose and maltose. The sound velocity of aqueous maltose is higher than aqueous sucrose. This is due to the molecular weight of maltose is higher than sucrose. The existence of molecular interactions between solute and solvent molecules is responsible for the observed increase in the sound velocity of these mixtures.

The compressibility is a very sensitive indicator of molecule interactions [101]. The change in adiabatic compressibility value in liquid and liquid mixtures may be ascribed to the strength of intermolecular interaction. The liquids solution having compact structure, rigid bonding and strong intermolecular interaction are less compressible. Evidently, hydrogen bonding, strong dipole-dipole interactions and geometrical fitting of one component into other structural network lead to decrease adiabatic compressibility.

The adiabatic compressibility (β_s) of aqueous sucrose and maltose has been shown in tables 4.51-4.52 at different temperatures. Figures 4.41-4.42 show the plots of adiabatic compressibility as a function of molality of aqueous sucrose and maltose. From the figures it is apparent that the values of β_s decrease with the increase of molar concentration of sucrose and maltose. The value of β_s also decreases with the increases of temperature. The decrease in the β_s values with increasing concentration of sucrose and maltose indicates that the water molecules around the disaccharides are less compressible than the water molecule in the bulk solution [102, 103]. The decrease in β_s may be due to the introduction of disaccharides molecule into water which reduces the void space in solution.

The values of adiabatic compressibility, β_s of sucrose and maltose in aqueous TPC solution are shown in tables 4.53-4.60 and figures 4.43-4.50 show the plots of adiabatic compressibility as a function of molality of sucrose and maltose in aqueous solution of tri-potassium citrate. From these figures it is apparent that the values of β_s decrease with the increase of concentration of sucrose and maltose in TPC solution which is similar with binary systems. The values of β_s also decrease with the increase of temperature. The decrease in the β_s values of sucrose and maltose in aqueous TPC solutions by increasing concentration of disaccharides indicates that the water molecules around the disaccharides are less compressible than the water molecule in the bulk solution [102, 103]. The decrease in β_s may be due to the introduction of disaccharides molecule into water and aqueous TPC solutions which reduce the void space in solution.

The apparent molar adiabatic compressibility (φ_k) of aqueous sucrose and maltose are calculated from density and sound velocity data. The values of apparent molar adiabatic compressibility (φ_k) of aqueous sucrose and maltose at different temperatures (293.15, 298.15, 303.15, 308.15, 313.15) K are given in tables 4.61-4.62 and the variation of φ_k with molality of sucrose and maltose are graphically represented in figures 4.51-4.52. From the data it is observed that the values of φ_k increase with an increase in the concentration of disaccharides. The values of φ_k for the studied system are negative. The negative φ_k values show that water molecules around ionic charged groups of disaccharides are less compressible than water molecules in the bulk solution. The negative φ_k values indicate greater loss of structural compressibility of water implying a greater ordering effect by the solute on the solvent [106].

The value of apparent molar adiabatic compressibility (φ_k) of sucrose and maltose in ternary (water + tri-Potassium) solution are given in tables 4.63-4.70 and the variation of φ_k with molality of sucrose and maltose are graphically represented in figures 4.53-4.60. From the data it is observed that values of φ_k are both negative and positive. The values of φ_k increases with the increase of concentration and temperature which are suggest that values change sign from negative to positive. The values of φ_k is large negative at low concentration and low temperature predict strong interactions among solute and solvent molecules. Interactions between ions of TPC and water molecules induce hydration of the molecules of saccharides when present in the aqueous TPC solutions. Because of dehydration of saccharide molecules, water molecules surrounding saccharides are more compressible at higher concentration of TPC than at lower concentration of TPC which is the reason behind the less negative and positive φ_k values at high concentration and high temperature [106]. The values of apparent molar adiabatic compressibility (φ_k) of disaccharides in aqueous TPC are higher than the values of disaccharides in water systems.

The values of limiting apparent molar adiabatic compressibility (φ_k^0) and experimental slope (S_k) of aqueous disaccharides and disaccharides in aqueous TPC solution at different temperatures (293.15, 298.15, 303.15, 308.15, 313.15) K are tabulated in tables 4.71-4.80. The value of S_k is the indicative of solute-solute interactions. As solute-solute interactions are negligible at infinite dilution due to small size of S_k values, this indicates that solute-solvent interactions are prevailing in the mixtures [104].

The more negative values of φ_k^0 for disaccharides at low temperature are attributed to the strong attractive interactions between disaccharides and water [105]. With an increase in temperature and concentration the φ_k^0 values become both less negative and positive, which means that electrostriction reduces and some water molecules are released to bulk. Furthermore, the attractive interactions between TPC and water molecules induce the dehydration of disaccharides and therefore at high TPC concentrations the water molecules around the disaccharides are more compressible than those at lower TPC concentrations.

The values of apparent molar adiabatic compressibility of transfer ($\Delta_{tr}\varphi_k^0$) for molal concentrations of aqueous sucrose and maltose in TPC at different temperatures are reported in tables 4.73-4.80. The values of apparent molar adiabatic compressibility of transfer ($\Delta_{tr}\varphi_k^0$) of disaccharides are positive. The positive values of $\Delta_{tr}\varphi_k^0$ occurred due to the interactions between (-OH and -O-) of the disaccharides and (K^+ and $C_6H_5O_7^{3-}$) ions of the tri-potassium citrate. These interactions are hydrophilic interactions which include the hydrophilic sites of saccharides. The positive $\Delta_{tr}\varphi_k^0$ values for all the saccharides indicate the presence of hydrophilic-ionic and hydrophilic-hydrophilic interactions. The $\Delta_{tr}\varphi_k^0$ values increase with the increase of concentration of the TPC which indicates the presence of strong ion-hydrophilic interactions in the solutions [106].

The values of acoustic impedance, Z of sucrose and maltose in water and in aqueous TPC solution have been shown in tables 4.91-4.100 at different temperatures. Figures 4.71-4.80 show the plots of acoustic impedance as a function of molality of sucrose and maltose in water and in aqueous TPC solution. It is evident from the figures 4.71-4.80 that acoustic impedance increases with the increase in molality of disaccharides. The increase in Z with the molality of disaccharides indicates that as concentration increases the sound wave has to face resistance to flow. The positive acoustic impedance is, therefore, an evidential parameter for solute-solvent interaction [89]. The values of acoustic impedance, Z of disaccharides in aqueous TPC are higher than the values of disaccharides in aqueous systems. These higher values of ternary systems than the binary systems show strong solute-solvent interaction in ternary systems than binary systems.

The hydration number (n_H) of sucrose and maltose in water are listed in tables 4.81-4.82 and figures are graphically shown in 4.61-4.62. The hydration numbers decrease with the increase of concentration for aqueous sucrose and maltose system. The hydration numbers also decrease with the increase of temperature. The hydration number of aqueous maltose is higher than the aqueous sucrose. The values of hydration number decreases as appreciable increases of solutes. This also suggests that compressibility of the solution is less than that of the solvent. This may enhance the interaction between solute and solvent molecules [106]

The hydration number (n_H) of sucrose and maltose in aqueous TPC (0.05, 0.20, 0.35 and 0.50) mol.kg^{-1} solutions at different temperatures are presented in tables 4.83-4.90. The variation of n_H with molality is graphically shown in figures 4.63-4.70. The hydration numbers decrease with the increase of concentration for sucrose and maltose in aqueous TPC systems which is similar with binary systems. The hydration numbers decrease with the increase of temperature.

The hydration number of maltose in aqueous TPC is higher than sucrose in aqueous TPC solution. The hydration number of disaccharides at concentrated TPC solution is lower than the dilute solutions. This is due to the decrease of water molecule around the disaccharides at higher concentration. This also suggests that compressibility of the solution is less than that of the solvent. As a result disaccharides have more probability of contacting aqueous TPC molecules. This may enhance the interaction between solute and solvent molecules [106].

The values of hydration number (n_H) of disaccharides in aqueous TPC are lower than the values of disaccharides in water systems. The lower values of hydration number in ternary system compared to binary system suggest strong disaccharides TPC interaction in ternary system.

Table 4.1: Density (ρ) of sucrose in water as a function of molality at different temperature

$m/\text{mol.kg}^{-1}$	Sucrose + water				
	Density, $\rho/\text{kg.m}^{-3}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	998.489	997.341	995.935	994.261	992.248
0.0500	1005.019	1003.833	1002.401	1000.711	998.688
0.1000	1011.401	1010.179	1008.718	1007.014	1004.982
0.1498	1017.615	1016.357	1014.869	1013.152	1011.112
0.1995	1023.683	1022.391	1020.872	1019.137	1017.091
0.2497	1029.678	1028.355	1026.806	1025.055	1022.993
0.3003	1035.591	1034.234	1032.656	1030.885	1028.817
0.3503	1041.307	1039.926	1038.312	1036.528	1034.461
0.4004	1046.912	1045.501	1043.861	1042.063	1040.001

Table 4.2: Density (ρ) of maltose in water as a function of molality at different temperature

$m/\text{mol.kg}^{-1}$	Maltose + water				
	Density, $\rho/\text{kg.m}^{-3}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	998.489	997.341	995.935	994.261	992.248
0.0498	1004.976	1003.789	1002.357	1000.669	998.635
0.1004	1011.412	1010.185	1008.722	1007.025	1004.973
0.1497	1017.535	1016.271	1014.778	1013.067	1011.001
0.2003	1023.682	1022.376	1020.851	1019.125	1017.042
0.2505	1029.634	1028.285	1026.734	1025.001	1022.903
0.3004	1035.422	1034.032	1032.445	1030.701	1028.595
0.3505	1041.095	1039.667	1038.045	1036.281	1034.171
0.3995	1046.523	1045.054	1043.399	1041.611	1039.498

Table 4.3: Density (ρ) of sucrose in aqueous solution of TPC (0.05 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.05 mol.kg^{-1} TPC				
	Density, ρ/kg.m^{-3}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1008.585	1007.359	1005.904	1004.242	1002.370
0.0497	1014.950	1013.691	1012.205	1010.515	1008.624
0.0999	1021.241	1019.949	1018.432	1016.712	1014.802
0.1493	1027.274	1025.952	1024.405	1022.657	1020.730
0.2002	1033.358	1031.999	1030.425	1028.650	1026.703
0.2503	1039.211	1037.818	1036.212	1034.415	1032.451
0.2994	1044.811	1043.386	1041.755	1039.935	1037.954
0.3506	1050.522	1049.077	1047.424	1045.580	1043.572
0.4006	1056.001	1054.501	1052.825	1050.958	1048.931

Table 4.4: Density (ρ) of sucrose in aqueous solution of TPC (0.20 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.20 mol.kg^{-1} TPC				
	Density, ρ/kg.m^{-3}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1037.630	1036.210	1034.590	1032.789	1030.822
0.0498	1043.508	1042.064	1040.423	1038.602	1036.610
0.0992	1049.200	1047.731	1046.070	1044.227	1042.212
0.1502	1054.935	1053.441	1051.755	1049.886	1047.852
0.2000	1060.406	1058.886	1057.175	1055.284	1053.230
0.2503	1065.798	1064.249	1062.521	1060.603	1058.539
0.3004	1071.058	1069.481	1067.733	1065.805	1063.714
0.3497	1076.108	1074.499	1072.731	1070.781	1068.668
0.4004	1081.191	1079.558	1077.769	1075.809	1073.692

Table 4.5: Density (ρ) of sucrose in aqueous solution of TPC (0.35 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.35 mol.kg^{-1} TPC				
	Density, ρ/kg.m^{-3}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1064.822	1063.244	1061.494	1059.581	1057.521
0.0504	1070.585	1068.964	1067.182	1065.251	1063.176
0.0997	1076.001	1074.333	1072.519	1070.578	1068.484
0.1502	1081.332	1079.637	1077.786	1075.816	1073.713
0.1997	1086.346	1084.596	1082.692	1080.691	1078.552
0.2498	1091.149	1089.345	1087.391	1085.378	1083.252
0.3004	1095.798	1093.976	1091.991	1089.967	1087.848
0.3500	1100.246	1098.391	1096.381	1094.321	1092.181
0.4004	1104.491	1102.591	1100.551	1098.485	1096.312

Table 4.6: Density (ρ) of sucrose in aqueous solution of TPC (0.50 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.50 mol.kg^{-1} TPC				
	Density, ρ/kg.m^{-3}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1090.390	1088.682	1086.818	1084.820	1082.681
0.0502	1095.682	1093.958	1092.073	1090.058	1087.903
0.1000	1100.749	1099.005	1097.101	1095.072	1092.903
0.1501	1105.665	1103.899	1101.979	1099.942	1097.763
0.1996	1110.353	1108.568	1106.633	1104.578	1102.385
0.2498	1114.937	1113.137	1111.189	1109.108	1106.895
0.3002	1119.402	1117.582	1115.616	1113.518	1111.299
0.3497	1123.658	1121.816	1119.827	1117.728	1115.484
0.4004	1127.881	1126.018	1124.017	1121.901	1119.618

Table 4.7: Density (ρ) of maltose in aqueous solution of TPC (0.05 $mol.kg^{-1}$) as a function of molality at different temperature

$m/mol.kg^{-1}$	Maltose + water + 0.05$mol.kg^{-1}$ TPC				
	Density, $\rho/kg.m^{-3}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1008.585	1007.359	1005.904	1004.242	1002.370
0.0494	1014.886	1013.623	1012.143	1010.455	1008.565
0.0995	1021.127	1019.825	1018.310	1016.596	1014.690
0.1507	1027.349	1026.015	1024.455	1022.724	1020.797
0.1997	1033.163	1031.797	1030.211	1028.444	1026.494
0.2505	1039.057	1037.651	1036.036	1034.245	1032.268
0.2994	1044.592	1043.144	1041.501	1039.685	1037.694
0.3506	1050.261	1048.780	1047.101	1045.261	1043.251
0.4002	1055.606	1054.103	1052.404	1050.514	1048.480

Table 4.8: Density (ρ) of maltose in aqueous solution of tri-Potassium citrate (0.20 $mol.kg^{-1}$) as a function of molality at different temperature

$m/mol.kg^{-1}$	Maltose + water + 0.20$mol.kg^{-1}$ TPC				
	Density, $\rho/kg.m^{-3}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1037.630	1036.210	1034.590	1032.789	1030.822
0.0495	1043.551	1042.102	1040.455	1038.629	1036.638
0.0997	1049.403	1047.929	1046.253	1044.399	1042.389
0.1505	1055.178	1053.679	1051.971	1050.101	1048.056
0.1999	1060.649	1059.126	1057.401	1055.501	1053.442
0.2502	1066.086	1064.535	1062.779	1060.864	1058.787
0.3006	1071.388	1069.816	1068.035	1066.103	1064.002
0.3497	1076.427	1074.818	1072.999	1071.070	1068.932
0.3997	1081.424	1079.786	1077.938	1075.977	1073.819

Table 4.9: Density (ρ) of maltose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Maltose + water + 0.35mol.kg^{-1} TPC				
	Density, ρ/kg.m^{-3}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1064.822	1063.244	1061.494	1059.581	1057.521
0.0495	1070.302	1068.701	1066.928	1064.997	1062.918
0.0996	1075.688	1074.069	1072.268	1070.316	1068.229
0.1508	1081.038	1079.403	1077.572	1075.604	1073.507
0.2008	1086.124	1084.457	1082.614	1080.628	1078.515
0.2500	1090.995	1089.291	1087.43	1085.420	1083.295
0.2994	1095.739	1093.999	1092.128	1090.108	1087.982
0.3505	1100.518	1098.768	1096.859	1094.819	1092.693
0.4006	1105.107	1103.322	1101.411	1099.356	1097.231

Table 4.10: Density (ρ) of maltose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Maltose + water + 0.50mol.kg^{-1} TPC				
	Density, ρ/kg.m^{-3}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1090.390	1088.682	1086.818	1084.820	1082.681
0.0502	1095.555	1093.825	1091.944	1089.918	1087.766
0.0995	1100.468	1098.718	1096.822	1094.776	1092.609
0.1498	1105.333	1103.565	1101.649	1099.587	1097.405
0.2005	1110.107	1108.317	1106.380	1104.301	1102.100
0.2498	1114.600	1112.792	1110.836	1108.746	1106.532
0.3003	1119.085	1117.258	1115.285	1113.178	1110.935
0.3497	1123.333	1121.487	1119.498	1117.379	1115.132
0.4001	1127.582	1125.720	1123.711	1121.572	1119.297

Table 4.11: Apparent molar volume (φ_v) of sucrose in water as a function of molality ($m/mol.kg^{-1}$) at different temperature

$m/mol.kg^{-1}$	Sucrose + water				
	$\varphi_v \times 10^6/m^3 \cdot mol^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0500	210.44	211.29	211.93	212.39	212.76
0.1000	210.57	211.42	212.09	212.53	212.89
0.1498	210.71	211.55	212.22	212.66	213.01
0.1995	210.82	211.65	212.35	212.81	213.15
0.2497	210.93	211.75	212.46	212.92	213.30
0.3003	211.04	211.86	212.57	213.05	213.41
0.3503	211.15	211.94	212.67	213.15	213.49
0.4004	211.26	212.04	212.77	213.25	213.55

Table 4.12: Apparent molar volume (φ_v) of maltose in water as a function of molality ($m/mol.kg^{-1}$) at different temperature

$m/mol.kg^{-1}$	Maltose+ water				
	$\varphi_v \times 10^6/m^3 \cdot mol^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	228.72	229.63	230.30	230.75	231.38
0.1004	228.80	229.71	230.43	230.83	231.44
0.1497	228.89	229.79	230.53	230.95	231.52
0.2003	228.93	229.86	230.61	231.05	231.62
0.2505	229.01	229.96	230.70	231.12	231.68
0.3004	229.07	230.03	230.80	231.22	231.75
0.3505	229.16	230.11	230.90	231.35	231.85
0.3995	229.24	230.20	231.00	231.48	231.96

Table 4.13: Apparent molar volume (φ_v) of sucrose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.05 mol.kg^{-1} TPC				
	$\varphi_v \times 10^6$/m$^3\cdot$mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0497	212.01	212.78	213.52	214.23	214.77
0.0999	212.17	212.94	213.68	214.41	214.96
0.1493	212.36	213.11	213.86	214.58	215.12
0.2002	212.51	213.29	214.01	214.73	215.29
0.2503	212.64	213.42	214.16	214.86	215.40
0.2994	212.79	213.57	214.30	214.99	215.54
0.3506	212.94	213.68	214.39	215.08	215.65
0.4006	213.01	213.82	214.52	215.20	215.78

Table 4.14: Apparent molar volume (φ_v) of sucrose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.20 mol.kg^{-1} TPC				
	$\varphi_v \times 10^6$/m$^3\cdot$mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	219.01	219.61	220.18	220.75	221.43
0.0992	219.11	219.72	220.28	220.88	221.55
0.1502	219.21	219.83	220.42	221.05	221.69
0.2000	219.29	219.92	220.53	221.16	221.79
0.2503	219.38	220.02	220.62	221.26	221.86
0.3004	219.45	220.11	220.70	221.31	221.93
0.3497	219.54	220.22	220.81	221.42	222.05
0.4004	219.61	220.29	220.88	221.47	222.06

Table 4.15: Apparent molar volume (φ_v) of sucrose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.35 mol.kg^{-1} TPC				
	$\varphi_v \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0504	219.42	220.35	221.12	221.65	222.16
0.0997	220.25	221.24	222.01	222.49	223.04
0.1502	221.08	221.96	222.78	223.35	223.85
0.1997	221.91	222.88	223.78	224.42	225.03
0.2498	222.99	224.00	224.96	225.57	226.07
0.3004	223.99	224.93	225.87	226.45	226.89
0.3500	224.71	225.64	226.55	227.19	227.66
0.4004	225.67	226.62	227.52	228.12	228.66

Table 4.16: Apparent molar volume (φ_v) of sucrose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.50 mol.kg^{-1} TPC				
	$\varphi_v \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	224.16	224.64	225.23	225.77	226.32
0.1000	224.65	225.18	225.75	226.27	226.81
0.1501	225.17	225.72	226.28	226.76	227.27
0.1996	225.66	226.22	226.77	227.27	227.79
0.2498	226.17	226.72	227.25	227.81	228.35
0.3002	226.60	227.15	227.70	228.26	228.78
0.3497	226.98	227.54	228.10	228.63	229.18
0.4004	227.34	227.92	228.47	229.01	229.62

Table 4.17: Apparent molar volume (φ_v) of maltose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.05 mol.kg^{-1} TPC				
	φ_v ×10^6/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0494	230.42	231.29	231.95	232.65	233.21
0.0995	230.47	231.36	232.12	232.82	233.37
0.1507	230.56	231.41	232.26	232.90	233.48
0.1997	230.64	231.48	232.30	233.01	233.62
0.2505	230.70	231.56	232.37	233.07	233.71
0.2994	230.79	231.68	232.48	233.19	233.80
0.3506	230.86	231.74	232.55	233.26	233.88
0.4002	230.98	231.83	232.62	233.40	234.03

Table 4.18: Apparent molar volume (φ_v) of maltose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.20 mol.kg^{-1} TPC				
	φ_v ×10^6/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0495	234.82	235.53	236.24	236.93	237.63
0.0997	234.91	235.59	236.32	237.04	237.70
0.1505	234.98	235.65	236.41	237.06	237.80
0.1999	235.09	235.75	236.45	237.15	237.84
0.2502	235.17	235.85	236.57	237.23	237.91
0.3006	235.29	235.96	236.68	237.33	238.01
0.3497	235.41	236.11	236.87	237.45	238.18
0.3997	235.55	236.26	237.02	237.64	238.37

Table 4.19: Apparent molar volume (φ_v) of maltose in aqueous solution of tri-Potassium citrate (0.35 $mol.kg^{-1}$) as a function of molality ($m/mol.kg^{-1}$) at different temperature

$m/mol.kg^{-1}$	Maltose + water + 0.35 $mol.kg^{-1}$ TPC				
	$\varphi_v \times 10^6/m^3 \cdot mol^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0495	239.51	240.14	240.79	241.37	241.99
0.0996	239.72	240.30	241.00	241.61	242.14
0.1508	239.89	240.45	241.17	241.76	242.27
0.2008	240.02	240.64	241.30	241.89	242.42
0.2500	240.15	240.83	241.47	242.10	242.62
0.2994	240.33	241.05	241.67	242.26	242.76
0.3505	240.50	241.18	241.84	242.45	242.91
0.4006	240.59	241.29	241.92	242.52	242.96

Table 4.20: Apparent molar volume (φ_v) of maltose in aqueous solution of tri-Potassium citrate (0.50 $mol.kg^{-1}$) as a function of molality ($m/mol.kg^{-1}$) at different temperature

$m/mol.kg^{-1}$	Maltose + water + 0.50 $mol.kg^{-1}$ TPC				
	$\varphi_v \times 10^6/m^3 \cdot mol^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	242.76	243.38	243.94	244.70	245.24
0.0995	243.01	243.62	244.17	244.87	245.43
0.1498	243.22	243.81	244.38	245.05	245.61
0.2005	243.34	243.94	244.53	245.18	245.77
0.2498	243.53	244.13	244.73	245.35	245.93
0.3003	243.67	244.27	244.87	245.49	246.12
0.3497	243.85	244.45	245.05	245.66	246.26
0.4001	243.95	244.54	245.15	245.77	246.40

Table 4.21: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	210.34	2.32	18.22	-0.68
298.15K	211.21	2.11	14.84	
303.15K	211.85	2.37	11.46	
308.15K	212.29	2.45	8.08	
313.15K	212.67	2.34	4.70	

Table 4.22: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	228.65	1.44	16.95	-0.43
298.15K	229.54	1.62	14.82	
303.15K	230.22	1.95	12.69	
308.15K	230.63	2.04	10.56	
313.15K	231.28	1.64	8.43	

Table 4.23: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_v^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of sucrose in aqueous 0.05 $mol.kg^{-1}$ tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	211.90	2.89	1.56	16.70	-0.26
298.15K	212.66	2.98	1.44	15.39	
303.15K	213.41	2.85	1.56	14.08	
308.15K	214.14	2.74	1.85	12.77	
313.15K	214.68	2.82	2.01	11.46	

Table 4.24: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_v^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of sucrose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	218.94	1.71	8.60	13.40	-0.13
298.15K	219.53	1.94	8.32	12.76	
303.15K	220.10	2.01	8.25	12.12	
308.15K	220.70	2.06	8.41	11.48	
313.15K	221.39	1.82	8.72	10.84	

Table 4.25: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_v^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of sucrose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	218.44	18.06	8.09	20.44	-0.67
298.15K	219.39	18.07	8.17	17.08	
303.15K	220.15	18.56	8.30	13.72	
308.15K	220.66	18.86	8.37	10.36	
313.15K	221.20	18.75	8.53	7.00	

Table 4.26: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_v^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of sucrose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	223.77	9.21	13.43	10.85	-0.03
298.15K	224.27	9.41	13.05	10.71	
303.15K	224.85	9.33	12.99	10.57	
308.15K	225.36	9.39	13.07	10.43	
313.15K	225.87	9.55	13.20	10.29	

Table 4.27: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_v^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of maltose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	230.33	1.56	1.67	18.07	-0.40
298.15K	231.20	1.54	1.65	16.05	
303.15K	231.93	1.54	1.71	14.03	
308.15K	232.59	1.98	1.96	12.01	
313.15K	233.14	2.22	1.86	9.99	

Table 4.28: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_v^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of maltose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	234.69	2.05	6.04	13.97	0.01
298.15K	235.37	2.06	5.83	14.01	
303.15K	236.08	2.17	5.86	14.05	
308.15K	236.81	1.88	6.17	14.09	
313.15K	237.49	1.96	6.21	14.13	

Table 4.29: Limiting apparent molar volume (φ_v^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_v^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of maltose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_v^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	239.40	3.07	10.75	12.50	-0.01
298.15K	239.96	3.44	10.41	12.44	
303.15K	240.66	3.44	10.44	12.38	
308.15K	241.25	3.31	10.62	12.32	
313.15K	241.85	2.93	10.57	12.26	

Table 4.30; Limiting apparent molar volume (φ_V^0), experimental slope (S_V), limiting apparent molar volume transfer ($\Delta\varphi_V^0$), limiting apparent molar volume expansibilities (E_φ^0) and $(\delta E_\varphi^0/\delta T)_p$ of maltose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_V^0\times10^6$ ($m^3.mol^{-1}$)	$S_V\times10^6$ ($m^3.mol^{-2}.kg$)	$\Delta_{tr}\varphi_V^0\times10^6$ ($m^3.mol^{-1}$)	$E_\varphi^0\times10^8$ ($m^3.mol^{-1}.K^{-1}$)	$(\delta E_\varphi^0/\delta T)_p\times10^8$ ($m^3.mol^{-1}.K^{-2}$)
293.15K	242.67	3.33	14.01	12.54	-0.02
298.15K	243.28	3.30	13.73	12.43	
303.15K	243.82	3.30	13.60	12.32	
308.15K	244.57	3.06	13.94	12.21	
313.15K	245.10	3.31	13.82	12.10	

Table 4.31: Partial molar volume ($\bar{V}_2$) of sucrose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water				
	$\bar{V}_2\times10^6/m^3\cdot mol^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0500	210.66	211.50	212.16	212.63	212.99
0.1000	210.89	211.71	212.42	212.87	213.22
0.1498	211.10	211.90	212.62	213.07	213.41
0.1995	211.27	212.06	212.81	213.28	213.60
0.2497	211.44	212.21	212.97	213.45	213.81
0.3003	211.60	212.36	213.13	213.63	213.97
0.3503	211.75	212.48	213.29	213.78	214.09
0.4004	211.90	212.62	213.43	213.92	214.20

Table 4.32: Partial molar volume ($\bar{V}_2$) of maltose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water				
	$\bar{V}_2 \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	228.86	229.78	230.48	230.94	231.54
0.1004	229.00	229.93	230.70	231.11	231.66
0.1497	229.13	230.06	230.86	231.29	231.80
0.2003	229.21	230.17	230.99	231.44	231.94
0.2505	229.32	230.31	231.12	231.56	232.03
0.3004	229.41	230.41	231.26	231.70	232.14
0.3505	229.53	230.52	231.40	231.87	232.27
0.3995	229.63	230.64	231.54	232.03	232.41

Table 4.33: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) with sucrose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.05 mol.kg^{-1} TPC				
	$\bar{V}_2 \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0497	212.29	213.06	213.80	214.49	215.05
0.0999	212.57	213.35	214.08	214.79	215.35
0.1493	212.85	213.61	214.34	215.05	215.60
0.2002	213.08	213.87	214.57	215.27	215.84
0.2503	213.27	214.07	214.78	215.46	216.02
0.2994	213.48	214.28	214.98	215.65	216.21
0.3506	213.68	214.45	215.13	215.79	216.38
0.4006	213.80	214.64	215.31	215.96	216.56

Table 4.34: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) with sucrose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.20 mol.kg^{-1} TPC				
	$\bar{V}_2 \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	219.18	219.80	220.37	220.95	221.61
0.0992	219.34	219.99	220.56	221.17	221.80
0.1502	219.50	220.16	220.76	221.40	222.00
0.2000	219.63	220.30	220.92	221.57	222.15
0.2503	219.75	220.45	221.05	221.72	222.26
0.3004	219.86	220.57	221.18	221.81	222.37
0.3497	219.98	220.72	221.33	221.96	222.53
0.4004	220.08	220.82	221.43	222.04	222.57

Table 4.35: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) with sucrose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.35 mol.kg^{-1} TPC				
	$\bar{V}_2 \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0504	221.17	222.10	222.92	223.48	223.98
0.0997	222.71	223.72	224.55	225.06	225.60
0.1502	224.10	225.01	225.88	226.51	227.00
0.1997	225.39	226.38	227.37	228.06	228.66
0.2498	226.88	227.93	228.97	229.65	230.12
0.3004	228.26	229.24	230.27	230.92	231.34
0.3500	229.32	230.29	231.30	232.01	232.46
0.4004	230.60	231.59	232.59	233.29	233.79

Table 4.36: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) with sucrose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.50 mol.kg^{-1} TPC				
	$\bar{V}_2 \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	225.06	225.56	226.14	226.69	227.24
0.1000	225.92	226.47	227.04	227.56	228.11
0.1501	226.72	227.31	227.85	228.34	228.87
0.1996	227.45	228.05	228.58	229.10	229.64
0.2498	228.18	228.77	229.28	229.85	230.42
0.3002	228.80	229.40	229.92	230.49	231.05
0.3497	229.35	229.97	230.51	231.04	231.63
0.4004	229.88	230.51	231.04	231.59	232.24

Table 4.37: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) with maltose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.05 mol.kg^{-1} TPC				
	$\bar{V}_2 \times 10^6$/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0494	230.57	231.44	232.12	232.84	233.43
0.0995	230.68	231.57	232.37	233.09	233.67
0.1507	230.82	231.66	232.57	233.24	233.85
0.1997	230.94	231.77	232.65	233.40	234.05
0.2505	231.03	231.89	232.76	233.50	234.19
0.2994	231.15	232.04	232.91	233.66	234.33
0.3506	231.25	232.13	233.02	233.77	234.45
0.4002	231.40	232.24	233.12	233.94	234.64

Table 4.38: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) with maltose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.20 mol.kg^{-1} TPC				
	$\bar{V}_2\times10^6$/m$^3\cdot$mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.04948	235.01	235.73	236.44	237.11	237.82
0.09950	235.19	235.87	236.61	237.29	237.96
0.14951	235.32	235.99	236.76	237.37	238.12
0.19982	235.48	236.14	236.86	237.50	238.21
0.25015	235.61	236.28	237.03	237.63	238.32
0.29969	235.77	236.43	237.18	237.76	238.46
0.35020	235.92	236.62	237.41	237.92	238.67
0.39985	236.10	236.81	237.60	238.14	238.89

Table 4.39: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) with maltose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.35 mol.kg^{-1} TPC				
	$\bar{V}_2\times10^6$/m$^3\cdot$mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0495	239.81	240.47	241.10	241.69	242.28
0.0996	240.14	240.77	241.45	242.06	242.54
0.1508	240.41	241.02	241.72	242.32	242.76
0.2008	240.62	241.30	241.94	242.54	242.99
0.2500	240.81	241.57	242.18	242.81	243.26
0.2994	241.06	241.86	242.44	243.05	243.45
0.3505	241.29	242.05	242.68	243.30	243.66
0.4006	241.43	242.23	242.82	243.43	243.76

Table 4.40: Partial molar volume ($\bar{V}_2$) of aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) with maltose as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.50 mol.kg^{-1} TPC				
	$\bar{V}_2$×10^6/m^3·mol^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	243.09	243.70	244.28	245.00	245.56
0.0995	243.47	244.08	244.65	245.29	245.89
0.1498	243.78	244.37	244.97	245.56	246.17
0.2005	243.99	244.59	245.21	245.78	246.41
0.2498	244.26	244.85	245.48	246.01	246.65
0.3003	244.47	245.06	245.70	246.21	246.90
0.3497	244.71	245.31	245.94	246.44	247.11
0.4001	244.87	245.46	246.11	246.61	247.31

Table 4.41: Sound velocity (u) of sucrose in water as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1482.69	1496.53	1508.81	1519.45	1528.54
0.0500	1487.33	1500.99	1513.10	1523.61	1532.52
0.1000	1491.87	1505.42	1517.38	1527.62	1536.36
0.1498	1496.50	1509.83	1521.57	1531.68	1540.24
0.1995	1501.08	1514.24	1525.87	1535.77	1544.09
0.2497	1505.68	1518.79	1530.14	1539.88	1548.12
0.3003	1510.58	1523.29	1534.45	1544.03	1552.09
0.3503	1515.29	1527.82	1538.80	1548.21	1556.12
0.4004	1520.02	1532.28	1543.07	1552.31	1560.05

Table 4.42: Sound velocity (u) of maltose in water as a function of molality at different temperature

$m/mol.kg^{-1}$	Maltose + water				
	Sound velocity, $u/m.s^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1482.69	1496.53	1508.81	1519.45	1528.54
0.0498	1487.64	1501.28	1513.38	1523.84	1532.72
0.1004	1492.68	1506.14	1517.99	1528.28	1536.97
0.1497	1497.59	1510.84	1522.51	1532.56	1541.21
0.2003	1502.72	1515.82	1527.3	1537.22	1545.45
0.2505	1507.71	1520.54	1531.91	1541.51	1549.73
0.3004	1512.58	1525.3	1536.43	1546.01	1553.92
0.3505	1517.29	1529.79	1540.65	1550.04	1557.85
0.3995	1522.18	1534.3	1544.94	1554.05	1561.77

Table 4.43: Sound velocity (u) of sucrose in aqueous solution of tri-Potassium citrate (0.05 $mol.kg^{-1}$) as a function of molality at different temperature

$m/mol.kg^{-1}$	Sucrose + water+ 0.05 $mol.kg^{-1}$ TPC				
	Sound velocity, $u/m.s^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1493.35	1506.88	1518.86	1529.23	1538.03
0.0497	1497.81	1511.16	1522.97	1533.16	1541.79
0.0999	1502.41	1515.56	1527.19	1537.21	1545.70
0.1493	1507.05	1520.02	1531.47	1541.31	1549.66
0.2002	1511.81	1524.53	1535.77	1545.58	1553.75
0.2503	1516.49	1529.03	1540.10	1549.69	1557.67
0.2994	1520.82	1533.21	1544.08	1553.58	1561.44
0.3506	1525.65	1537.79	1548.49	1557.88	1565.54
0.4006	1530.35	1542.51	1553.05	1562.01	1569.48

Table 4.44: Sound velocity (u) of sucrose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water+ 0.20 mol.kg^{-1} TPC				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1522.09	1534.85	1546.03	1555.64	1563.75
0.0498	1527.34	1539.83	1550.82	1560.27	1568.21
0.0992	1532.29	1544.64	1555.38	1564.66	1572.48
0.1502	1536.95	1549.01	1559.65	1568.76	1576.47
0.2000	1541.02	1552.86	1563.32	1572.25	1579.97
0.2503	1545.08	1556.84	1567.09	1575.85	1583.45
0.3004	1548.85	1560.33	1570.41	1579.02	1586.42
0.3497	1552.78	1564.11	1574.03	1582.48	1589.54
0.4004	1556.01	1567.45	1577.02	1585.11	1592.01

Table 4.45: Sound velocity (u) of sucrose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water+ 0.35 mol.kg^{-1} TPC				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1549.53	1561.46	1571.82	1580.67	1588.13
0.0504	1553.91	1565.65	1575.76	1584.48	1591.76
0.0997	1558.25	1569.81	1579.81	1588.35	1595.45
0.1502	1562.71	1574.09	1583.96	1592.29	1599.21
0.1997	1567.15	1578.33	1588.02	1596.24	1603.01
0.2498	1571.54	1582.52	1592.21	1600.07	1606.72
0.3004	1575.73	1586.51	1595.91	1603.82	1610.38
0.3500	1580.07	1590.6	1599.88	1607.63	1614.04
0.4004	1584.05	1594.36	1603.57	1611.09	1617.46

Table 4.46: Sound velocity (u) of sucrose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Sucrose + water+ 0.50 mol.kg^{-1} TPC				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1575.8	1586.9	1596.51	1604.68	1611.52
0.0502	1580.06	1590.96	1600.42	1608.43	1615.16
0.1000	1584.38	1595.13	1604.41	1612.3	1618.88
0.1501	1588.67	1599.21	1608.33	1616.05	1622.47
0.1996	1592.73	1603.12	1612.09	1619.66	1625.94
0.2498	1597.19	1607.35	1616.14	1623.57	1629.72
0.3002	1601.26	1611.26	1619.89	1627.17	1633.17
0.3497	1605.13	1614.83	1623.45	1630.56	1636.44
0.4004	1609.83	1619.43	1628.01	1634.91	1640.57

Table 4.47: Sound velocity (u) of maltose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Maltose + water+ 0.05 mol.kg^{-1} TPC				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1493.35	1506.88	1518.86	1529.23	1538.03
0.0494	1498.12	1511.48	1523.28	1533.47	1542.08
0.0995	1502.94	1516.06	1527.65	1537.63	1546.20
0.1507	1507.91	1520.89	1532.23	1542.01	1550.41
0.1997	1512.62	1525.41	1536.60	1546.21	1554.41
0.2505	1517.70	1530.17	1541.13	1550.53	1558.54
0.2994	1522.09	1534.58	1545.39	1554.63	1562.38
0.3506	1527.28	1539.35	1549.96	1559.00	1566.58
0.4002	1531.68	1543.85	1554.30	1563.13	1570.45

Table 4.48: Sound velocity (u) of maltose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Maltose + water+ 0.20 mol.kg^{-1} TPC				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1522.09	1534.85	1546.03	1555.64	1563.75
0.0495	1526.91	1539.44	1550.45	1559.85	1567.77
0.0997	1531.79	1544.12	1554.94	1564.11	1571.85
0.1505	1536.76	1548.88	1559.45	1568.47	1576.02
0.1999	1541.55	1553.46	1563.83	1572.59	1579.95
0.2502	1546.33	1558.08	1568.17	1576.81	1584.01
0.3006	1551.06	1562.61	1572.44	1580.84	1587.91
0.3497	1555.36	1566.65	1576.38	1584.53	1591.54
0.3997	1559.76	1570.86	1580.29	1588.43	1595.18

Table 4.49: Sound velocity (u) of maltose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Maltose + water+ 0.35 mol.kg^{-1} TPC				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1549.53	1561.46	1571.82	1580.67	1588.13
0.0495	1554.45	1566.12	1576.28	1584.91	1592.17
0.0996	1559.27	1570.63	1580.61	1589.09	1596.16
0.1508	1564	1575.17	1585.01	1593.24	1600.17
0.2008	1568.24	1579.3	1588.92	1597.08	1603.88
0.2500	1572.43	1583.21	1592.64	1600.59	1607.23
0.2994	1576.41	1586.99	1596.38	1604.17	1610.69
0.3505	1580.83	1591.32	1600.39	1608.04	1614.37
0.4006	1584.81	1595.2	1604.08	1611.71	1617.93

Table 4.50: Sound velocity (u) of maltose in water solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality at different temperature

m/mol.kg^{-1}	Maltose + water+ 0.50 mol.kg^{-1} TPC				
	Sound velocity, u/m.s^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1575.8	1586.9	1596.51	1604.68	1611.52
0.0502	1580.25	1591.17	1600.59	1608.6	1615.28
0.0995	1584.54	1595.23	1604.46	1612.3	1618.83
0.1498	1588.92	1599.44	1608.5	1616.18	1622.56
0.2005	1593.47	1603.82	1612.67	1620.16	1626.36
0.2498	1597.59	1607.65	1616.37	1623.74	1629.83
0.3003	1601.75	1611.63	1620.18	1627.38	1633.29
0.3497	1605.67	1615.43	1623.83	1630.88	1636.65
0.4001	1610.66	1620.14	1628.31	1635.13	1640.72

Table 4.51: Adiabatic compressibility ($\beta_s \times 10^{10}/\text{Pa}^{-1}$) of sucrose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	4.56	4.48	4.41	4.36	4.31
0.0500	4.50	4.42	4.36	4.30	4.26
0.1000	4.44	4.37	4.31	4.26	4.22
0.1498	4.39	4.32	4.26	4.21	4.17
0.1995	4.34	4.27	4.21	4.16	4.12
0.2497	4.28	4.22	4.16	4.11	4.08
0.3003	4.23	4.17	4.11	4.07	4.03
0.3503	4.18	4.12	4.07	4.02	3.99
0.4004	4.13	4.07	4.02	3.98	3.95

Table 4.52: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of maltose in water as a function of molality ($m/mol.kg^{-1}$) at different temperature

$m/mol.kg^{-1}$	Maltose + water				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	4.56	4.48	4.41	4.36	4.31
0.0498	4.50	4.42	4.36	4.30	4.26
0.1004	4.44	4.36	4.30	4.25	4.21
0.1497	4.38	4.31	4.25	4.20	4.16
0.2003	4.33	4.26	4.20	4.15	4.12
0.2505	4.27	4.21	4.15	4.11	4.07
0.3004	4.22	4.16	4.10	4.06	4.03
0.3505	4.17	4.11	4.06	4.02	3.98
0.3995	4.12	4.06	4.02	3.98	3.94

Table 4.53: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of sucrose in aqueous solution of tri-Potassium citrate (0.05 $mol.kg^{-1}$) as a function of molality ($m/mol.kg^{-1}$) at different temperature

$m/mol.kg^{-1}$	Sucrose + water + 0.05 $mol.kg^{-1}$ TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	4.45	4.37	4.31	4.26	4.22
0.0497	4.39	4.32	4.26	4.21	4.17
0.0999	4.34	4.27	4.21	4.16	4.12
0.1493	4.29	4.22	4.16	4.12	4.08
0.2002	4.23	4.17	4.11	4.07	4.03
0.2503	4.18	4.12	4.07	4.03	3.99
0.2994	4.14	4.08	4.03	3.98	3.95
0.3506	4.09	4.03	3.98	3.94	3.91
0.4006	4.04	3.99	3.94	3.90	3.87

Table 4.54: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of sucrose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.20 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	4.16	4.10	4.04	4.00	3.97
0.0498	4.11	4.05	4.00	3.96	3.92
0.0992	4.06	4.00	3.95	3.91	3.88
0.1502	4.01	3.96	3.91	3.87	3.84
0.2000	3.97	3.92	3.87	3.83	3.80
0.2503	3.93	3.88	3.83	3.80	3.77
0.3004	3.89	3.84	3.80	3.76	3.74
0.3497	3.85	3.80	3.76	3.73	3.70
0.4004	3.82	3.77	3.73	3.70	3.67

Table 4.55: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of sucrose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.35 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	3.91	3.86	3.81	3.78	3.75
0.0504	3.87	3.82	3.77	3.74	3.71
0.0997	3.83	3.78	3.74	3.70	3.68
0.1502	3.79	3.74	3.70	3.67	3.64
0.1997	3.75	3.70	3.66	3.63	3.61
0.2498	3.71	3.67	3.63	3.60	3.58
0.3004	3.68	3.63	3.60	3.57	3.54
0.3500	3.64	3.60	3.56	3.54	3.51
0.4004	3.61	3.57	3.53	3.51	3.49

Table 4.56: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of sucrose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.50 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	3.69	3.65	3.61	3.58	3.56
0.0502	3.66	3.61	3.58	3.55	3.52
0.1000	3.62	3.58	3.54	3.51	3.49
0.1501	3.58	3.54	3.51	3.48	3.46
0.1996	3.55	3.51	3.48	3.45	3.43
0.2498	3.52	3.48	3.45	3.42	3.40
0.3002	3.48	3.45	3.42	3.39	3.37
0.3497	3.45	3.42	3.39	3.37	3.35
0.4004	3.42	3.39	3.36	3.33	3.32

Table 4.57: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of maltose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.05 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	4.45	4.37	4.31	4.26	4.22
0.0494	4.39	4.32	4.26	4.21	4.17
0.0995	4.34	4.27	4.21	4.16	4.12
0.1507	4.28	4.21	4.16	4.11	4.08
0.1997	4.23	4.17	4.11	4.07	4.03
0.2505	4.18	4.12	4.06	4.02	3.99
0.2994	4.13	4.07	4.02	3.98	3.95
0.3506	4.08	4.02	3.98	3.94	3.91
0.4002	4.04	3.98	3.93	3.90	3.87

Table 4.58: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of maltose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.20 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	4.16	4.10	4.04	4.00	3.97
0.0495	4.11	4.05	4.00	3.96	3.92
0.0997	4.06	4.00	3.95	3.91	3.88
0.1505	4.01	3.96	3.91	3.87	3.84
0.1999	3.97	3.91	3.87	3.83	3.80
0.2502	3.92	3.87	3.83	3.79	3.76
0.3006	3.88	3.83	3.79	3.75	3.73
0.3497	3.84	3.79	3.75	3.72	3.69
0.3997	3.80	3.75	3.71	3.68	3.66

Table 4.59: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of maltose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.35 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	3.91	3.86	3.81	3.78	3.75
0.0495	3.87	3.81	3.77	3.74	3.71
0.0996	3.82	3.77	3.73	3.70	3.67
0.1508	3.78	3.73	3.69	3.66	3.64
0.2008	3.74	3.70	3.66	3.63	3.60
0.2500	3.71	3.66	3.63	3.60	3.57
0.2994	3.67	3.63	3.59	3.56	3.54
0.3505	3.64	3.59	3.56	3.53	3.51
0.4006	3.60	3.56	3.53	3.50	3.48

Table 4.60: Adiabatic compressibility ($\beta_s \times 10^{10}/Pa^{-1}$) of maltose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.50 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	3.69	3.65	3.61	3.58	3.56
0.0502	3.66	3.61	3.57	3.55	3.52
0.0995	3.62	3.58	3.54	3.51	3.49
0.1498	3.58	3.54	3.51	3.48	3.46
0.2005	3.55	3.51	3.48	3.45	3.43
0.2498	3.52	3.48	3.45	3.42	3.40
0.3003	3.48	3.45	3.42	3.39	3.37
0.3497	3.45	3.42	3.39	3.36	3.35
0.4001	3.42	3.38	3.36	3.33	3.32

Table 4.61: Apparent molar adiabatic compressibility (φ_k) of sucrose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water				
	$\varphi_k \times 10^{14}/m^3.mol^{-1}.Pa^{-1}$				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0500	-2.1115	-1.7564	-1.4617	-1.2531	-1.0165
0.1000	-1.9967	-1.6890	-1.4054	-1.1198	-0.8917
0.1498	-1.9691	-1.6337	-1.3288	-1.0724	-0.8440
0.1995	-1.9211	-1.5888	-1.3040	-1.0373	-0.7927
0.2497	-1.8682	-1.5684	-1.2575	-0.9978	-0.7770
0.3003	-1.8719	-1.5245	-1.2151	-0.9595	-0.7392
0.3503	-1.8406	-1.4990	-1.1902	-0.9375	-0.7235
0.4004	-1.8093	-1.4583	-1.1514	-0.9010	-0.6902

Table 4.62: Apparent molar adiabatic compressibility (φ_k) of maltose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	-1.6776	-1.2988	-0.9944	-0.7333	-0.4446
0.1004	-1.6386	-1.2755	-0.9295	-0.6819	-0.4105
0.1497	-1.5969	-1.2278	-0.8947	-0.6206	-0.4122
0.2003	-1.5860	-1.2319	-0.9032	-0.6482	-0.3641
0.2505	-1.5385	-1.1657	-0.8614	-0.5780	-0.3420
0.3004	-1.4792	-1.1265	-0.8106	-0.5640	-0.3056
0.3505	-1.3951	-1.0405	-0.7132	-0.4643	-0.2256
0.3995	-1.3687	-0.9875	-0.6583	-0.3936	-0.1705

Table 4.63: Apparent molar adiabatic compressibility (φ_k) of sucrose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.05 mol.kg^{-1} TPC				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0497	-1.5030	-1.1817	-0.8984	-0.6279	-0.3992
0.0999	-1.5040	-1.1737	-0.8871	-0.6227	-0.4119
0.1493	-1.5181	-1.1928	-0.9042	-0.6378	-0.4329
0.2002	-1.4969	-1.1546	-0.8612	-0.6382	-0.4259
0.2503	-1.4693	-1.1335	-0.8439	-0.6062	-0.3882
0.2994	-1.3873	-1.0628	-0.7724	-0.5487	-0.3393
0.3506	-1.3680	-1.0394	-0.7552	-0.5389	-0.3220
0.4006	-1.3485	-1.0469	-0.7674	-0.5128	-0.2929

Table 4.64: Apparent molar adiabatic compressibility (φ_k) of sucrose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.20 mol.kg^{-1} TPC				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	-1.0312	-0.6693	-0.4150	-0.2074	0.0060
0.0992	-0.8655	-0.5731	-0.2906	-0.0779	0.1084
0.1502	-0.6337	-0.3201	-0.0828	0.1289	0.2973
0.2000	-0.3863	-0.0811	0.1532	0.3647	0.4948
0.2503	-0.2186	0.0531	0.2889	0.4995	0.6290
0.3004	-0.0531	0.2289	0.4583	0.6600	0.8055
0.3497	0.0357	0.3081	0.5330	0.7332	0.9096
0.4004	0.2116	0.4395	0.6828	0.9026	1.0753

Table 4.65: Apparent molar adiabatic compressibility (φ_k) of sucrose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.35 mol.kg^{-1} TPC				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0504	0.4839	0.7303	1.0049	1.1436	1.3179
0.0997	0.5331	0.7794	0.9924	1.1506	1.3299
0.1502	0.5931	0.8278	1.0265	1.2072	1.3821
0.1997	0.6416	0.8855	1.0945	1.2651	1.4411
0.2498	0.7354	0.9831	1.1636	1.3677	1.5252
0.3004	0.8577	1.0986	1.2989	1.4624	1.6041
0.3500	0.9132	1.1599	1.3521	1.5193	1.6633
0.4004	1.0351	1.2831	1.4630	1.6351	1.7699

Table 4.66: Apparent molar adiabatic compressibility (φ_k) of sucrose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.50 mol.kg^{-1} TPC				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	1.3200	1.5085	1.6547	1.8003	1.9013
0.1000	1.3185	1.4895	1.6482	1.7766	1.8938
0.1501	1.3603	1.5422	1.6975	1.8309	1.9541
0.1996	1.4366	1.6102	1.7615	1.8965	2.0202
0.2498	1.4386	1.6201	1.7736	1.9099	2.0337
0.3002	1.5036	1.6804	1.8330	1.9692	2.0926
0.3497	1.5689	1.7600	1.8948	2.0309	2.1541
0.4004	1.5449	1.7260	1.8498	1.9928	2.1285

Table 4.67: Apparent molar adiabatic compressibility (φ_k) of maltose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.05 mol.kg^{-1} TPC				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0494	-1.0619	-0.7471	-0.4638	-0.1972	0.0520
0.0995	-1.0158	-0.6629	-0.3583	-0.0789	0.0830
0.1507	-0.9913	-0.6708	-0.3407	-0.0678	0.1145
0.1997	-0.9495	-0.6290	-0.3201	-0.0484	0.1546
0.2505	-0.9586	-0.6077	-0.2949	-0.0213	0.1916
0.2994	-0.8563	-0.5494	-0.2483	0.0187	0.2482
0.3506	-0.8709	-0.5269	-0.2262	0.0406	0.2678
0.4002	-0.7808	-0.4854	-0.1931	0.0806	0.3198

Table 4.68: Apparent molar adiabatic compressibility (φ_k) of maltose in aqueous solution of tri-Potassium citrate (0.20mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.20 mol.kg^{-1} TPC				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0495	-0.0201	0.2928	0.5238	0.7799	1.0046
0.0997	0.0097	0.3009	0.5416	0.8077	1.0217
0.1505	0.0226	0.3086	0.5727	0.8082	1.0291
0.1999	0.0523	0.3364	0.5952	0.8493	1.0670
0.2502	0.0974	0.3698	0.6442	0.8761	1.0862
0.3006	0.1466	0.4156	0.6951	0.9320	1.1333
0.3497	0.2311	0.5097	0.7726	1.0108	1.1992
0.3997	0.2988	0.5735	0.8469	1.0620	1.2617

Table 4.69: Apparent molar adiabatic compressibility (φ_k) of maltose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.35 mol.kg^{-1} TPC				
	φ_k ×10^{14}/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0495	0.7959	1.0857	1.3070	1.5314	1.7328
0.0996	0.8940	1.1999	1.4123	1.6045	1.7923
0.1508	0.9991	1.2690	1.4653	1.6730	1.8408
0.2008	1.1440	1.3828	1.5833	1.7593	1.9176
0.2500	1.2313	1.4849	1.6843	1.8683	2.0254
0.2994	1.3332	1.5834	1.7570	1.9357	2.0836
0.3505	1.3700	1.5976	1.7945	1.9681	2.1177
0.4006	1.4358	1.6518	1.8453	2.0009	2.1430

Table 4.70: Apparent molar adiabatic compressibility (φ_k) of maltose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.50 mol.kg^{-1} TPC				
	$\varphi_k \times 10^{14}$/m^3.mol^{-1}.Pa^{-1}				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	1.9157	2.0897	2.2608	2.4169	2.5532
0.0995	1.9671	2.1622	2.3329	2.4894	2.6239
0.1498	1.9904	2.1736	2.3399	2.4915	2.6249
0.2005	1.9728	2.1514	2.3243	2.4800	2.6203
0.2498	2.0215	2.2170	2.3802	2.5257	2.6577
0.3003	2.0626	2.2532	2.4145	2.5609	2.6997
0.3497	2.1139	2.2941	2.4520	2.5962	2.7314
0.4001	2.0418	2.2319	2.3970	2.5496	2.6900

Table 4.71: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) of sucrose in aqueous system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ (m^3.mol^{-1}.Pa^{-1})	$S_k \times 10^{14}$ (m^3.mol^{-1}.kg^{-1})
293.15K	-2.0968	0.7700
298.15K	-1.7708	0.8045
303.15K	-1.4837	0.8642
308.15K	-1.2356	0.8924
313.15K	-0.9941	0.8210

Table 4.72: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) of maltose in aqueous system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)	$S_k \times 10^{14}$ ($m^3.mol^{-1}.kg^{-1}$)
293.15K	-1.7376	0.8997
298.15K	-1.3688	0.8861
303.15K	-1.0454	0.8871
308.15K	-0.7840	0.8818
313.15K	-0.5050	0.7578

Table 4.73: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of sucrose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)	$S_k \times 10^{14}$ ($m^3.mol^{-1}.kg$)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)
293.15K	-1.5659	0.5181	0.5309
298.15K	-1.2314	0.4811	0.5393
303.15K	-0.9424	0.4721	0.5413
308.15K	-0.6730	0.3618	0.5626
313.15K	-0.4573	0.3592	0.5368

Table 4.74: : Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of sucrose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)	$S_k \times 10^{14}$ ($m^3.mol^{-1}.kg$)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)
293.15K	-1.1761	3.5931	25.5835
298.15K	-0.8228	3.3159	22.0959
303.15K	-0.5593	3.2237	18.7614
308.15K	-0.3495	3.2219	0.8861
313.15K	-0.1625	3.1257	0.8316

Table 4.75: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of sucrose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)	$S_k \times 10^{14}$ ($m^3.mol^{-1}.kg$)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)
293.15K	0.3681	1.5820	2.4649
298.15K	0.6105	1.5905	2.3813
303.15K	0.8588	1.4027	2.3425
308.15K	1.0143	1.4644	2.2499
313.15K	1.2052	1.3284	2.1993

Table 4.76 : Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of sucrose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)	$S_k \times 10^{14}$ ($m^3.mol^{-1}.kg$)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)
293.15K	1.2619	0.7756	3.3587
298.15K	1.4404	0.7854	3.2112
303.15K	1.6026	0.7181	3.0863
308.15K	1.7377	0.7252	2.9733
313.15K	1.8445	0.7904	2.8386

Table 4.77: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of maltose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)	$S_k \times 10^{14}$ ($m^3.mol^{-1}.kg$)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ ($m^3.mol^{-1}.Pa^{-1}$)
293.15K	-1.1007	0.7334	0.6370
298.15K	-0.7648	0.6882	0.6040
303.15K	-0.4585	0.6791	0.5869
308.15K	-0.1855	0.6723	0.5985
313.15K	0.0059	0.7689	0.5110

Table 4.78: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of maltose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ (m^3.mol^{-1}.Pa^{-1})	$S_k \times 10^{14}$ (m^3.mol^{-1}.kg)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ (m^3.mol^{-1}.Pa^{-1})
293.15K	-0.0962	0.8933	1.6414
298.15K	0.2085	0.7995	1.5773
303.15K	0.4439	0.9117	1.4893
308.15K	0.7095	0.8057	1.4935
313.15K	0.9388	0.7179	1.4438

Table 4.79: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of maltose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ (m^3.mol^{-1}.Pa^{-1})	$S_k \times 10^{14}$ (m^3.mol^{-1}.kg)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ (m^3.mol^{-1}.Pa^{-1})
293.15K	0.7251	1.8891	2.4627
298.15K	1.0326	1.6624	2.4014
303.15K	1.2501	1.5814	2.2954
308.15K	1.4716	1.4261	2.2556
313.15K	1.6713	1.2675	2.1763

Table 4.80: Limiting apparent molar adiabatic compressibility (φ_k^0), experimental slope (S_k) and transfer compressibility ($\Delta_{tr}\varphi_k^0$) of maltose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

Temp (K)	$\varphi_k^0 \times 10^{14}$ (m^3.mol^{-1}.Pa^{-1})	$S_k \times 10^{14}$ (m^3.mol^{-1}.kg)	$\Delta_{tr}\varphi_k^0 \times 10^{14}$ (m^3.mol^{-1}.Pa^{-1})
293.15K	1.9100	0.4477	3.6476
298.15K	2.0918	0.4659	3.4606
303.15K	2.2649	0.4349	3.3102
308.15K	2.4219	0.4083	3.2059
313.15K	2.5561	0.4180	3.0611

Table 4.81: Hydration number (n_H) of sucrose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0500	14.10	13.74	13.42	13.18	12.89
0.1000	13.82	13.52	13.22	12.89	12.61
0.1498	13.65	13.32	13.00	12.70	12.43
0.1995	13.47	13.14	12.84	12.54	12.25
0.2497	13.28	12.99	12.66	12.37	12.11
0.3003	13.15	12.81	12.49	12.21	11.95
0.3503	12.99	12.66	12.34	12.07	11.82
0.4004	12.84	12.50	12.18	11.91	11.66

Table 4.82: Hydration number (n_H) of maltose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	14.57	14.17	13.83	13.52	13.18
0.1004	14.36	13.98	13.60	13.31	12.98
0.1497	14.16	13.78	13.42	13.09	12.85
0.2003	13.99	13.63	13.28	12.99	12.65
0.2505	13.79	13.41	13.09	12.76	12.49
0.3004	13.58	13.23	12.90	12.62	12.32
0.3505	13.34	12.99	12.65	12.37	12.09
0.3995	13.18	12.80	12.46	12.17	11.91

Table 4.83: Hydration number (n_H) of sucrose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.05 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0497	13.63	13.28	12.96	12.64	12.36
0.0999	13.51	13.15	12.83	12.52	12.26
0.1493	13.39	13.05	12.73	12.42	12.17
0.2002	13.24	12.87	12.55	12.30	12.04
0.2503	13.08	12.72	12.40	12.14	11.88
0.2994	12.86	12.52	12.20	11.95	11.71
0.3506	12.71	12.37	12.06	11.82	11.57
0.4006	12.57	12.26	11.96	11.68	11.42

Table 4.84: Hydration number (n_H) of sucrose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.20 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0498	13.94	13.48	13.14	12.86	12.57
0.0992	13.57	13.20	12.83	12.55	12.30
0.1502	13.12	12.72	12.41	12.13	11.90
0.2000	12.65	12.26	11.96	11.68	11.50
0.2503	12.29	11.95	11.65	11.37	11.20
0.3004	11.95	11.60	11.30	11.04	10.84
0.3497	11.72	11.38	11.09	10.83	10.60
0.4004	11.37	11.09	10.78	10.49	10.26

Table 4.85: Hydration number (n_H) of sucrose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.35 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0504	12.57	12.21	11.79	11.56	11.28
0.0997	12.23	11.88	11.56	11.31	11.02
0.1502	11.95	11.62	11.33	11.05	10.77
0.1997	11.69	11.35	11.06	10.80	10.54
0.2498	11.48	11.15	10.90	10.59	10.35
0.3004	11.27	10.94	10.66	10.42	10.20
0.3500	11.07	10.73	10.47	10.22	10.00
0.4004	10.84	10.50	10.25	10.00	9.80

Table 4.86: Hydration number (n_H) of sucrose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.50 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	11.40	11.07	10.82	10.56	10.38
0.1000	11.29	10.99	10.72	10.50	10.29
0.1501	11.10	10.80	10.53	10.30	10.09
0.1996	10.87	10.58	10.33	10.10	9.88
0.2498	10.78	10.48	10.22	9.99	9.78
0.3002	10.58	10.29	10.03	9.81	9.60
0.3497	10.38	10.07	9.85	9.62	9.42
0.4004	10.32	10.03	9.83	9.59	9.38

Table 4.87 : Hydration number (n_H) of maltose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.05 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0494	14.10	13.75	13.42	13.10	12.78
0.0995	13.89	13.50	13.14	12.81	12.60
0.1507	13.70	13.35	12.98	12.65	12.42
0.1997	13.50	13.16	12.81	12.49	12.24
0.2505	13.37	12.99	12.64	12.32	12.07
0.2994	13.11	12.79	12.45	12.15	11.87
0.3506	12.97	12.61	12.28	11.98	11.71
0.4002	12.75	12.44	12.13	11.82	11.54

Table 4.88: Hydration number (n_H) of maltose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.20 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0495	13.45	13.03	12.72	12.37	12.05
0.0997	13.26	12.87	12.55	12.19	11.89
0.1505	13.08	12.71	12.36	12.04	11.74
0.1999	12.90	12.53	12.19	11.85	11.56
0.2502	12.70	12.35	11.99	11.68	11.40
0.3006	12.49	12.15	11.79	11.48	11.21
0.3497	12.25	11.90	11.57	11.25	11.01
0.3997	12.04	11.70	11.35	11.07	10.81

Table 4.89: Hydration number (n_H) of maltose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.35 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0495	12.88	12.44	12.10	11.74	11.43
0.0996	12.59	12.13	11.80	11.50	11.20
0.1508	12.29	11.88	11.58	11.26	10.99
0.2008	11.94	11.58	11.28	11.00	10.76
0.2500	11.68	11.30	11.00	10.72	10.48
0.2994	11.40	11.04	10.78	10.51	10.28
0.3505	11.22	10.90	10.60	10.34	10.11
0.4006	11.01	10.70	10.41	10.18	9.96

Table 4.90: Hydration number (n_H) of maltose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.50 mol.kg^{-1} TPC				
	n_H				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0502	11.51	11.21	10.90	10.63	10.39
0.0995	11.30	10.96	10.66	10.39	10.15
0.1498	11.13	10.81	10.52	10.26	10.03
0.2005	11.02	10.72	10.42	10.16	9.92
0.2498	10.82	10.49	10.21	9.97	9.74
0.3003	10.63	10.31	10.04	9.80	9.56
0.3497	10.44	10.14	9.87	9.63	9.41
0.4001	10.42	10.11	9.84	9.59	9.36

Table 4.91: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of sucrose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.4804	1.4926	1.5027	1.5107	1.5167
0.0500	1.4948	1.5067	1.5167	1.5247	1.5305
0.1000	1.5089	1.5207	1.5306	1.5383	1.5440
0.1498	1.5229	1.5345	1.5442	1.5518	1.5574
0.1995	1.5366	1.5481	1.5577	1.5652	1.5705
0.2497	1.5504	1.5619	1.5712	1.5785	1.5837
0.3003	1.5643	1.5754	1.5846	1.5917	1.5968
0.3503	1.5779	1.5888	1.5978	1.6048	1.6097
0.4004	1.5913	1.6020	1.6108	1.6176	1.6225

Table 4.92: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of maltose in water as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.4804	1.4926	1.5027	1.5107	1.5167
0.0498	1.4950	1.5070	1.5169	1.5249	1.5306
0.1004	1.5097	1.5215	1.5312	1.5390	1.5446
0.1497	1.5239	1.5354	1.5450	1.5526	1.5582
0.2003	1.5383	1.5497	1.5591	1.5666	1.5718
0.2505	1.5524	1.5635	1.5729	1.5800	1.5852
0.3004	1.5662	1.5772	1.5863	1.5935	1.5984
0.3505	1.5796	1.5905	1.5993	1.6063	1.6111
0.3995	1.5930	1.6034	1.6120	1.6187	1.6235

Table 4.93: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of sucrose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.05 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.5062	1.5180	1.5278	1.5357	1.5417
0.0497	1.5202	1.5318	1.5416	1.5493	1.5551
0.0999	1.5343	1.5458	1.5553	1.5629	1.5686
0.1493	1.5482	1.5595	1.5688	1.5762	1.5818
0.2002	1.5622	1.5733	1.5825	1.5899	1.5952
0.2503	1.5760	1.5869	1.5959	1.6030	1.6082
0.2994	1.5890	1.5997	1.6086	1.6156	1.6207
0.3506	1.6027	1.6133	1.6219	1.6289	1.6338
0.4006	1.6161	1.6266	1.6351	1.6416	1.6463

Table 4.94: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of sucrose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.20 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.5794	1.5904	1.5995	1.6066	1.6119
0.0498	1.5938	1.6046	1.6135	1.6205	1.6256
0.0992	1.6077	1.6184	1.6270	1.6339	1.6389
0.1502	1.6214	1.6318	1.6404	1.6470	1.6519
0.2000	1.6341	1.6443	1.6527	1.6592	1.6641
0.2503	1.6467	1.6569	1.6651	1.6714	1.6761
0.3004	1.6589	1.6687	1.6768	1.6829	1.6875
0.3497	1.6710	1.6806	1.6885	1.6945	1.6987
0.4004	1.6823	1.6922	1.6997	1.7053	1.7093

Table 4.95: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of sucrose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.35 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.6500	1.6602	1.6685	1.6748	1.6795
0.0504	1.6636	1.6736	1.6816	1.6879	1.6923
0.0997	1.6767	1.6865	1.6944	1.7005	1.7047
0.1502	1.6898	1.6994	1.7072	1.7130	1.7171
0.1997	1.7025	1.7119	1.7193	1.7250	1.7289
0.2498	1.7148	1.7239	1.7314	1.7367	1.7405
0.3004	1.7267	1.7356	1.7427	1.7481	1.7518
0.3500	1.7385	1.7471	1.7541	1.7593	1.7628
0.4004	1.7496	1.7579	1.7648	1.7698	1.7732

Table 4.96: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of sucrose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Sucrose + water + 0.50 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.7182	1.7276	1.7351	1.7408	1.7448
0.0502	1.7312	1.7404	1.7478	1.7533	1.7571
0.1000	1.7440	1.7531	1.7602	1.7656	1.7693
0.1501	1.7565	1.7654	1.7723	1.7776	1.7811
0.1996	1.7685	1.7772	1.7840	1.7890	1.7924
0.2498	1.7808	1.7892	1.7958	1.8007	1.8039
0.3002	1.7925	1.8007	1.8072	1.8119	1.8149
0.3497	1.8036	1.8115	1.8180	1.8225	1.8254
0.4004	1.8157	1.8235	1.8299	1.8342	1.8368

Table 4.97: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of maltose in aqueous solution of tri-Potassium citrate (0.05 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.05 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.5062	1.5180	1.5278	1.5357	1.5417
0.0494	1.5204	1.5321	1.5418	1.5495	1.5553
0.0995	1.5347	1.5461	1.5556	1.5631	1.5689
0.1507	1.5491	1.5605	1.5697	1.5771	1.5827
0.1997	1.5628	1.5739	1.5830	1.5902	1.5956
0.2505	1.5770	1.5878	1.5967	1.6036	1.6088
0.2994	1.5900	1.6008	1.6095	1.6163	1.6213
0.3506	1.6040	1.6144	1.6230	1.6296	1.6343
0.4002	1.6169	1.6274	1.6358	1.6421	1.6466

Table 4.98: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of maltose in aqueous solution of tri-Potassium citrate (0.20 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.20 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.5794	1.5904	1.5995	1.6066	1.6119
0.0495	1.5934	1.6043	1.6132	1.6201	1.6252
0.0997	1.6075	1.6181	1.6269	1.6336	1.6385
0.1505	1.6216	1.6320	1.6405	1.6471	1.6518
0.1999	1.6350	1.6453	1.6536	1.6599	1.6644
0.2502	1.6485	1.6586	1.6666	1.6728	1.6771
0.3006	1.6618	1.6717	1.6794	1.6853	1.6895
0.3497	1.6742	1.6839	1.6915	1.6971	1.7012
0.3997	1.6868	1.6962	1.7035	1.7091	1.7129

Table 4.99: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of maltose in aqueous solution of tri-Potassium citrate (0.35 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.35 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.6500	1.6602	1.6685	1.6748	1.6795
0.0495	1.6637	1.6737	1.6818	1.6879	1.6923
0.0996	1.6773	1.6870	1.6948	1.7008	1.7051
0.1508	1.6907	1.7002	1.7080	1.7137	1.7178
0.2008	1.7033	1.7127	1.7202	1.7258	1.7298
0.2500	1.7155	1.7246	1.7319	1.7373	1.7411
0.2994	1.7273	1.7362	1.7435	1.7487	1.7524
0.3505	1.7397	1.7485	1.7554	1.7605	1.7640
0.4006	1.7514	1.7600	1.7668	1.7718	1.7752

Table 4.100: Acoustic impedance ($Z\times10^{-6}$/kg.m^{-2}.s^{-1}) of maltose in aqueous solution of tri-Potassium citrate (0.50 mol.kg^{-1}) as a function of molality (m/mol.kg^{-1}) at different temperature

m/mol.kg^{-1}	Maltose + water + 0.50 mol.kg^{-1} TPC				
	293.15K	298.15K	303.15K	308.15K	313.15K
0.0000	1.7182	1.7276	1.7351	1.7408	1.7448
0.0502	1.7313	1.7405	1.7478	1.7532	1.7570
0.0995	1.7437	1.7527	1.7598	1.7651	1.7687
0.1498	1.7563	1.7651	1.7720	1.7771	1.7806
0.2005	1.7689	1.7775	1.7842	1.7891	1.7924
0.2498	1.7807	1.7890	1.7955	1.8003	1.8035
0.3003	1.7925	1.8006	1.8070	1.8116	1.8145
0.3497	1.8037	1.8117	1.8179	1.8223	1.8251
0.4001	1.8162	1.8238	1.8297	1.8339	1.8365

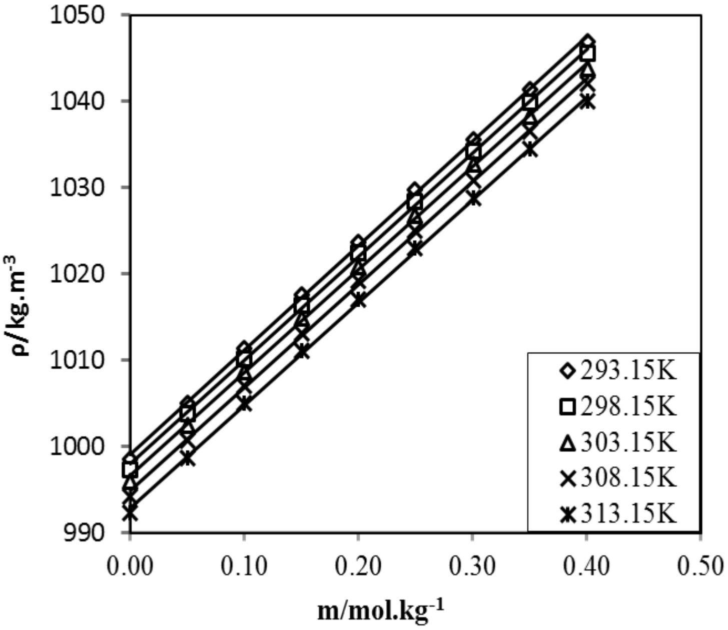


Figure 4.1**:** Plots of Density (ρ) vs. Molality (m) of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

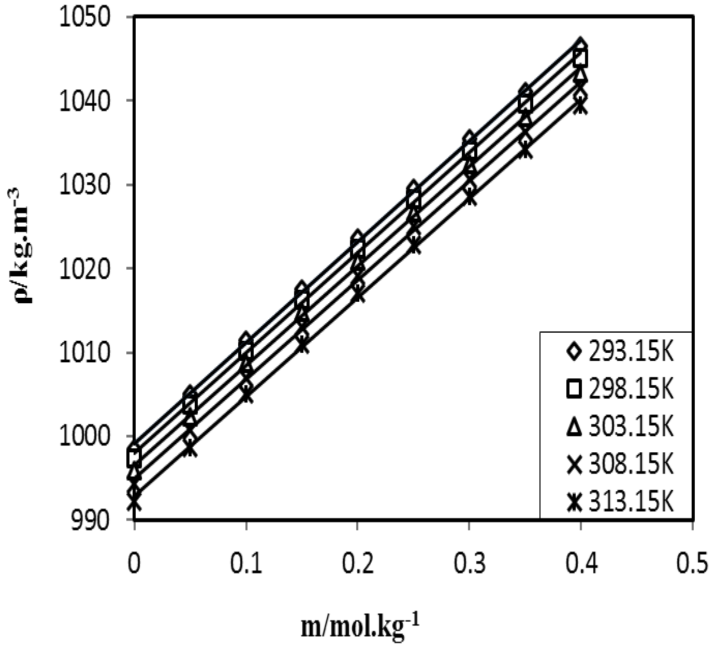


Figure 4.2**:** Plots of Density (ρ) vs. Molality (m) of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

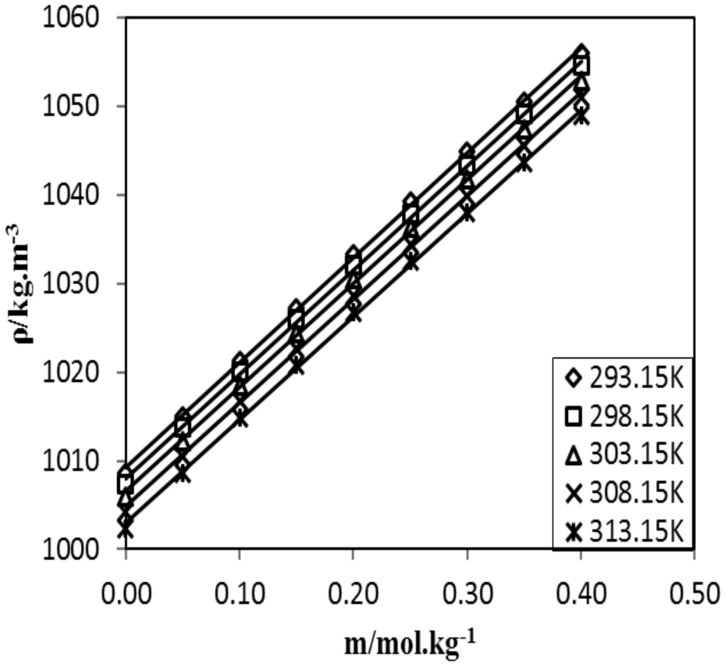


Figure 4.3: Plots of Density (ρ) vs. Molality (m) of sucrose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

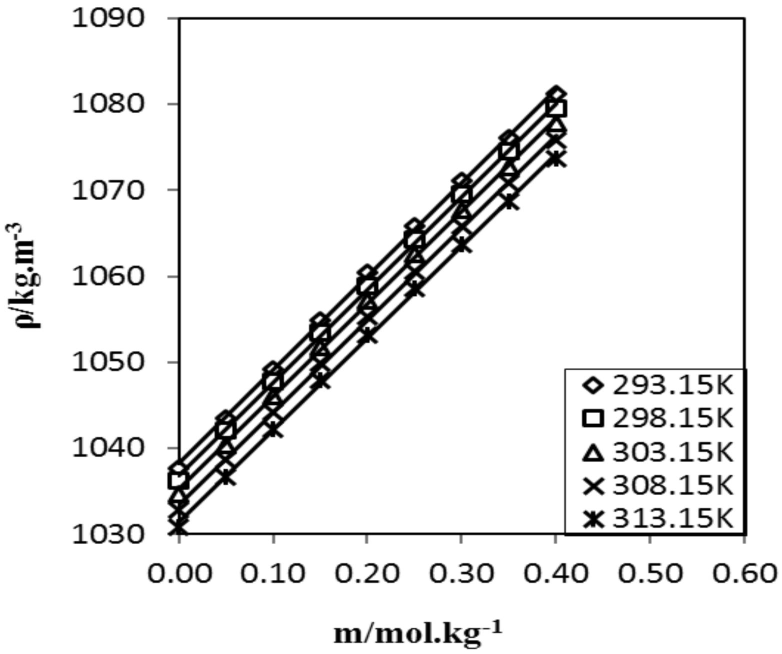


Figure 4.4: Plots of Density (ρ) vs. Molality (m) of sucrose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

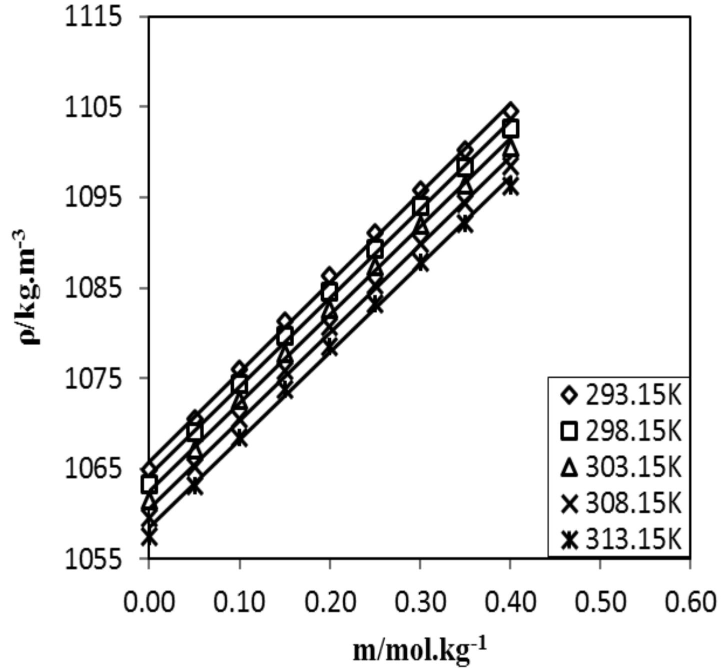


Figure 4.5: Plots of Density (ρ) vs. Molality (m) of sucrose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

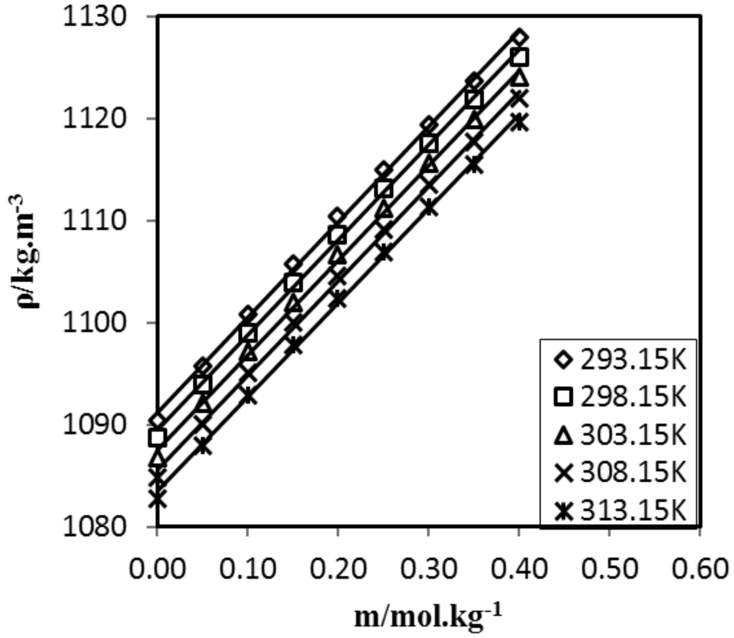


Figure 4.6: Plots of Density (ρ) vs. Molality (m) of sucrose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

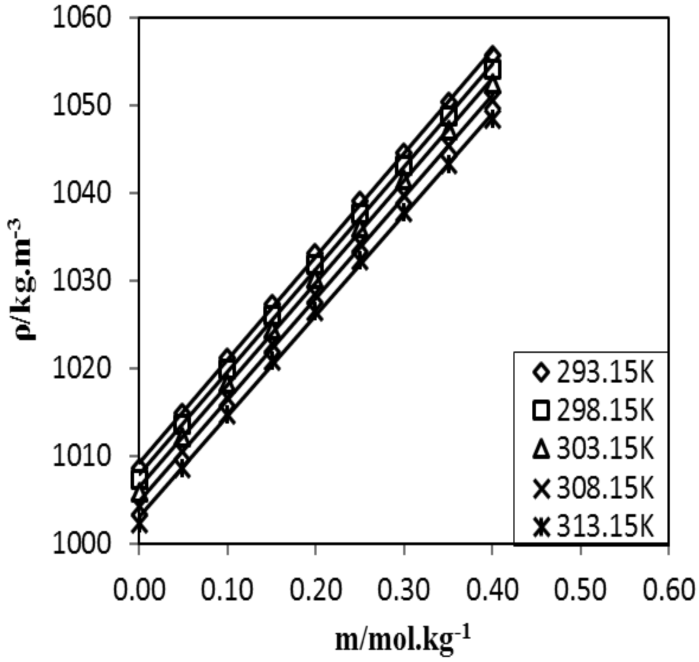


Figure 4.7: Plots of Density (ρ) vs. Molality (m) of maltose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

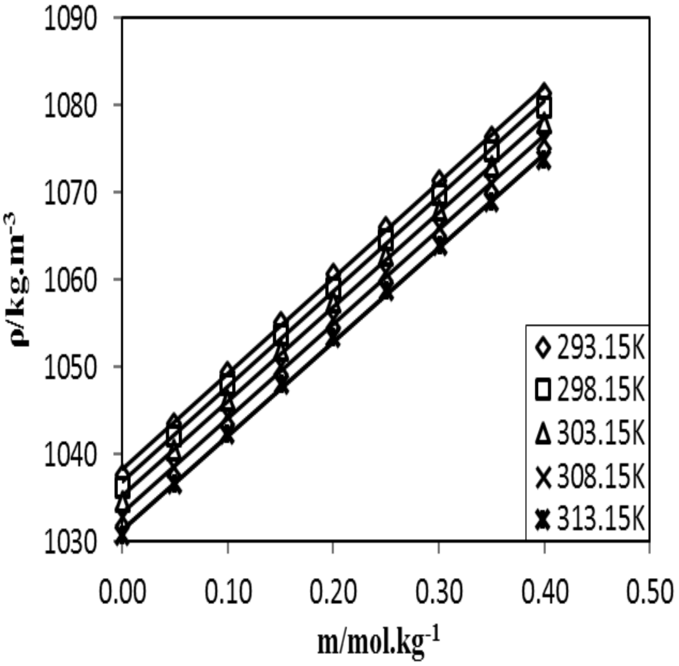


Figure 4.8: Plots of Density (ρ) vs. Molality (m) of maltose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

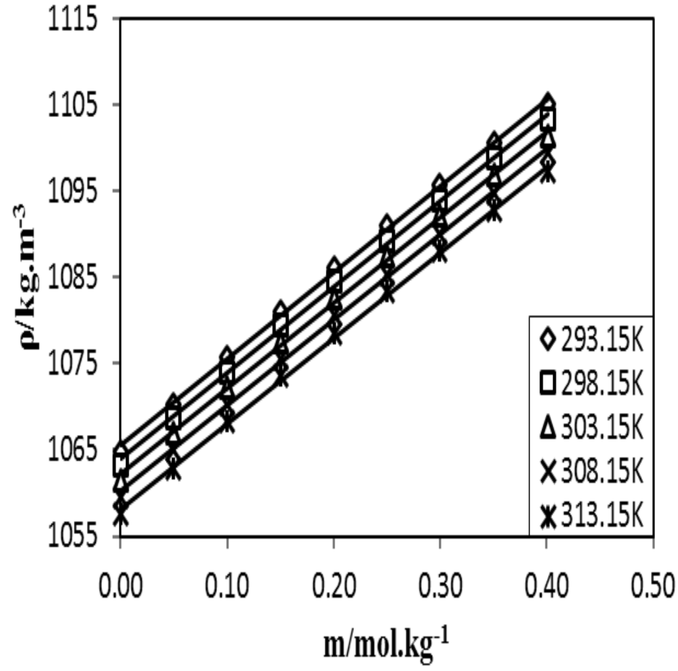


Figure 4.9: Plots of Density (ρ) vs. Molality (m) of maltose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

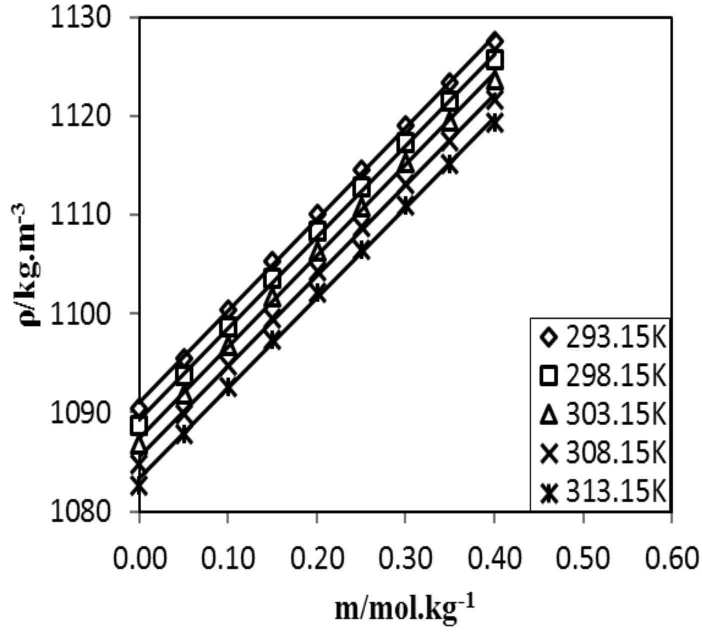


Figure 4.10: Plots of Density (ρ) vs. Molality (m) of maltose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively

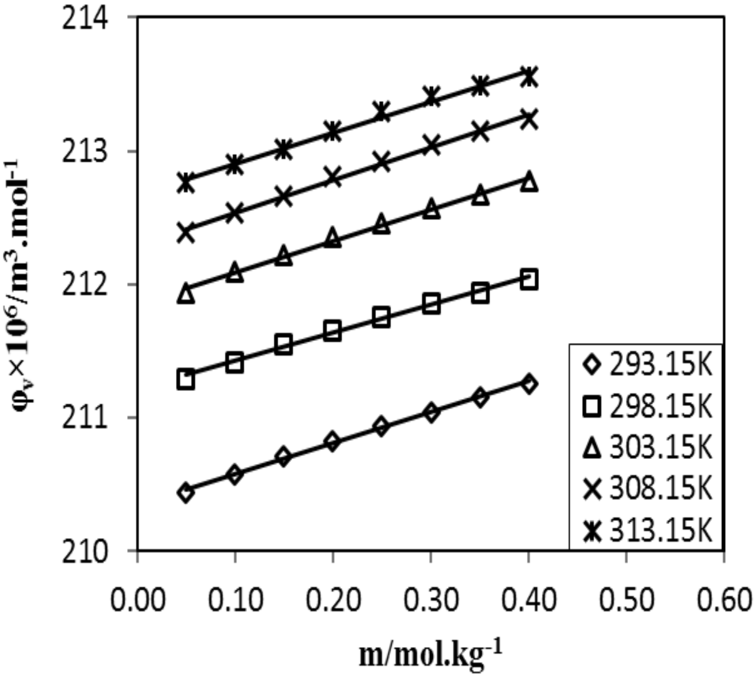


Figure 4.11: Plots of Apparent molar volume (φ_v) vs. Molality of sucrose in aqueous system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

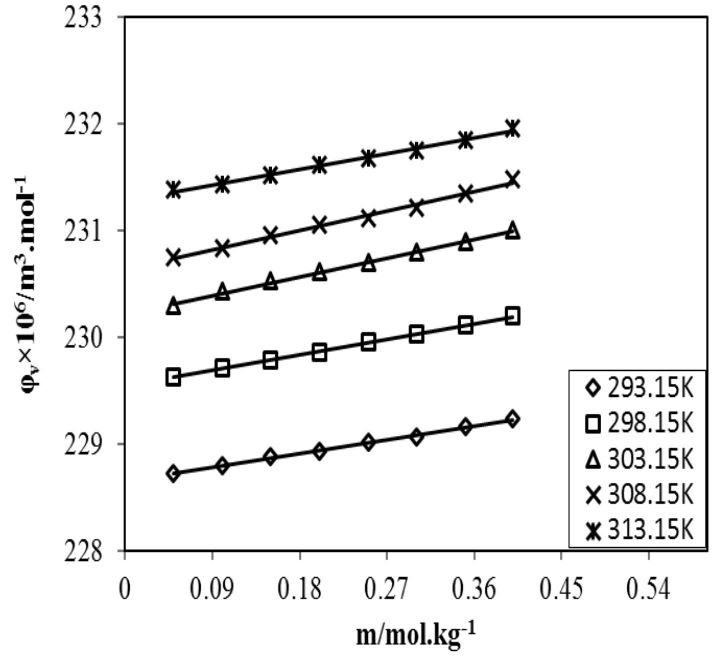


Figure 4.12: Plots of Apparent molar volume (φ_v) vs. Molality of maltose in aqueous system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

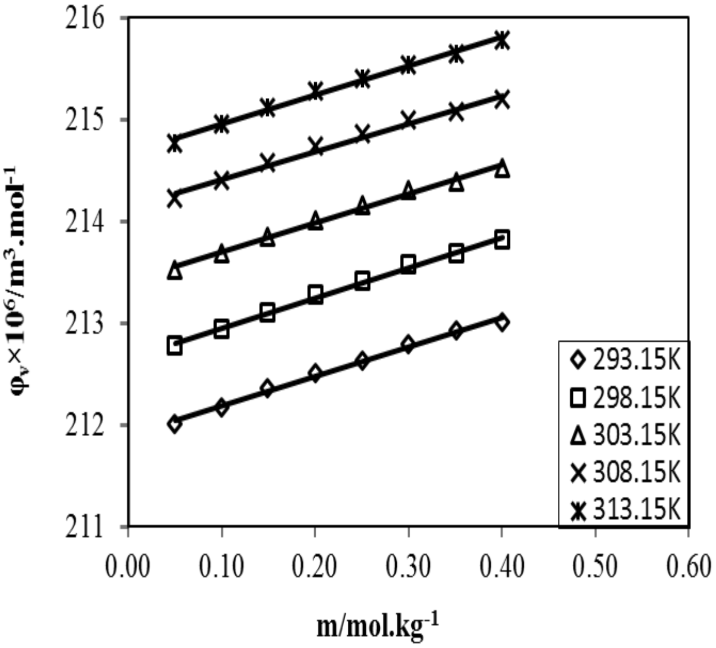


Figure 4.13: Plots of Apparent molar volume (φ_v) vs. Molality of sucrose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

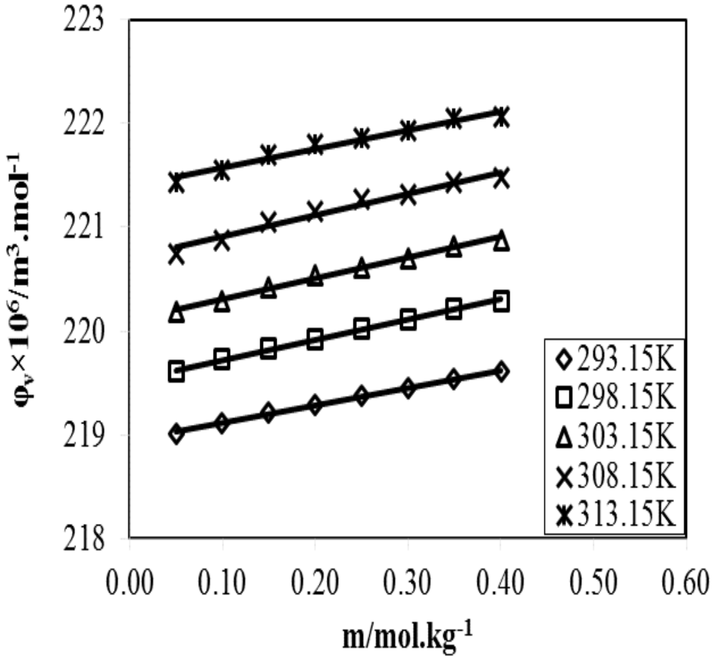


Figure 4.14: Plots of Apparent molar volume (φ_v) vs. Molality of sucrose in aqueous 0.20 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

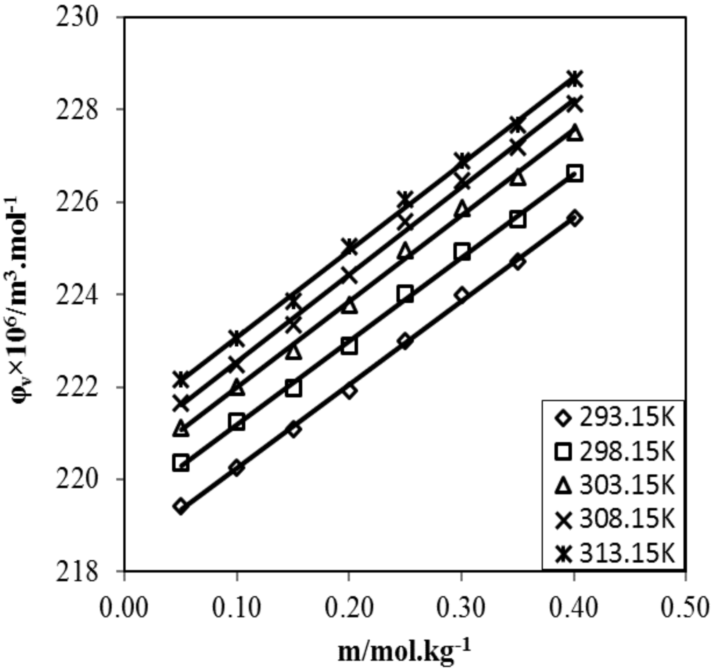


Figure 4.15: Plots of Apparent molar volume (φ_V) vs. Molality of sucrose in aqueous 0.35 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

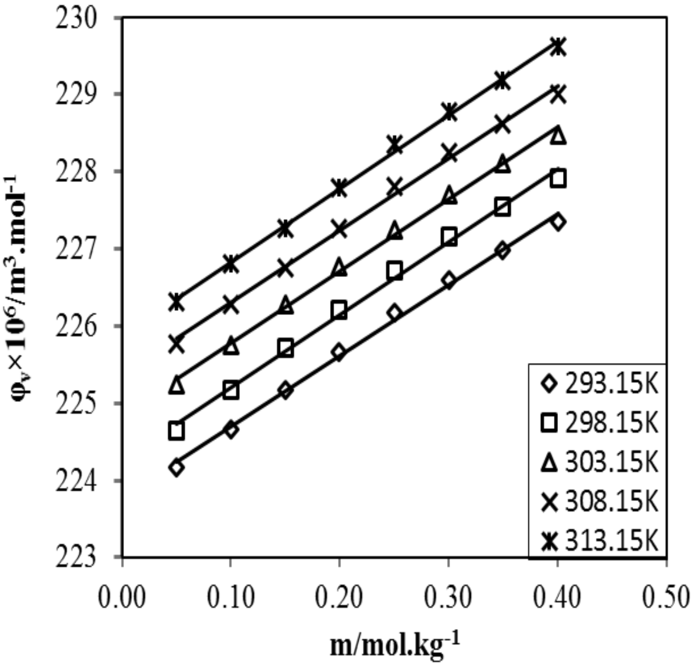


Figure 4.16: Plots of Apparent molar volume (φ_V) vs. Molality of sucrose in aqueous 0.50 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

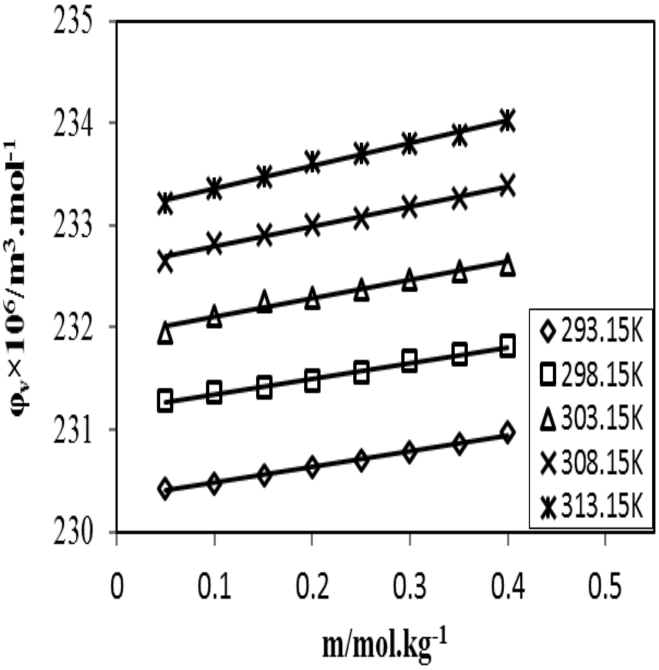


Figure 4.17: Plots of Apparent molar volume (φ_v) vs. Molality of maltose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

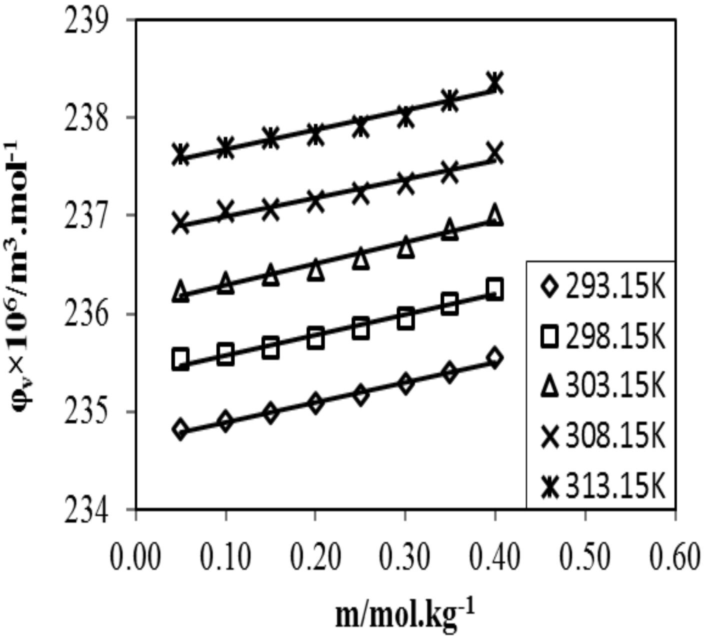


Figure 4.18: Plots of Apparent molar volume (φ_v) vs. Molality of maltose in aqueous 0.20 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

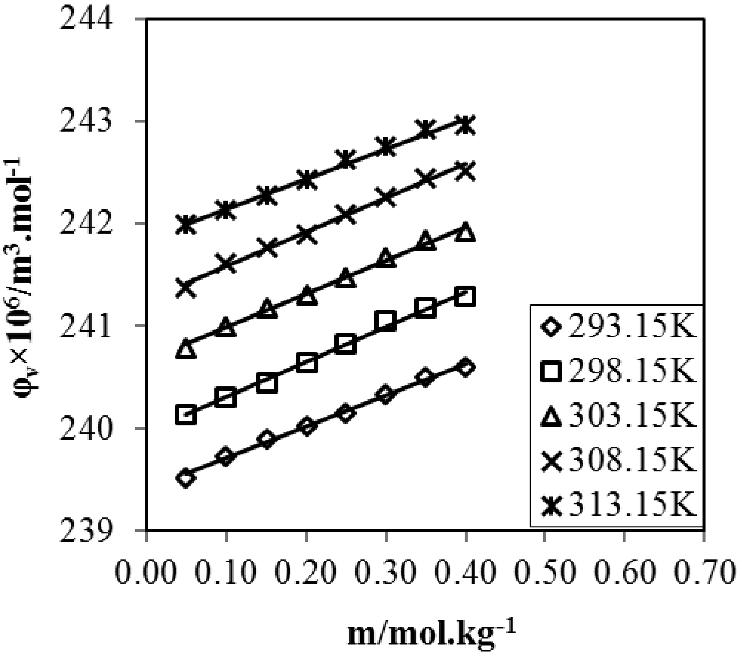


Figure 4.19: Plots of Apparent molar volume (φ_V) vs. Molality of maltose in aqueous 0.35 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

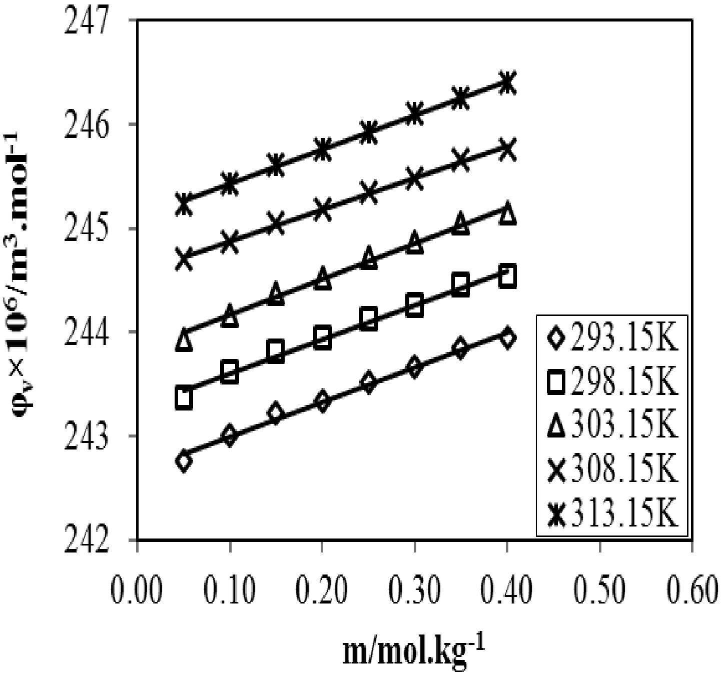


Figure 4.20: Plots of Apparent molar volume (φ_V) vs. Molality of maltose in aqueous 0.50 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

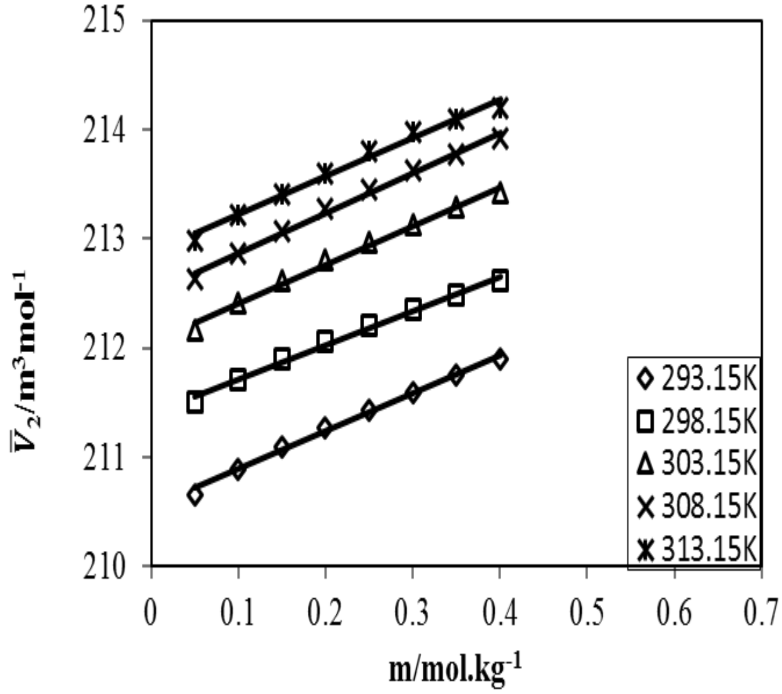


Figure 4.21: Plots of Partial molar volume *($\overline{V}_2$)* vs. Molality of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

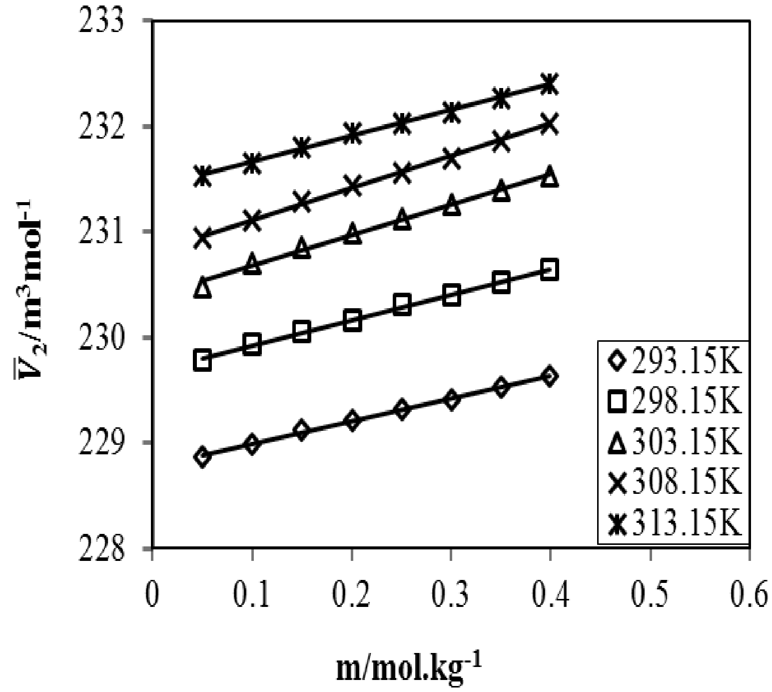


Figure 4.22: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

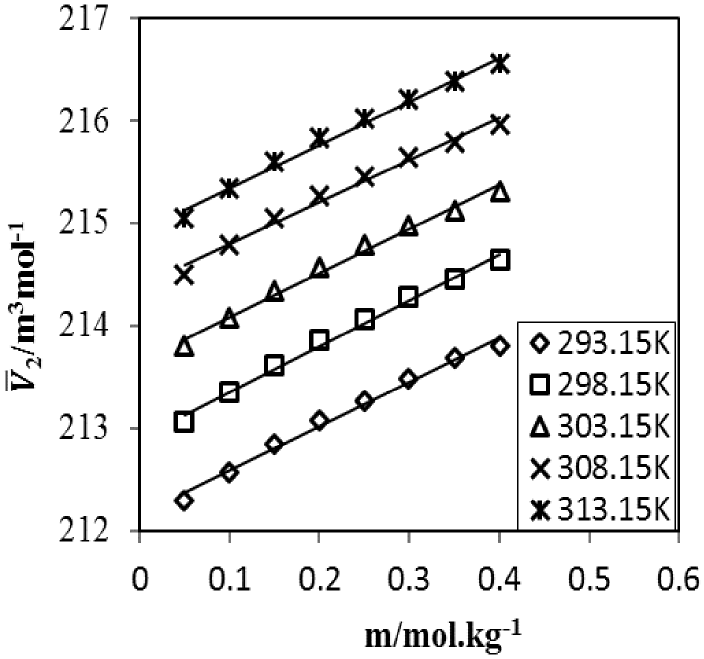


Figure 4.23: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of sucrose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

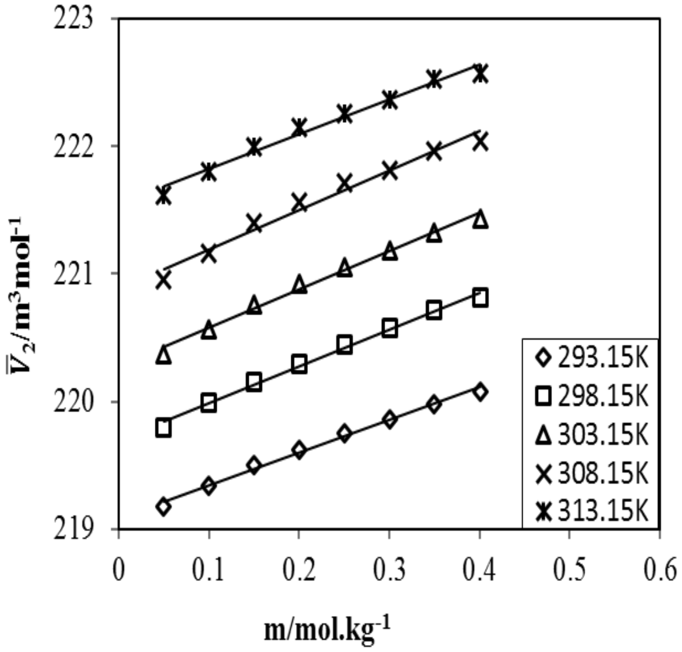


Figure 4.24: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of sucrose in aqueous 0.20 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

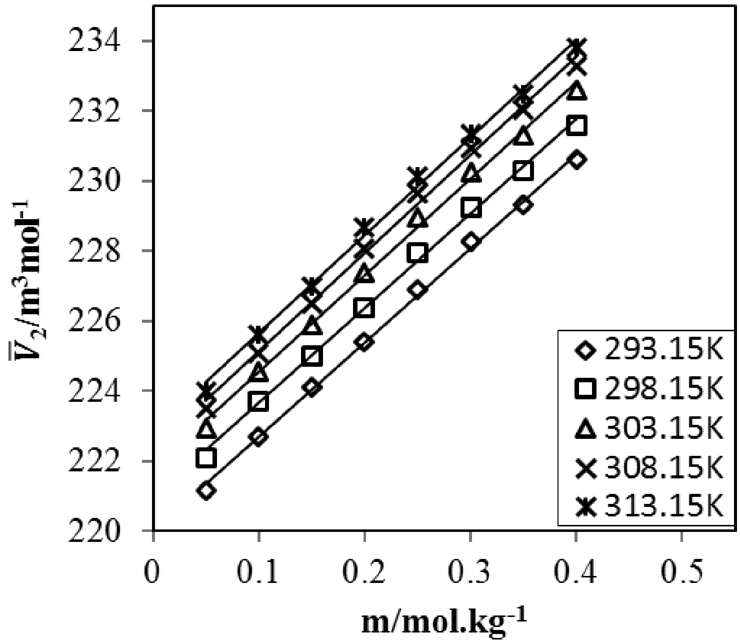


Figure 4.25: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of sucrose in aqueous 0.35 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

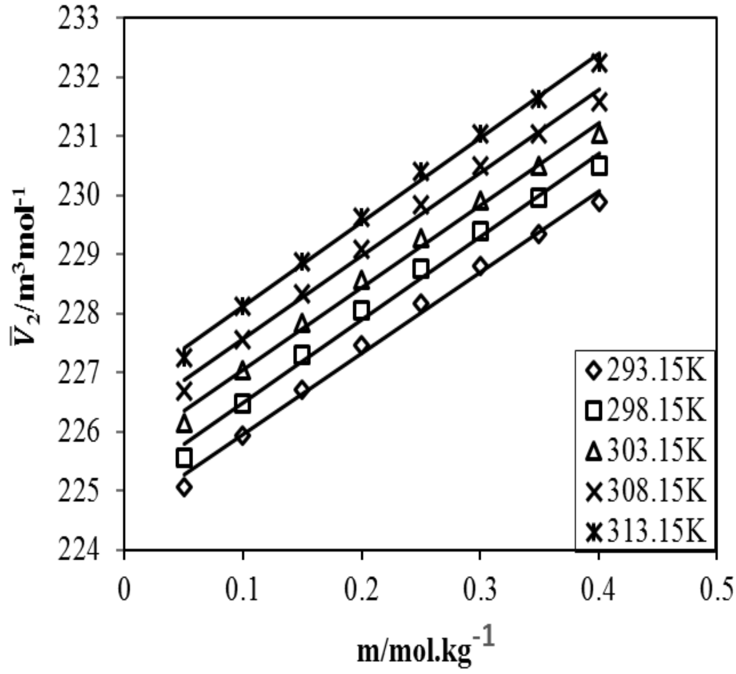


Figure 4.26: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of sucrose in aqueous 0.50 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

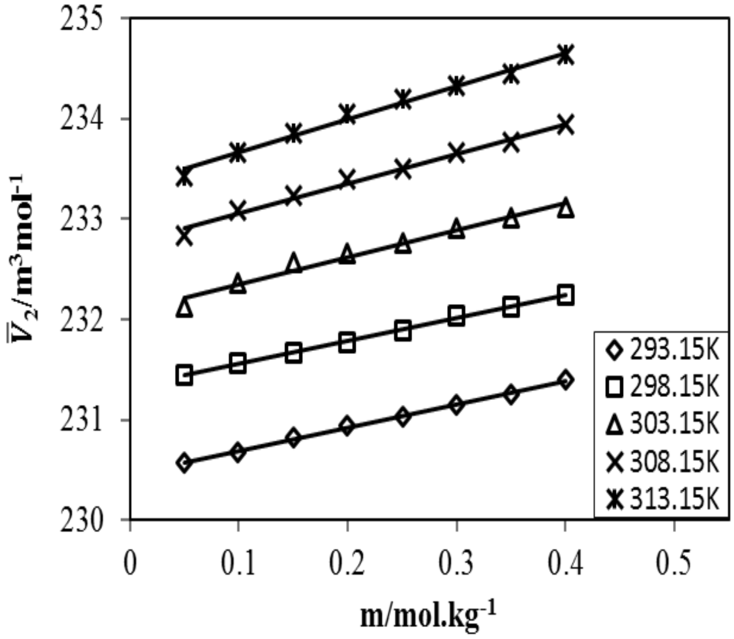


Figure 4.27: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of maltose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

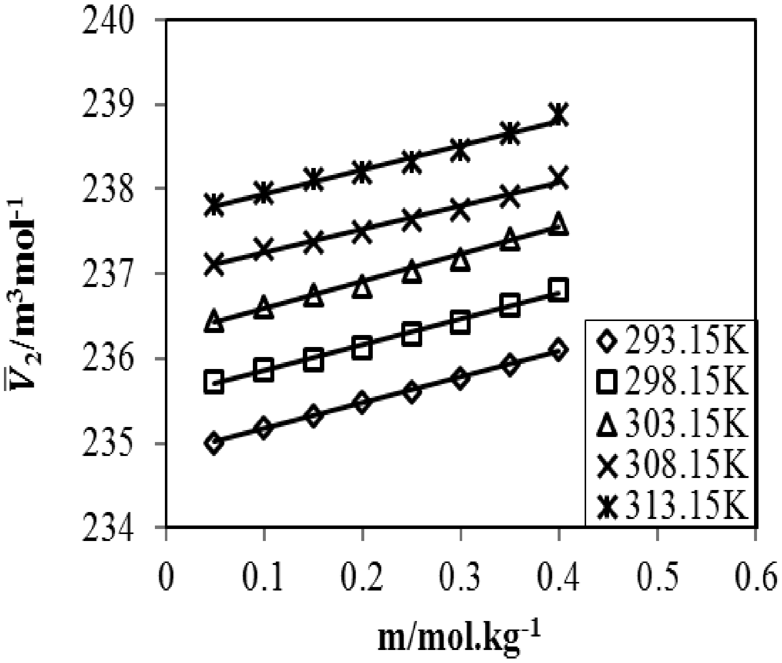


Figure 4.28: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of maltose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

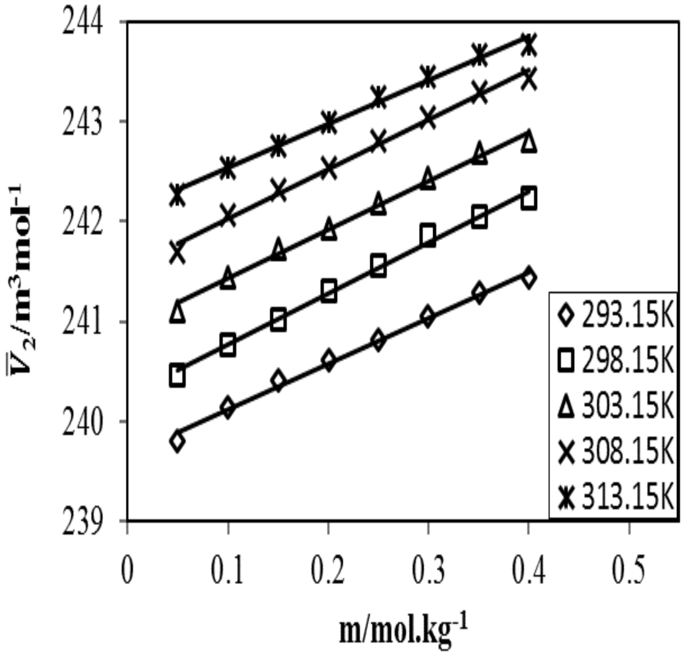


Figure 4.29: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of maltose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

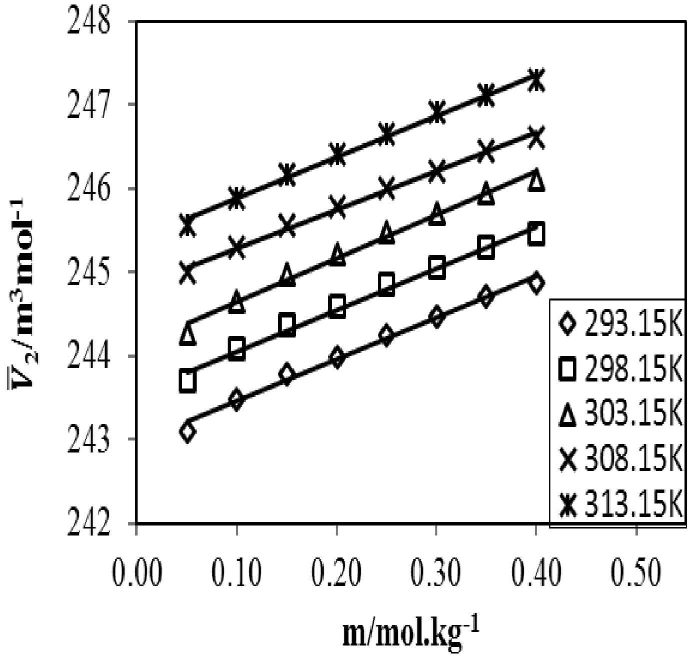


Figure 4.30: Plots of Partial molar volume ($\overline{V}_2$) vs. Molality of maltose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate systems at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

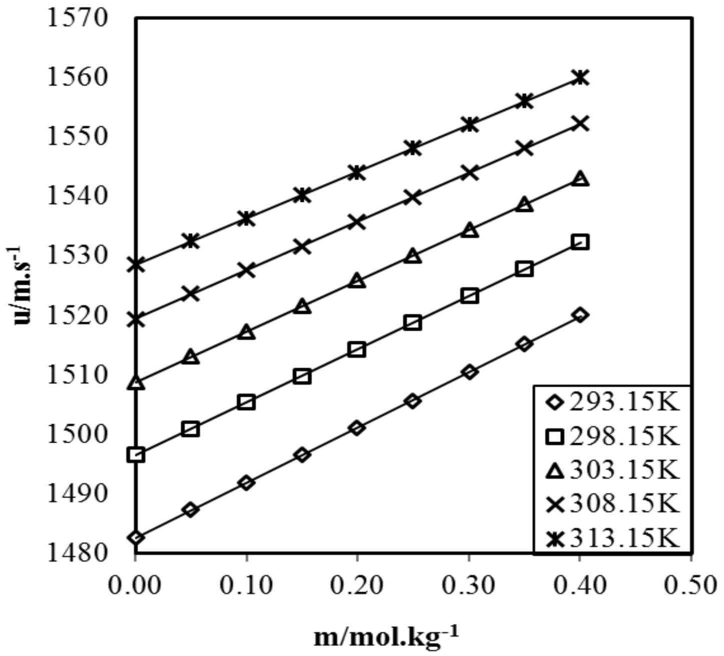


Figure 4.31**:** Plots of Sound velocity (u) vs. Molality (m) of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

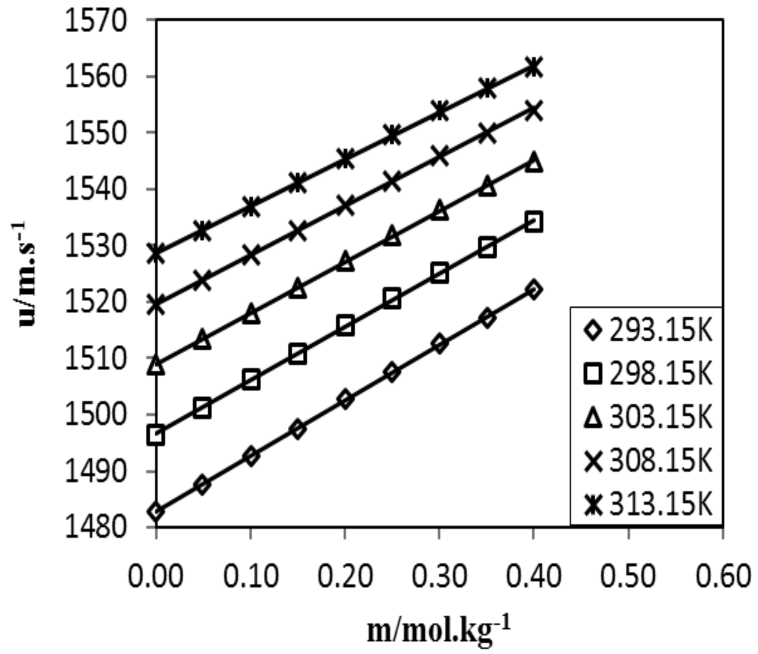


Figure 4.32**:** Plots of Sound velocity (u) vs. Molality (m) of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

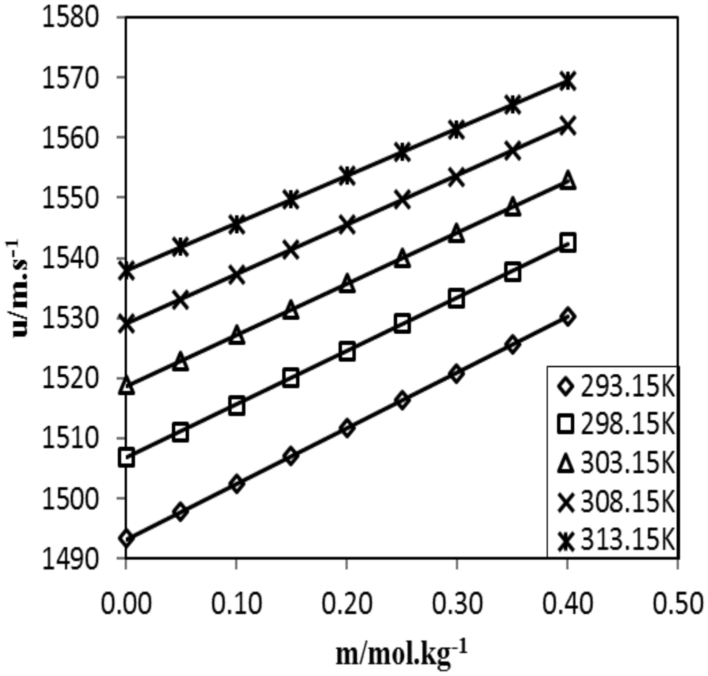


Figure 4.33: Plots of Sound velocity (u) vs. Molality (m) of sucrose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

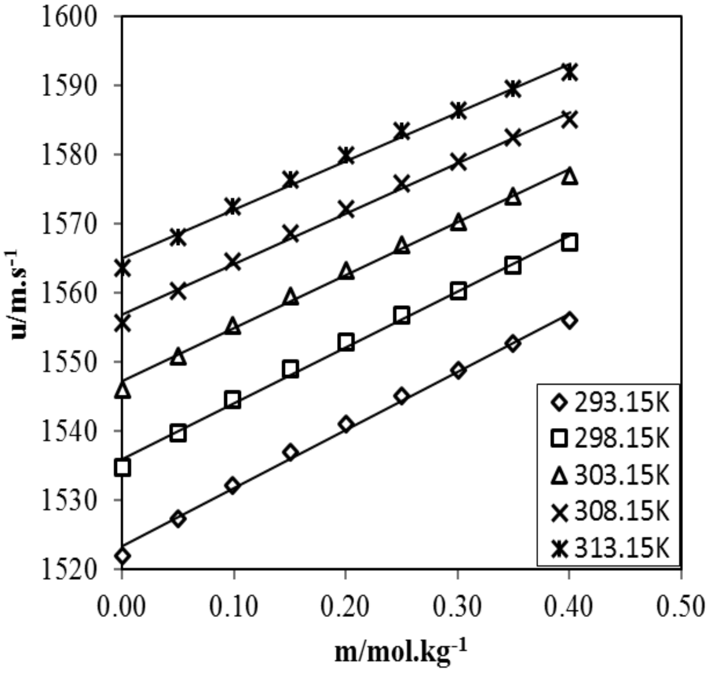


Figure 4.34: Plots of Sound velocity (u) vs. Molality (m) of sucrose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

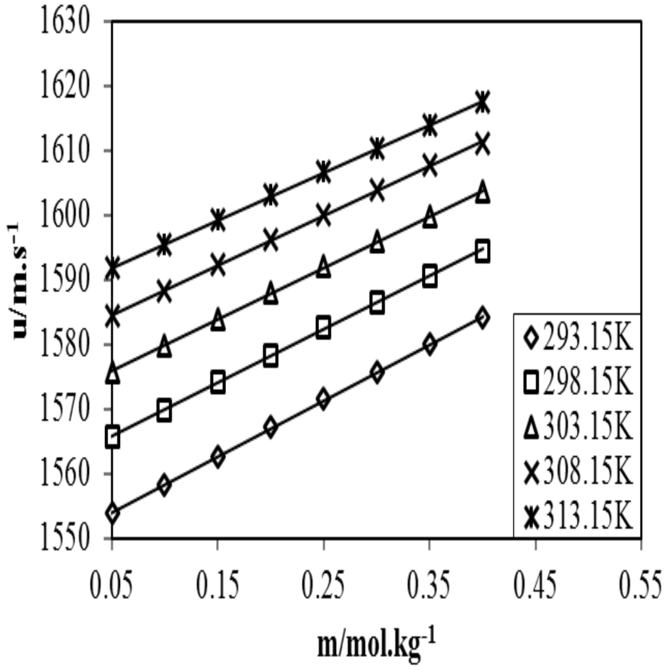


Figure 4.35: Plots of Sound velocity (u) vs. Molality (m) of sucrose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

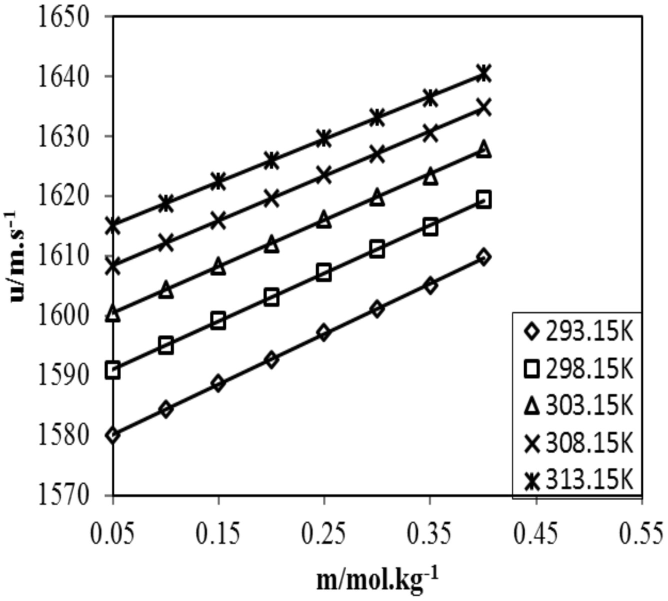


Figure 4.36: Plots of Sound velocity (u) vs. Molality (m) of sucrose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

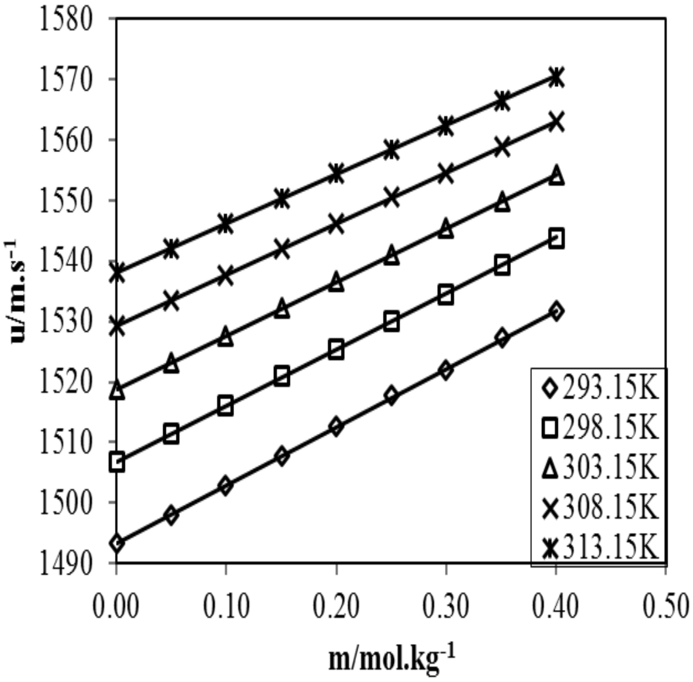


Figure 4.37: Plots of Sound velocity (u) vs. Molality (m) of maltose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

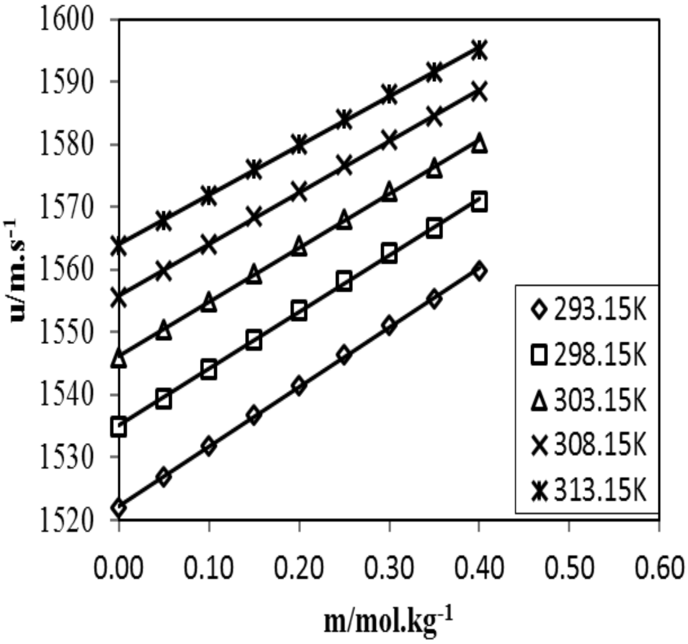


Figure 4.38: Plots of Sound velocity (u) vs. Molality (m) of maltose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

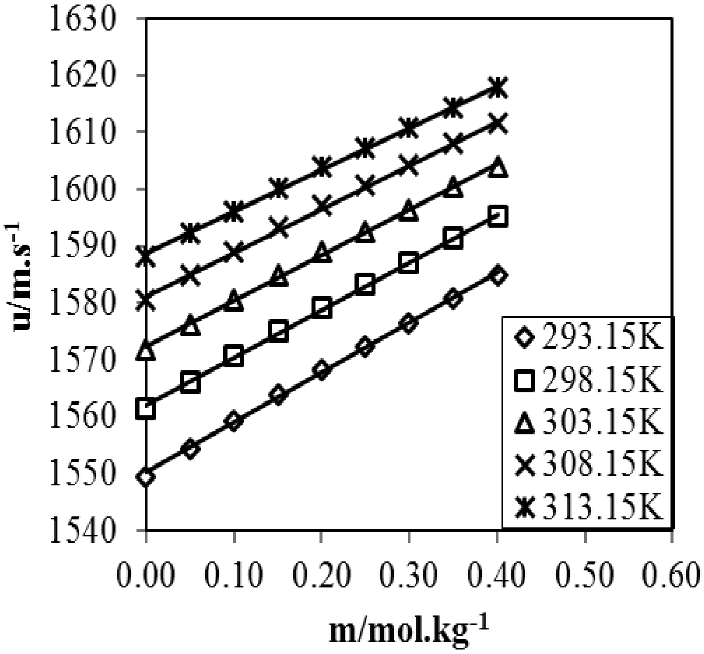


Figure 4.39: Plots of Sound velocity (u) vs. Molality (m) of maltose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

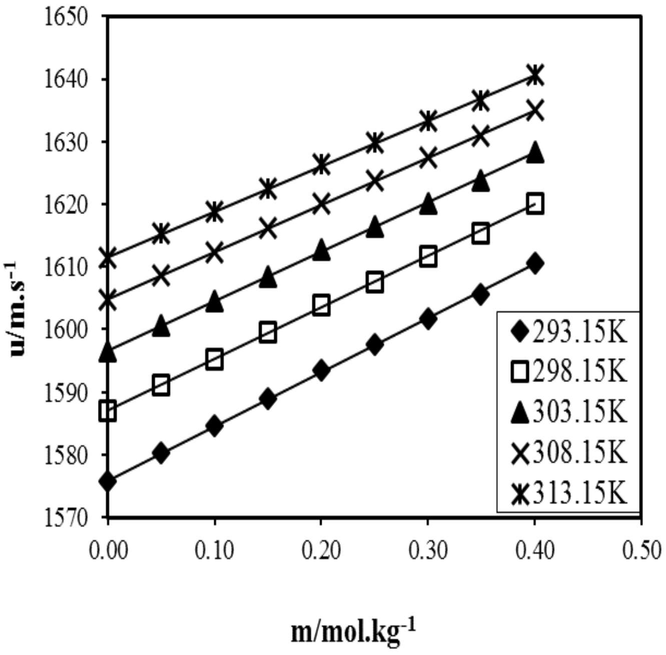


Figure 4.40: Plots of Sound velocity (u) vs. Molality (m) of maltose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

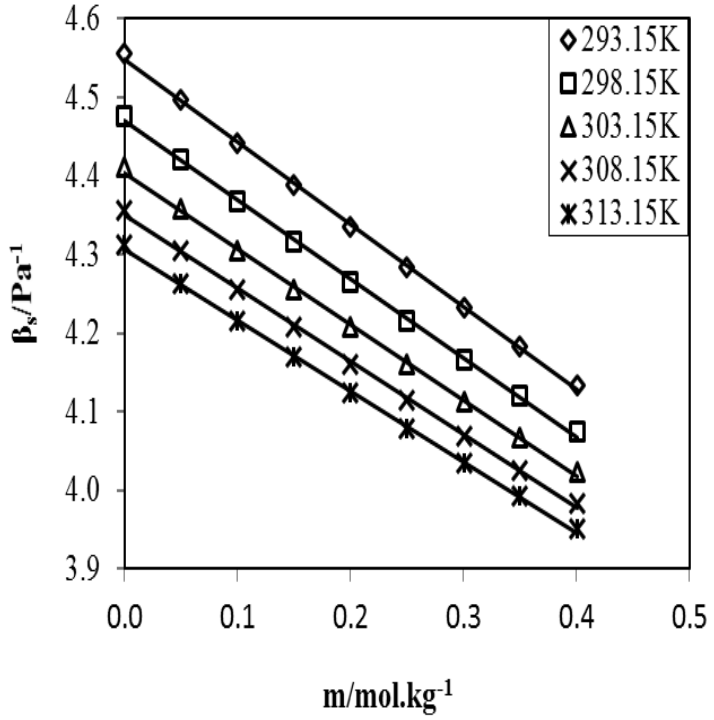


Figure 4.41**:** Plots of Adiabatic compressibility (β_s) vs. Molality (m) of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

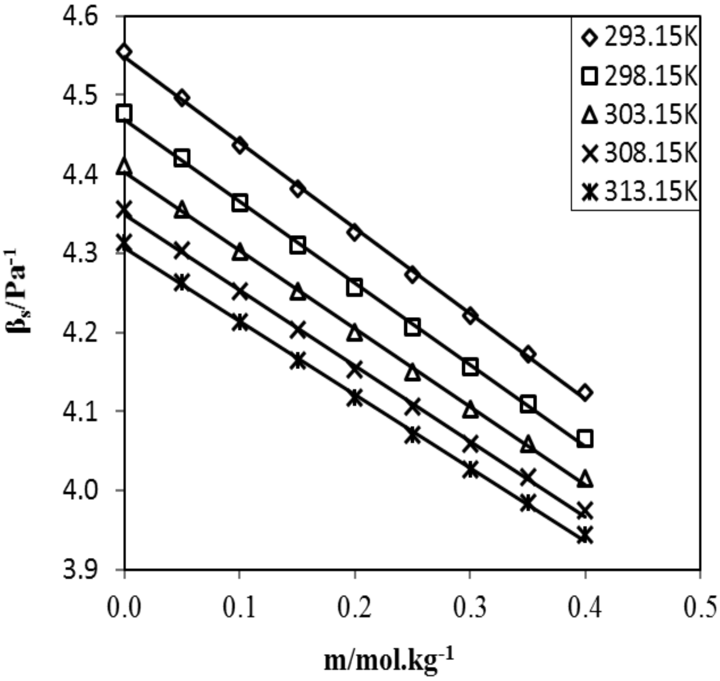


Figure 4.42**:** Plots of Adiabatic compressibility (β_s) vs. Molality (m) of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

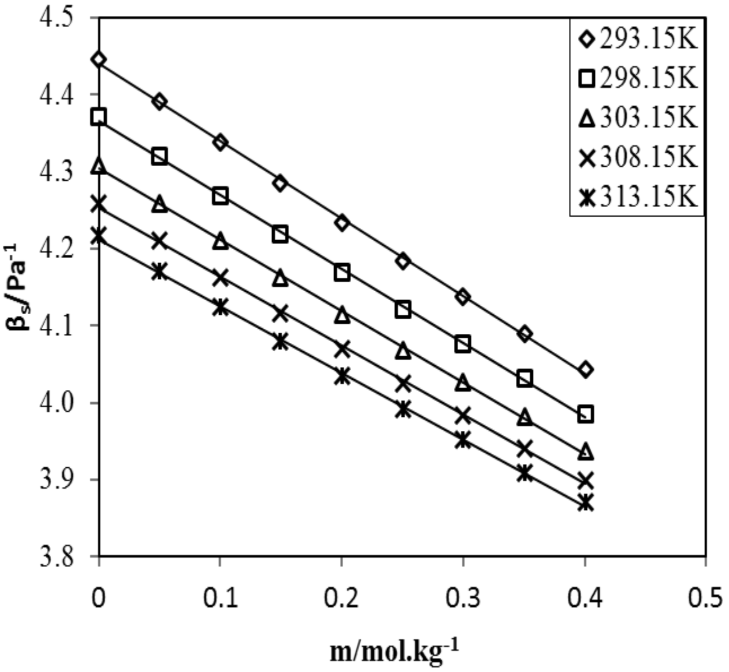


Figure 4.43: Plots of Adiabatic compressibility (β_s) vs. Molality (m) of sucrose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

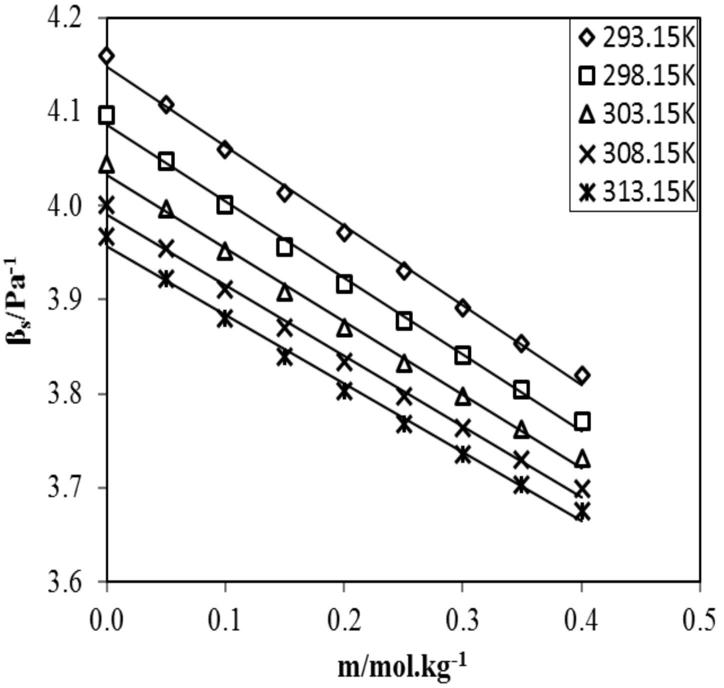


Figure 4.44: Plots of Adiabatic compressibility (β_s) vs. Molality (m) of sucrose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

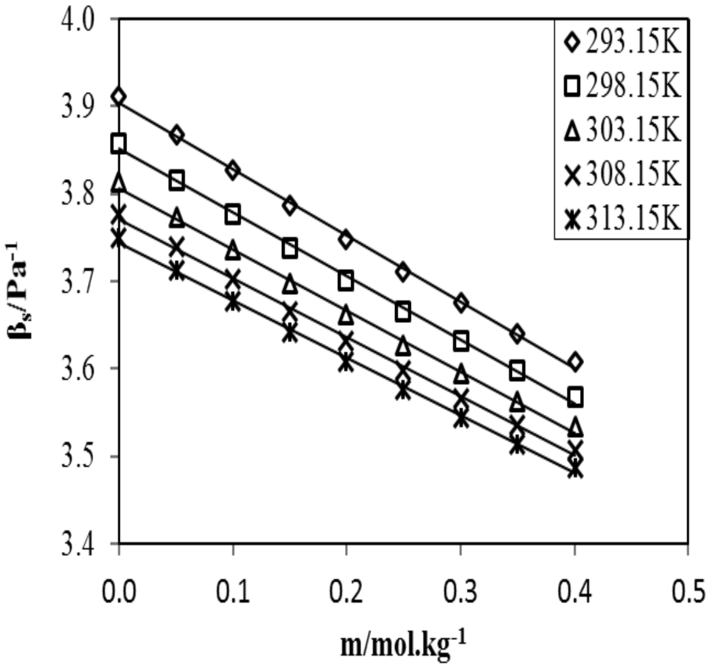


Figure 4.45: Plots of Adiabatic compressibility (β_s) vs. Molality (m) of sucrose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

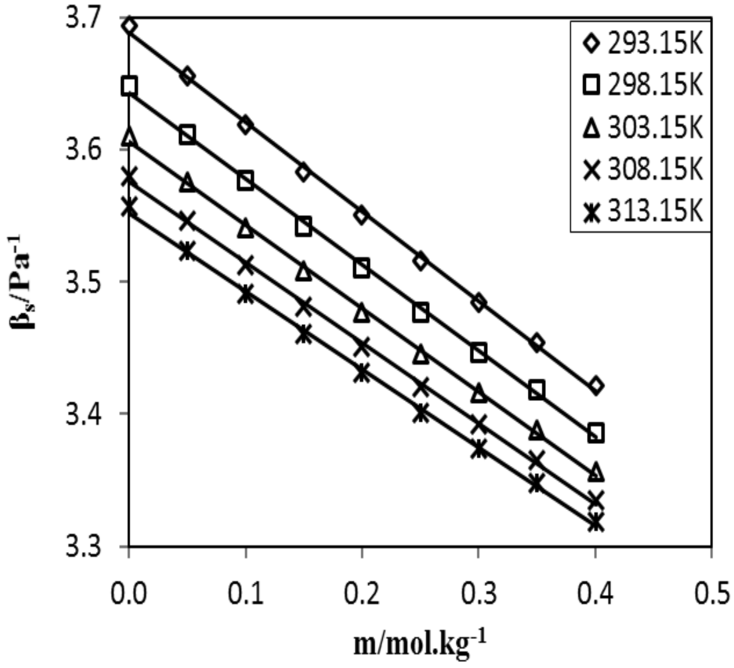


Figure 4.46: Plots of Adiabatic compressibility (β_s) vs. Molality (m) of sucrose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

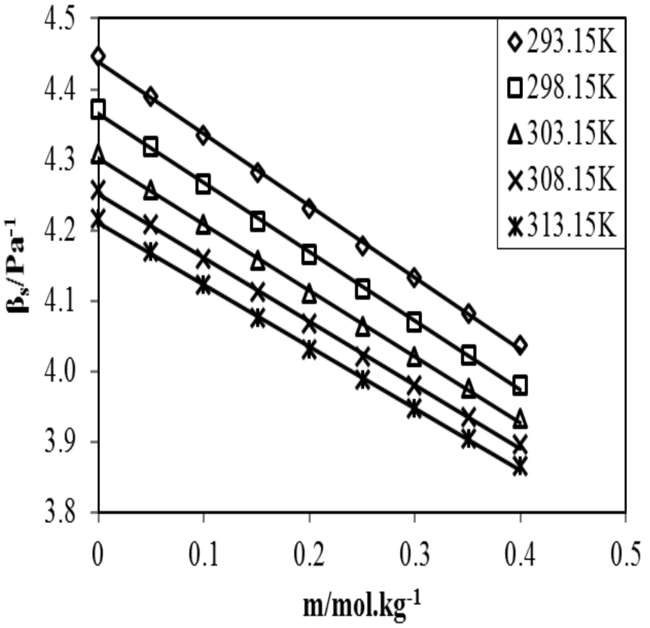


Figure 4.47: Plots of Adiabatic compressibility (β_S) vs. Molality (m) of maltose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

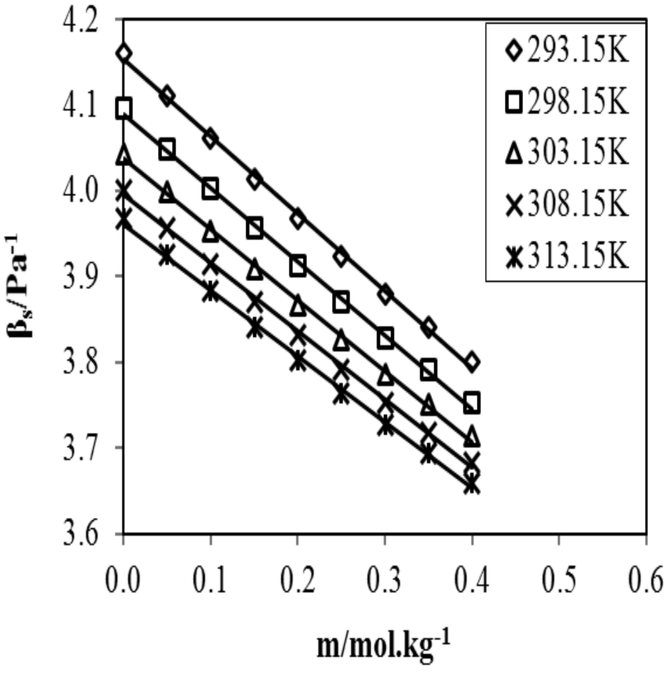


Figure 4.48: Plots of Adiabatic compressibility (β_S) vs. Molality (m) of maltose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

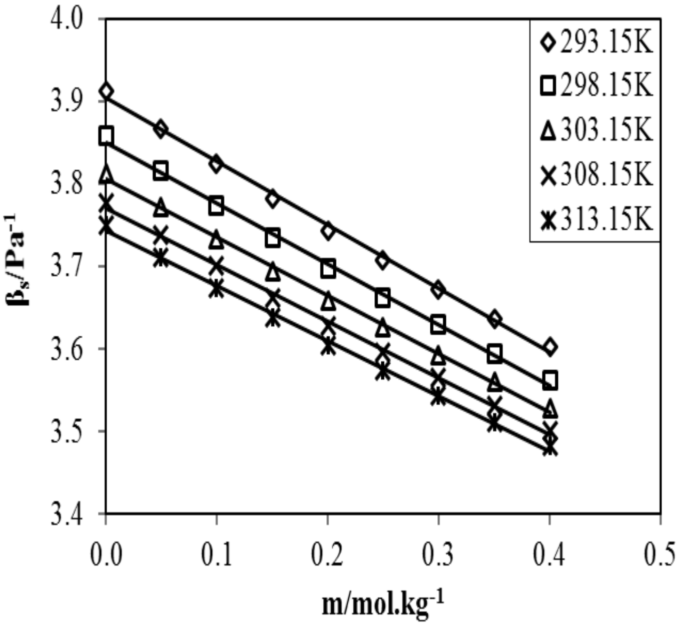


Figure 4.49: Plots of Adiabatic compressibility (β_s) vs. Molality (m) of maltose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

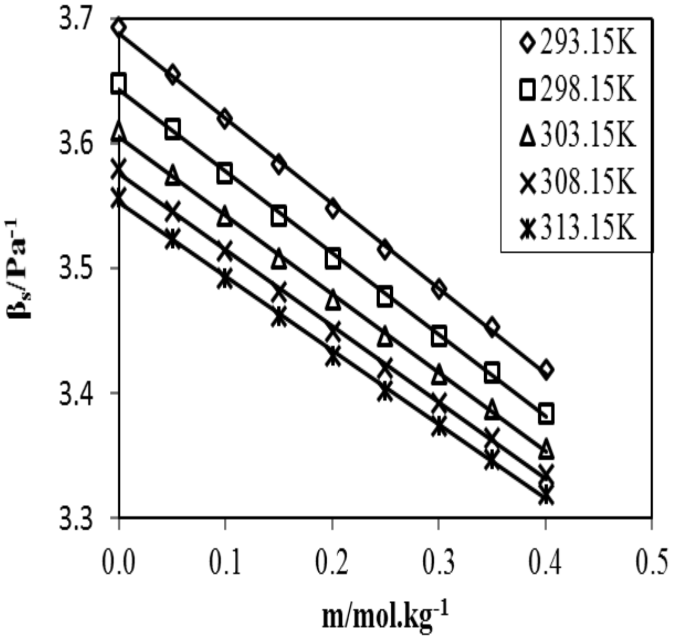


Figure 4.50: Plots of Adiabatic compressibility (β_s) vs. Molality (m) of maltose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

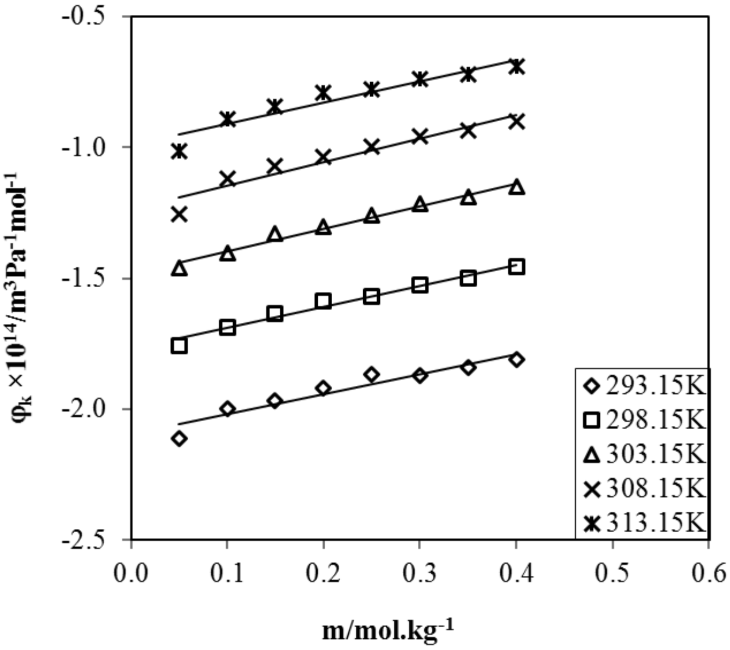


Figure 4.51**:** Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

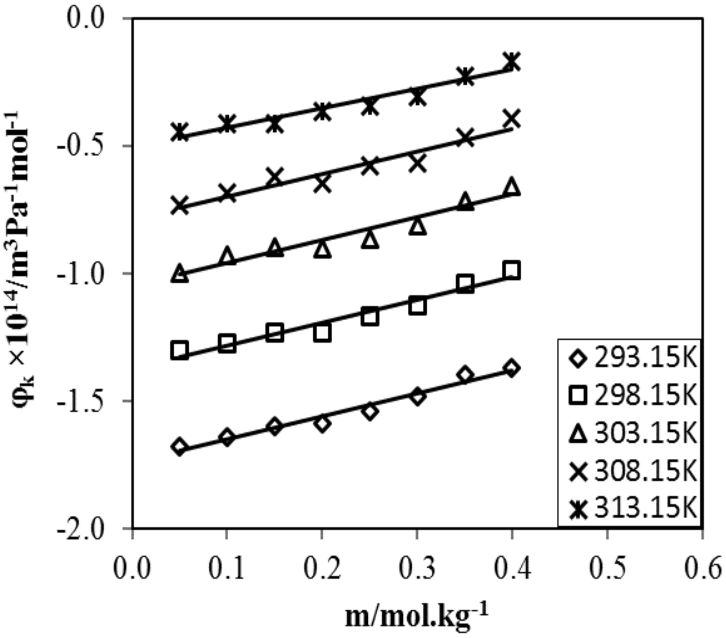


Figure 4.52**:** Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

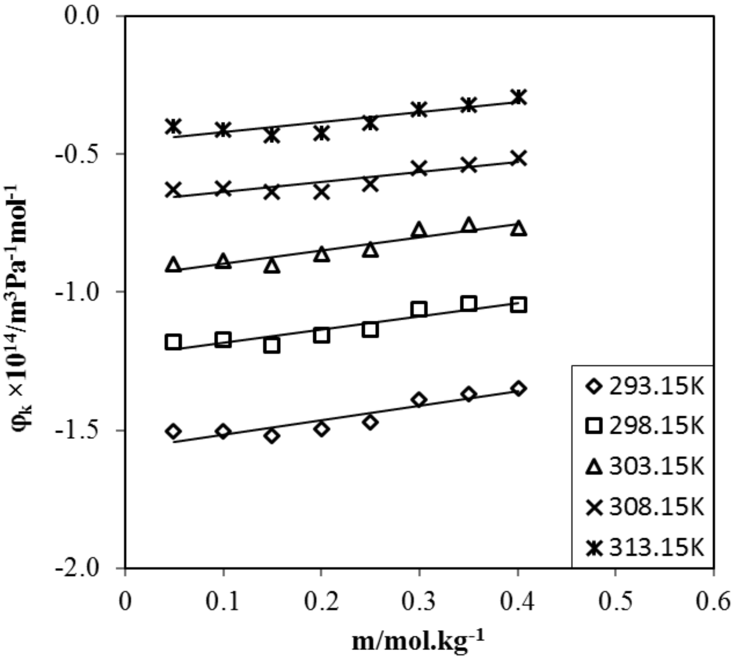


Figure 4.53: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of sucrose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

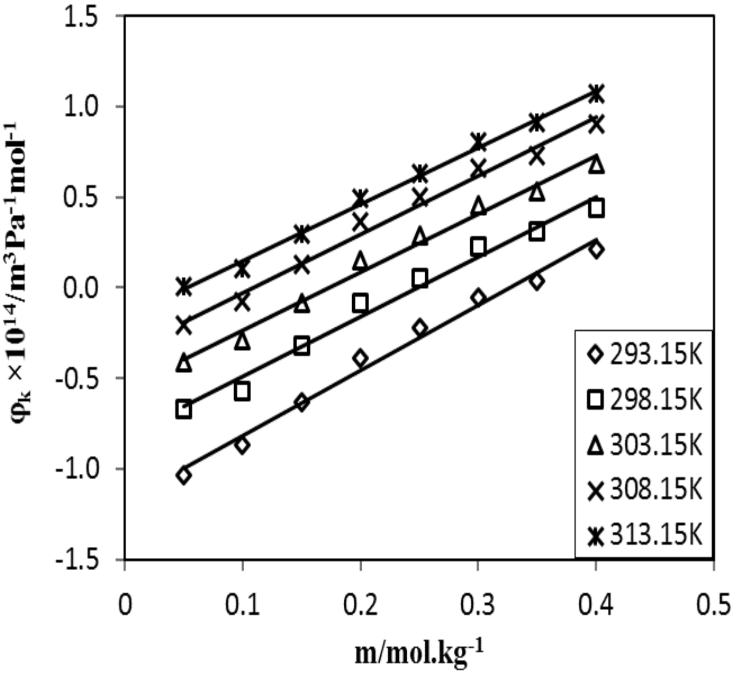


Figure 4.54: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of sucrose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

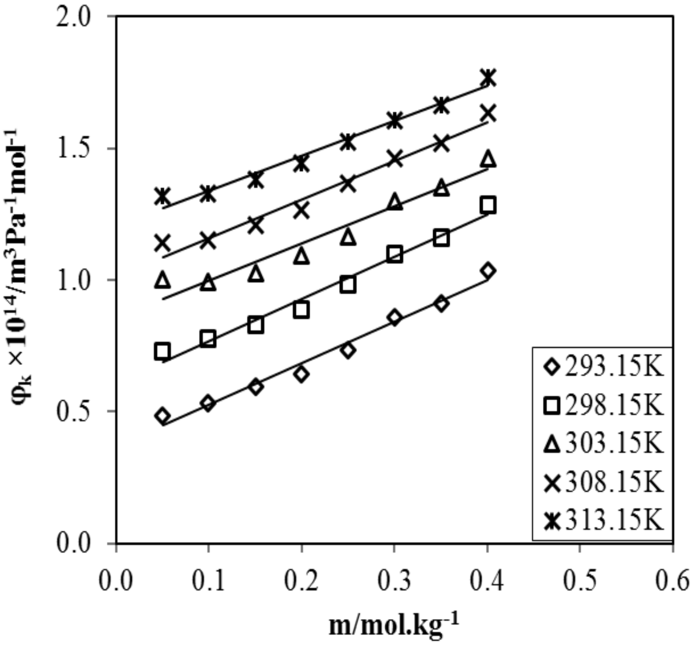


Figure 4.55: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of sucrose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

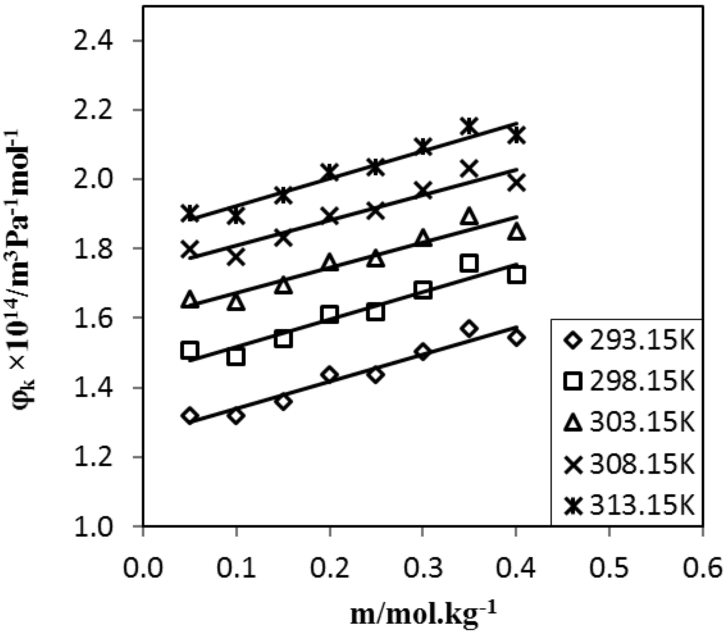


Figure 4.56: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of sucrose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

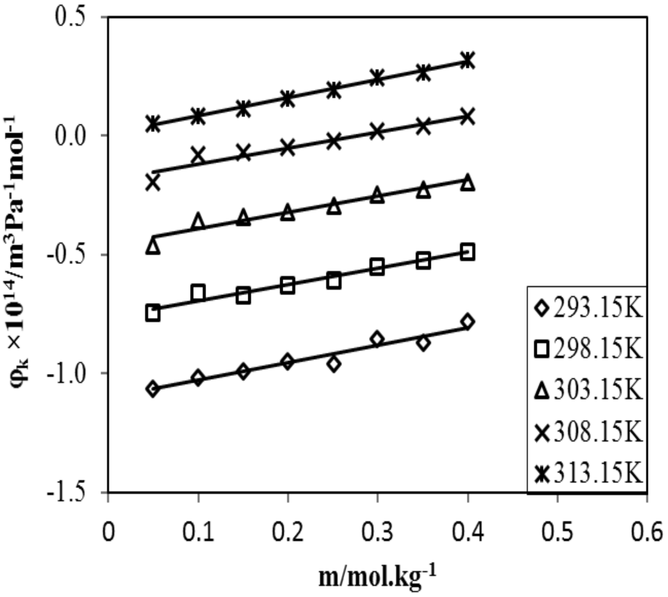


Figure 4.57: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of maltose in aqueous 0.05 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

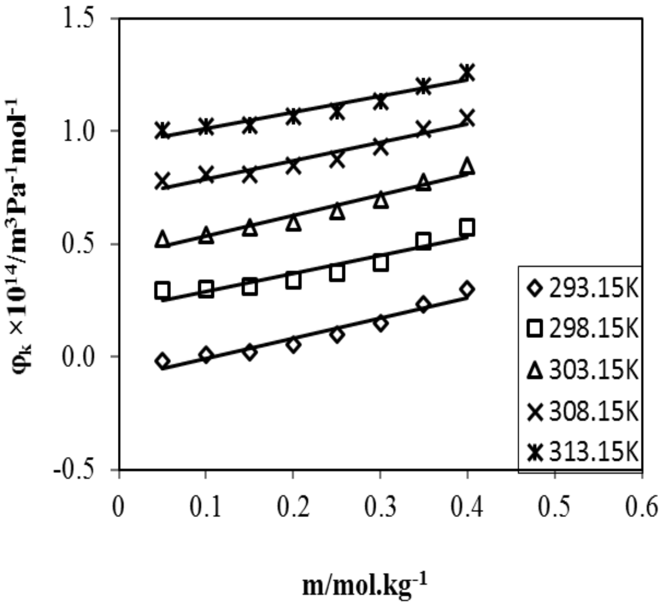


Figure 4.58: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of maltose in aqueous 0.20 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

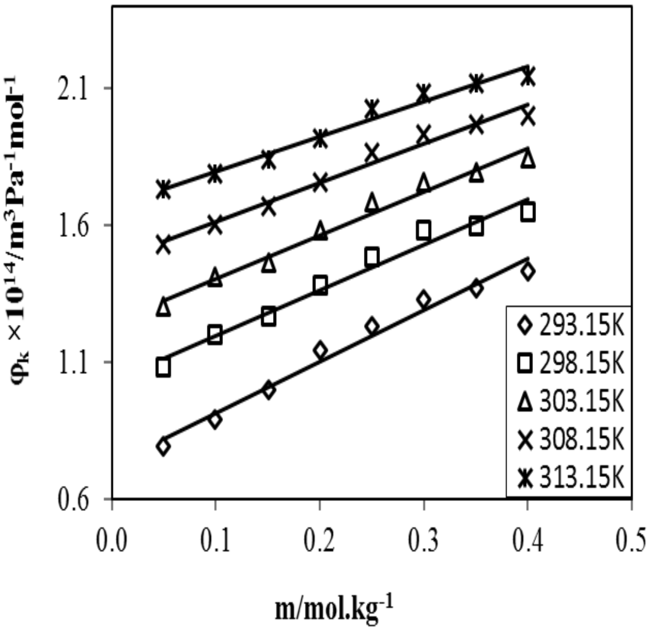


Figure 4.59: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of maltose in aqueous 0.35 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

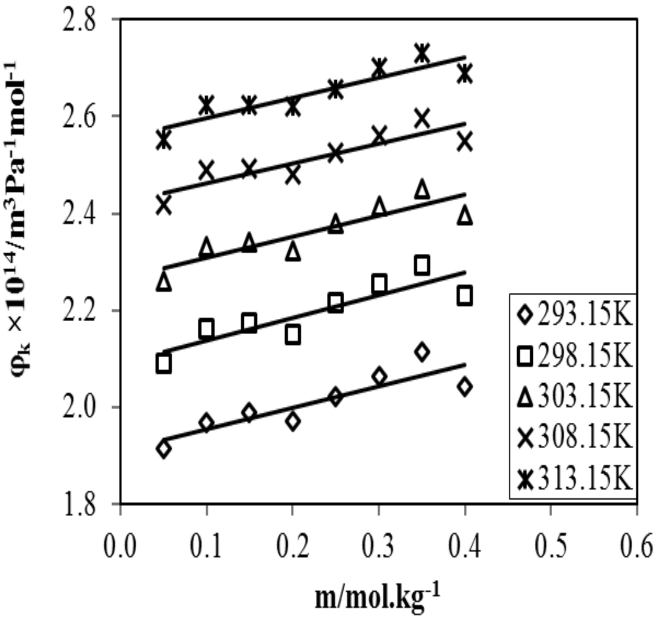


Figure 4.60: Plots of Apparent molar adiabatic compressibility (φ_k) vs. Molality (m) of maltose in aqueous 0.50 mol.kg^{-1} tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

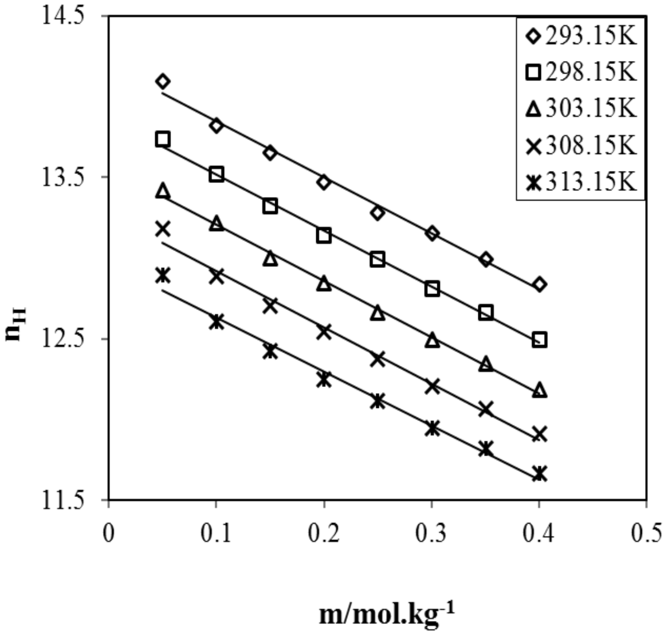


Figure 4.61**:** Plots of Hydration number (n_H) vs. Molality (m) of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

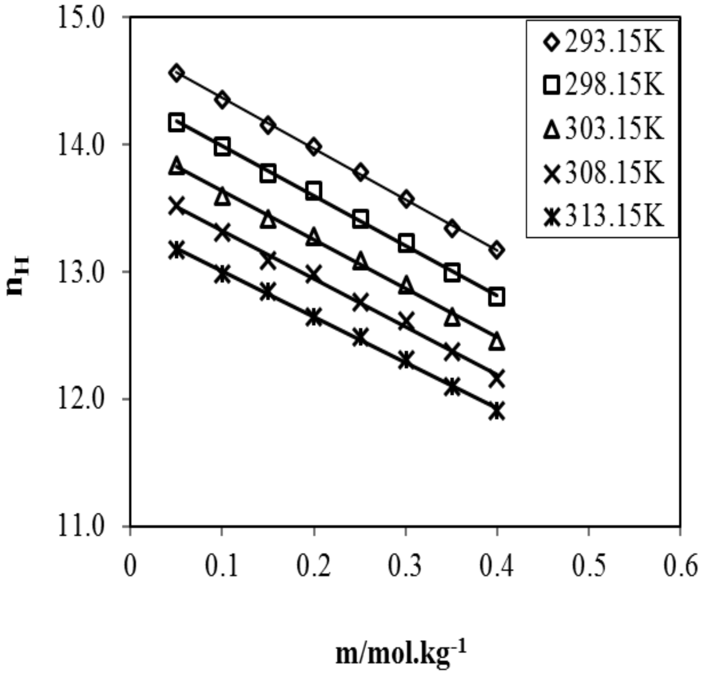


Figure 4.62**:** Plots of Hydration number (n_H) vs. Molality (m) of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

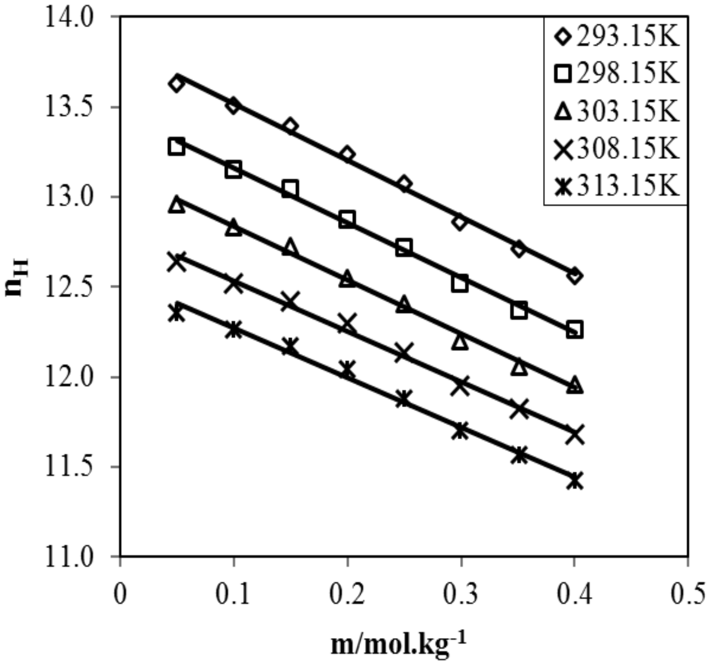


Figure 4.63: Plots of Hydration number (n_H) vs. Molality (m) of sucrose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

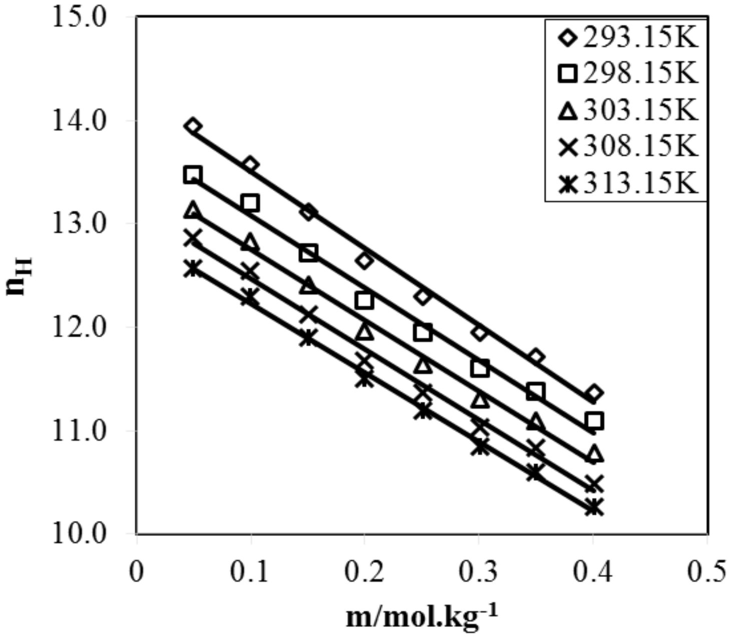


Figure 4.64: Plots of Hydration number (n_H) vs. Molality (m) of sucrose in aqueous 0.20 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

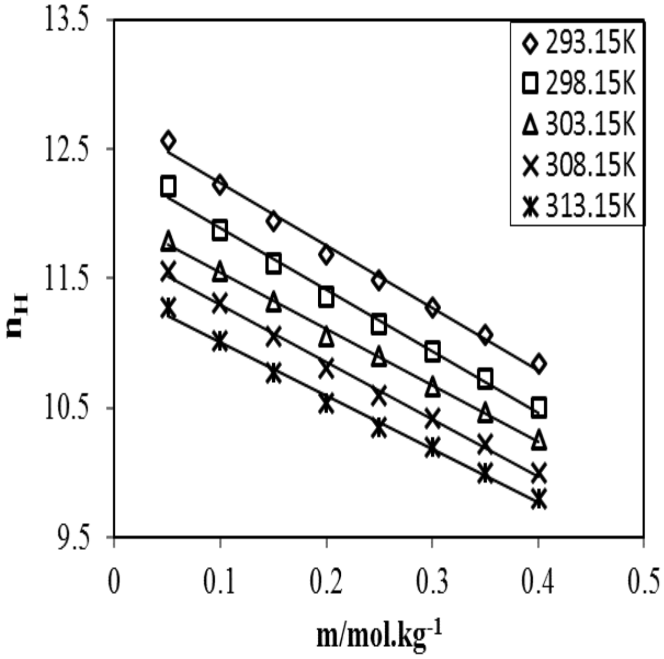


Figure 4.65: Plots of Hydration number (n_H) vs. Molality (m) of sucrose in aqueous 0.35 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

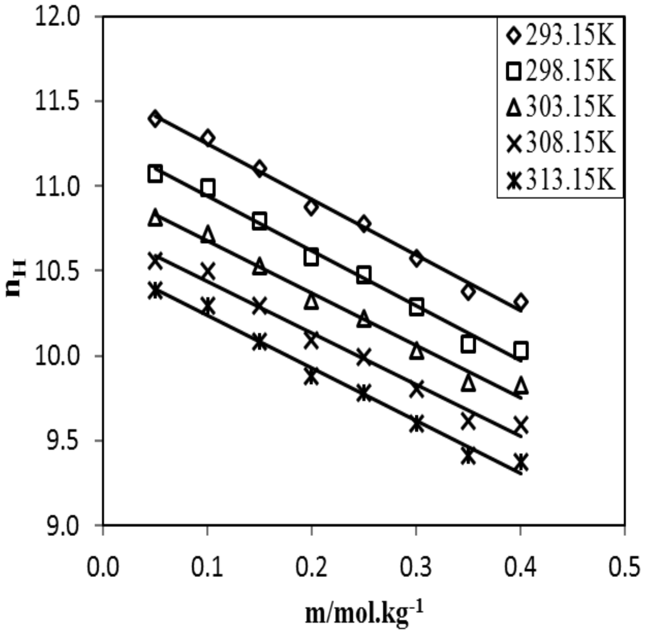


Figure 4.66: Plots of Hydration number (n_H) vs. Molality (m) of sucrose in aqueous 0.50 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

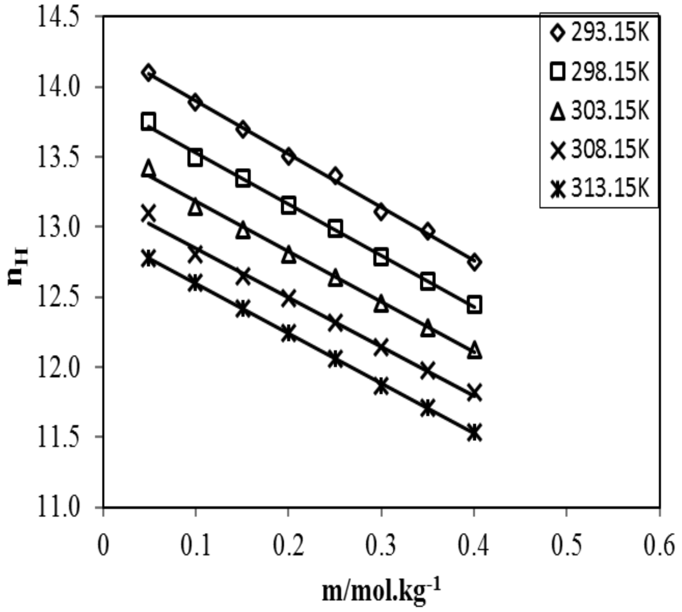


Figure 4.67: Plots of Hydration number (n_H) vs. Molality (m) of maltose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

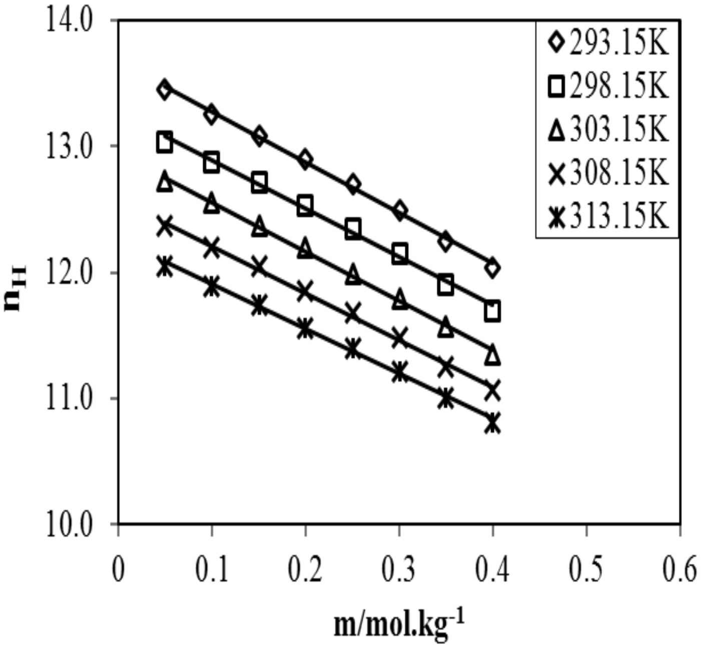


Figure 4.68: Plots of Hydration number (n_H) vs. Molality (m) of maltose in aqueous 0.20 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

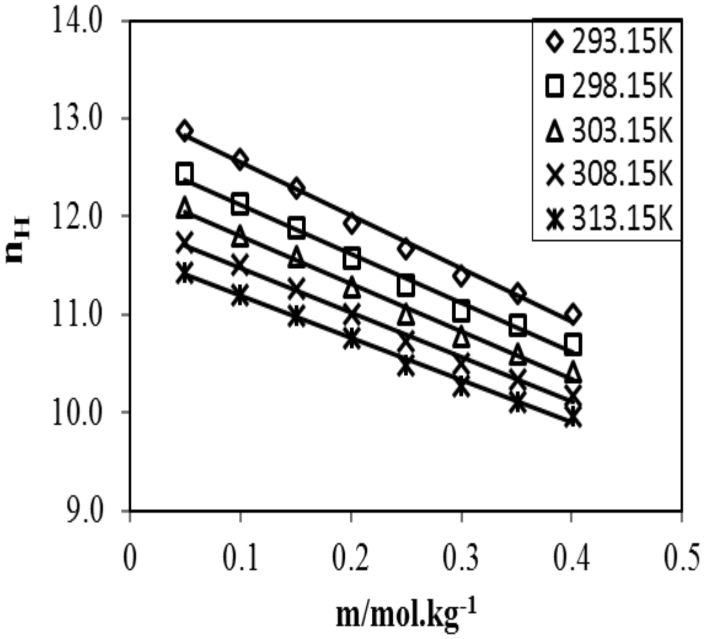


Figure 4.69: Plots of Hydration number (n_H) vs. Molality (m) of maltose in aqueous 0.35 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

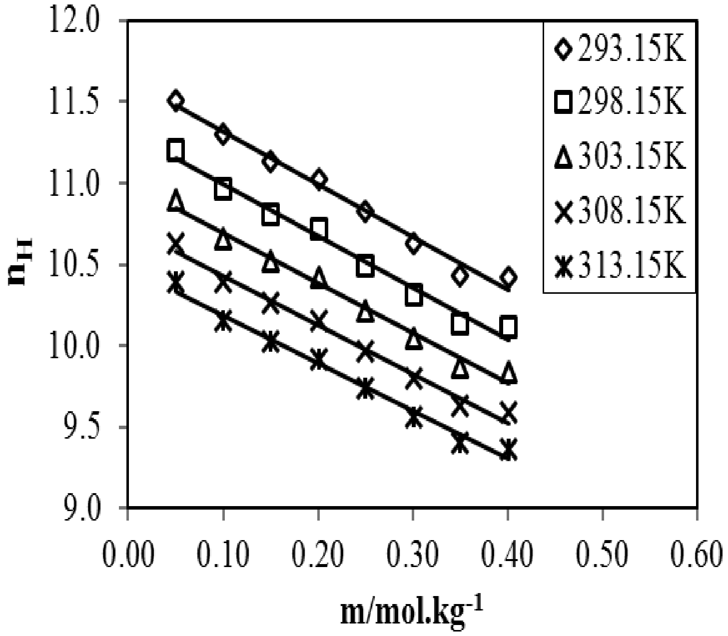


Figure 4.70: Plots of Hydration number (n_H) vs. Molality (m) of maltose in aqueous 0.50 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

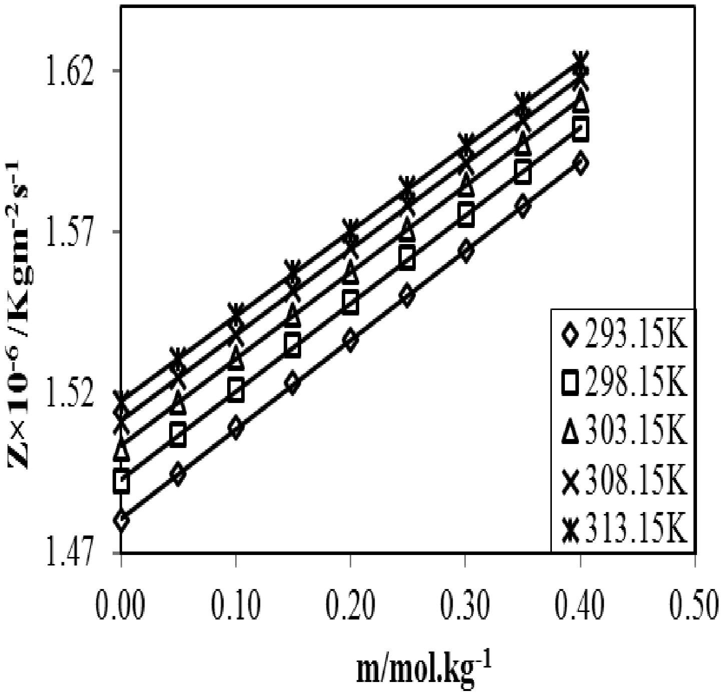


Figure 4.71**:** Plots of Acoustic impedance (Z) vs. Molality (m) of sucrose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

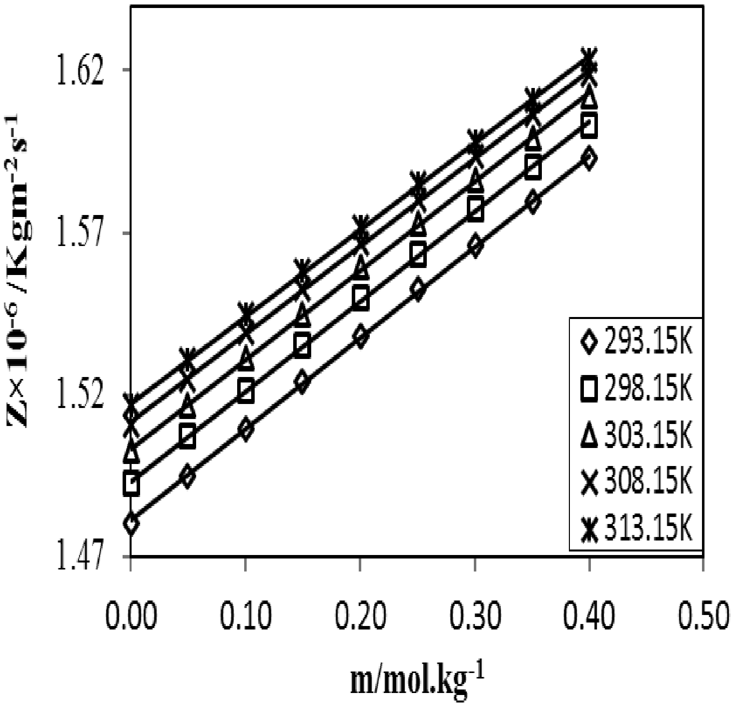


Figure 4.72**:** Plots of Acoustic impedance (Z) vs. Molality (m) of maltose in water system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

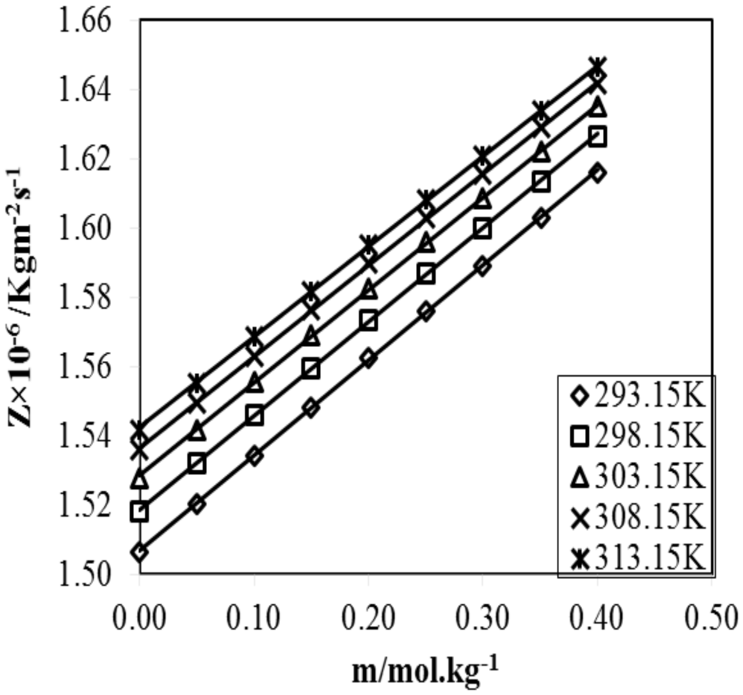


Figure 4.73: Plots of Acoustic impedance (Z) vs. Molality (m) of sucrose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

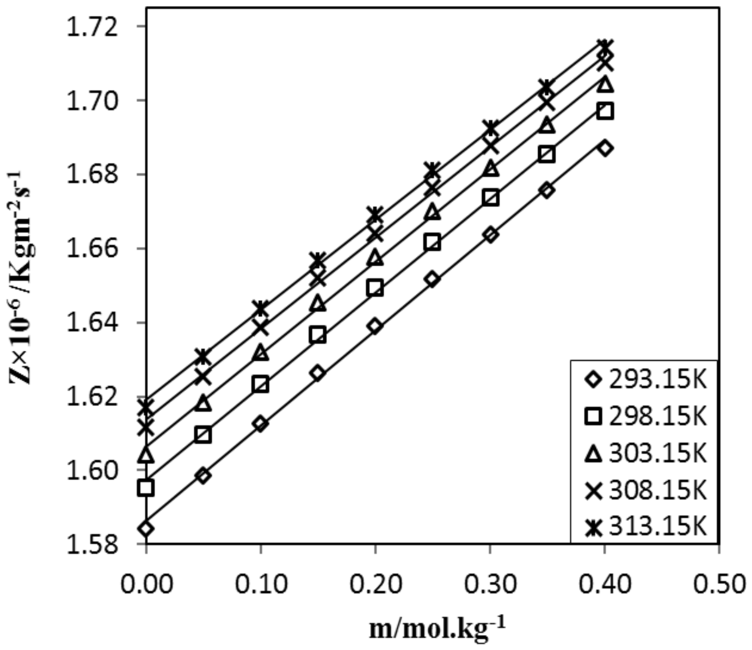


Figure 4.74: Plots of Acoustic impedance (Z) vs. Molality (m) of sucrose in aqueous 0.20 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

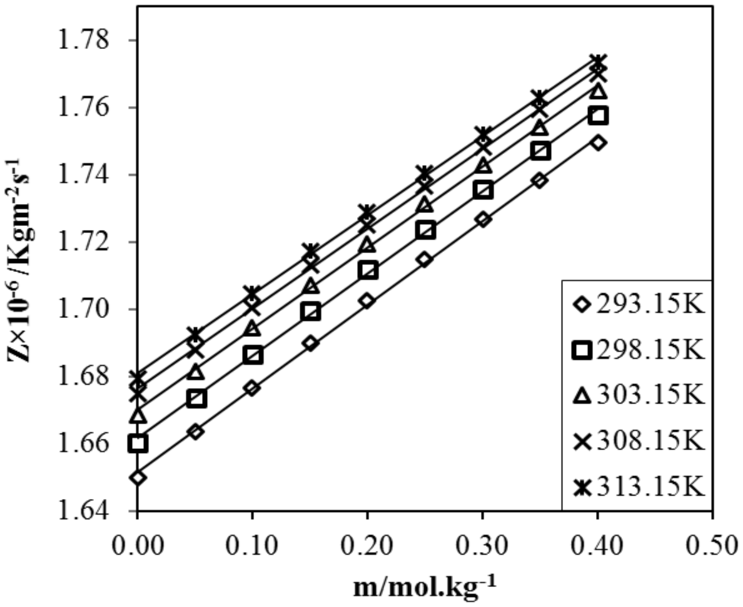


Figure 4.75: Plots of Acoustic impedance (Z) vs. Molality (m) of sucrose in aqueous 0.35 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

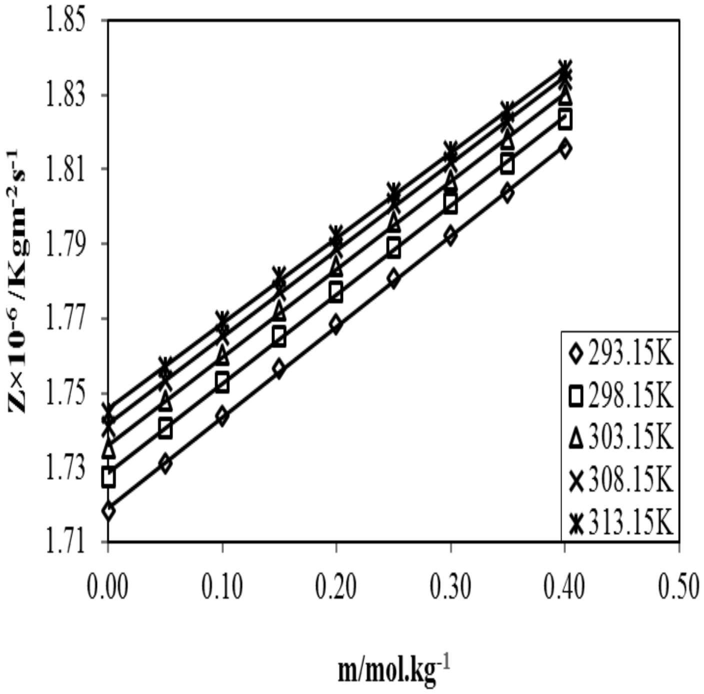


Figure 4.76: Plots of Acoustic impedance (Z) vs. Molality (m) of sucrose in aqueous 0.50 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

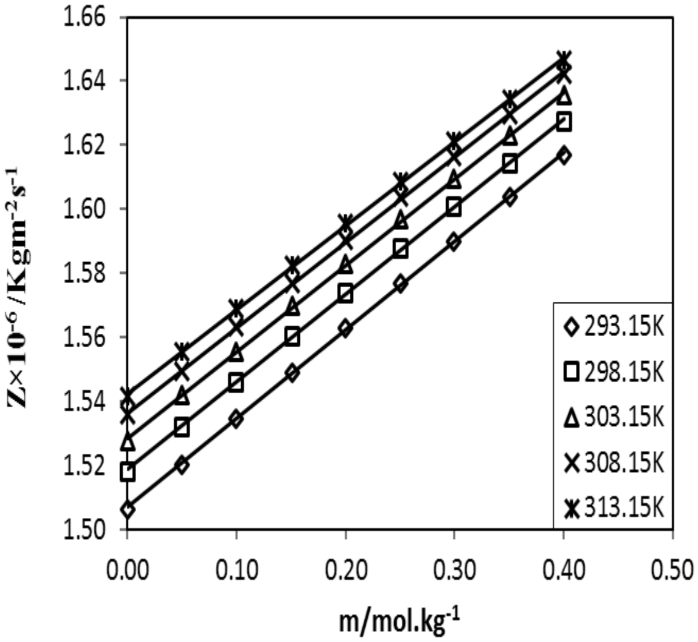


Figure 4.77: Plots of Acoustic impedance (Z) vs. Molality (m) of maltose in aqueous 0.05 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

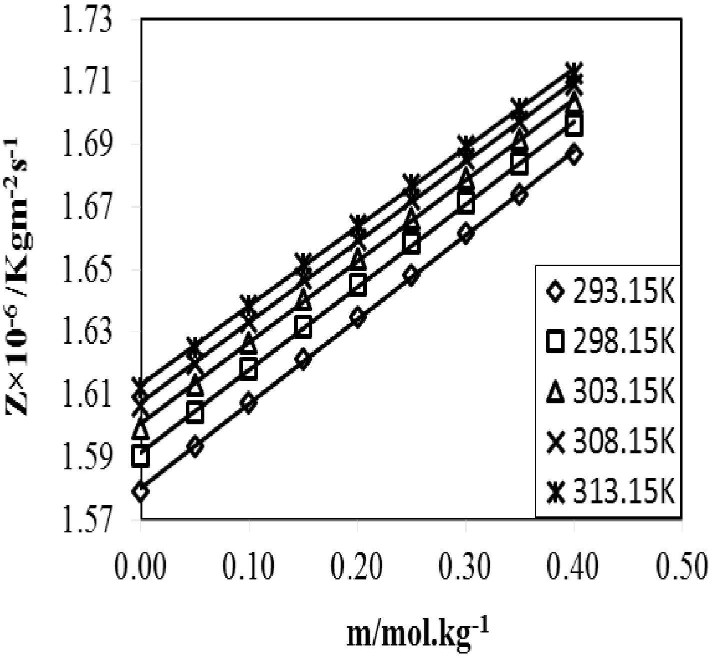


Figure 4.78: Plots of Acoustic impedance (Z) vs. Molality (m) of maltose in aqueous 0.20 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

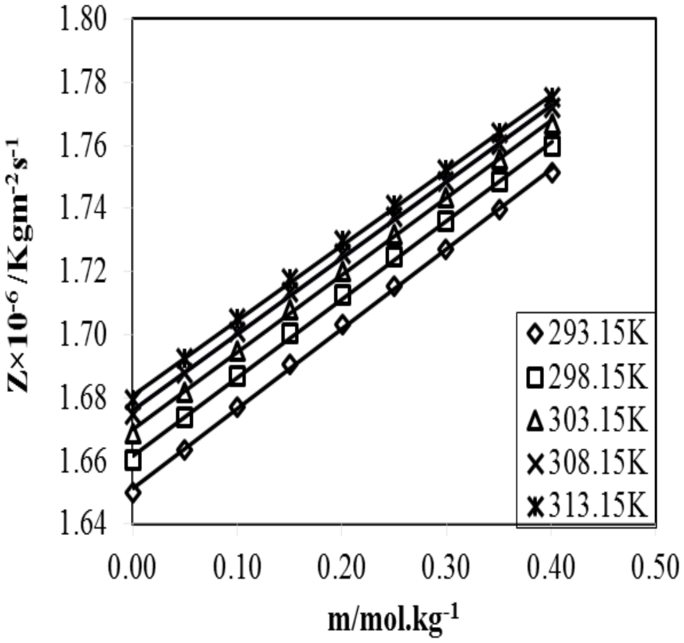


Figure 4.79: Plots of Acoustic impedance (Z) vs. Molality (m) of maltose in aqueous 0.35 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

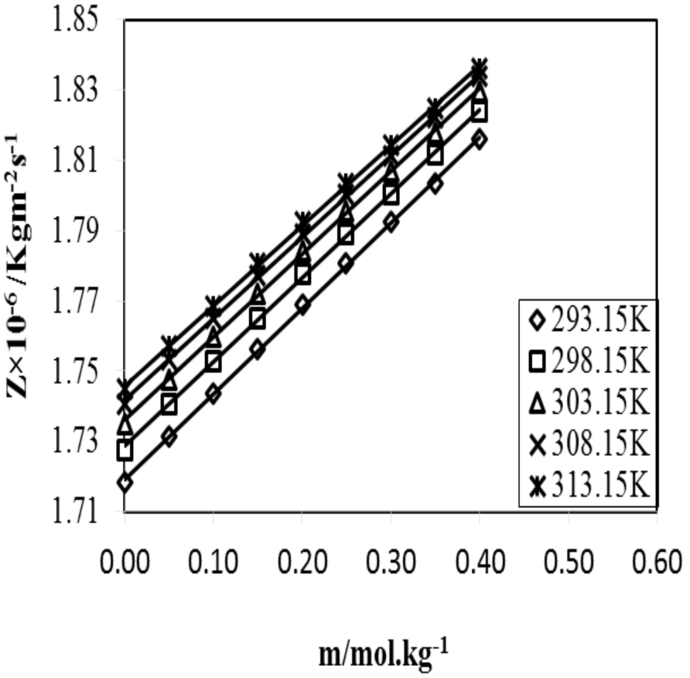


Figure 4.80: Plots of Acoustic impedance (Z) vs. Molality (m) of maltose in aqueous 0.50 mol.kg^{-1}tri-Potassium citrate system at 293.15K, 298.15K, 303.15K, 308.15K and 313.15K respectively.

CHAPTER V

Conclusion

Densities and sound velocities of sucrose and maltose in water and in aqueous TPC solutions are measured in the temperature range 293.15K to 313.15K with an interval of 5K. The densities increase with the increasing of concentration of disaccharides and decrease with increasing of temperature. Sound velocity also increases with increasing of concentration of disaccharides as well as temperature.

The apparent molar volumes (φ_v) of sucrose and maltose in water and in aqueous TPC solution are found to be positive and increase with increasing of concentration of sucrose and maltose. The values of apparent molar volume transfer ($\Delta_{tr}\varphi_v^0$) are found to be positive for sucrose and maltose. This suggest that the dominance of ion-hydrophilic and hydrophilic-hydrophilic interaction over the hydrophobic-hydrophobic interaction. The values of limiting apparent molar volume expansibilities (E_φ^0) are positive. The Hepler's constant ($\delta^2\varphi_v^0/\delta T^2$) values are positive or small negative suggest the structure making property of disaccharides in water and in aqueous TPC solution.

The value of adiabatic compressibility (β_s) decreases with the increases of temperature and concentration. The decrease in the β_s values with increasing concentration of sucrose and maltose indicates that the water molecules around the disaccharides are less compressible than the water molecule in the bulk solution. The values of apparent molar adiabatic compressibility (φ_k) are found to be negative mainly and the values of φ_k increase with increasing of concentration and temperature of sucrose and maltose. The values of φ_k is large negative at low concentration and low temperature indicate strong interactions among solute and solvent molecules, but at higher concentration positive φ_k values appeared due to dehydration of disaccharides.

The values of apparent molar adiabatic compressibility transfer ($\Delta_{tr}\varphi_k^0$) are found to be positive. The hydration number decrease with the increase of concentrations of disaccharides and TPC suggests that the strength of interaction gets weakened between the solute and water molecules. The increase of acoustic impedance, Z with the increase of concentration of disaccharides.

From the above experimental results we can conclude:

- The densities and apparent molar volume of sucrose and maltose in aqueous TPC solution are higher than only aqueous solution.
- The sound velocities and apparent molar adiabatic compressibility of sucrose and maltose in aqueous TPC solution are higher than only aqueous solution.
- Limiting apparent molar volume (φ_v^0) and limiting apparent molar adiabatic compressibility (φ_k^0) of maltose is higher than sucrose in aqueous and in aqueous TPC solution. This is due to the increase of number of carbon in cyclic ring present in maltose and sucrose.
- The smaller values of experimental slope (S_v) as compared to limiting apparent molar volume (φ_v^0) suggest the dominance of solute-solvent interaction over solute-solute interaction.
- Strong interactions are happened in sucrose and maltose with aqueous TPC solution.
- Hydrophilic-hydrophilic and ion-hydrophilic interaction are dominating over hydrophobic-hydrophobic interaction.
- The water molecules around disaccharides are less compressible than water molecules in the bulk solution.
- Hydration capacity of maltose is higher than sucrose in aqueous and in aqueous TPC solution.

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