Chapter 1: Introduction

1.1.1 Solvent and its Characteristics:

Recently, research on solvents and solutions has become a topic of interest because many of the solvents commonly used in laboratories and in the chemical industry are considered as unsafe for reasons of environmental protection. On the list of damaging chemicals, solvents rank highly because they are often used in huge amounts and because they are volatile liquids that are difficult to contain. Therefore, the introduction of cleaner technologies has become a major concern throughout both academia and industry. This includes the development of environmentally benign new solvents, sometimes called neoteric solvents (neoteric = recent, new, modern), constituting a class of novel solvents with desirable, less hazardous, new properties. The term neoteric solvents covers supercritical fluids, ionic liquids, and also perfluorohydrocarbons (as used in fluororous biphasic systems).

For the development of a sustainable chemistry based on clean technologies, the best solvent would be no solvent at all. For this reason, considerable efforts have recently been made to design reactions that proceed under solvent-free conditions, using modern techniques such as reactions on solid mineral supports (alumina, silica, clays), solid-state reactions without any solvent, support, or catalyst between neat reactants, solid-liquid phase-transfer catalysed and microwave-activated reactions, as well as gas-phase reactions. However, not all organic reactions can be carried out in the absence of a solvent; some organic reactions even proceed explosively in the solid state. Therefore, solvents will still be useful in mediating and moderating chemical reactions.

A solvent should not be considered a macroscopic continuum characterized only by physical constants such as density, dielectric constant, index of refraction etc. but as a discontinuum which consists of individual, mutually interacting solvent molecules. According to the extent of these interactions, there are solvents with a pronounced internal structure (e.g. water) and others in which the interaction
between the solvent molecules is small (e.g. hydrocarbons). The interactions between species in solvents (and in solutions) are at once too strong to be treated by the laws of the kinetic theory of gases, yet too weak to be treated by the laws of solid-state physics. Thus, the solvent is neither an indifferent medium in which the dissolved material diffuses in order to distribute itself evenly and randomly, nor does it possess an ordered structure resembling a crystal lattice. Nevertheless, the long-distance ordering in a crystal corresponds somewhat to the local ordering in a liquid. Thus, neither of the two possible models – the gas and crystal models – can be applied to solutions without limitation. There is such a wide gulf between the two models in terms of conceivable and experimentally established variants, that it is too difficult to develop a generally valid model for liquids. Due to the complexity of the interactions, the structure of liquids – in contrast to that of gases and solids – is the least-known of all aggregation states. Therefore, the experimental and theoretical examination of the structure of liquids is among the most difficult tasks of physical chemistry.

1.1.2 Solvent Mixtures:

Much of chemistry is carried out in solution, hence solvents are necessary and widely employed requisite in chemical processes, both in industry and in the laboratory. A solvent is a substance that is a liquid at the temperature of application, which other substances can be dissolved in or mixed with to yield a homogeneous isotropic liquid. Water is the most widely used solvent because of its availability, low cost, non-toxicity and safety as well as its ability to dissolve a great variety of substances including electrolytes and polar organic substances. Certain substances are more soluble in polar organic solvents, which also have other properties that make them useful and desirable solvents. In many of these applications the solvents are employed in substantially pure form, as so called neat solvents, and many have various impurities removed before use.

For certain applications, however, neat solvents fall short of the mark as far as their dissolving power or other properties are concerned. It is then expedient to use solvent mixtures, which may range from binary mixtures involving two
solvents to ternary (three solvents) or even higher multi-component mixtures. Some of the admixed substances may not be liquids at the temperature of application, hence mixtures involving them are not properly called solvent mixtures. Then again, the presence of a small amount of one liquid substance in a large excess of another at mole ratios or fraction of say, 1:100, may have far reaching effects on the properties of the major component. Such dilute solutions are proper subjects for study and lead to important insight concerning their behavior, but are not ordinary called “Solvent Mixtures”.

Mixed solvents are often used in chemistry to modify molecular environment in order to modulate processors such as chromatographic separation, organic synthesis, reaction kinetics & protein folding. Physical properties of binary mixtures are often studied to get information about the mutual interaction between the solvent molecules.

The solvent mixtures are used in chemical industries and in laboratory due to enhancement of the solubility of substances that have too low solubility in neat solvent i.e. for their solubilization. The components of the solvent may interact with the different parts of the intended solute and thus have a synergistic effect on the solubility. This aspect is of wide use in the pharmaceutical industry. In other cases the components may confer on the mixture physical properties that enhance solubility, apart from specific solvation of parts of the solute. For example, higher relative permittivity can be useful if ionic dissociation can increase the solubility. In still other cases the mixed solvent may have improved physical properties compared with its neat components e.g. with respect to density, viscosity, vapor pressure and the freezing or the boiling temperature.

Solvation of solute in a mixed binary system is another phenomenon, which depends on the mutual interaction of solvents. It has been observed that the maximum energy of charge transfer (CT) transition in various solutes act as a reporter of solvation interaction reflecting solute-solvent and solvent-solvent interactions at the microscopic level.
With the process so defined, the thermodynamics of the solvation process pertain entirely to:

i) The interactions of solute particles with its environment in the liquid phase (because in the ideal gas phase it is devoid of interactions).

ii) Changes in its internal degrees of freedom induced by these interactions.

iii) The effects of the solute particle on its environment due to its presence and interactions.

The properties of the solvated solute may be quite different from those of the pure, non-solvated solute as encountered in the ideal gas phase. As a thought process, the solvation of atoms or molecules in a solvent or solvent mixture may be considered as proceeding in several virtual steps.

i) A cavity of appropriate size and shape is created in the solvent to accommodate solute particle.

ii) The solute particle is inserted into the cavity without interacting with its surroundings. The configuration of the solute molecule relaxes to its equilibrium state in the solution.

iii) The solute particle interacts with its environment by dispersion and dipole induced dipole or dipole-dipole (quadrupole, etc.) interactions.

iv) The molecules of solvent or solvent mixture adjust themselves to the presence of solute in their midst.

In aqueous mixtures the solvents that are completely miscible with water may called its co-solvents. The properties of liquid mixtures are very important as some of the polymers which are insoluble in pure solvents can be dissolved in a solvent mixture. Therefore in addition to the studies of polymer solutions in a single solvent considerable attention has recently been paid to the study of polymer solutions in mixed solvents.

A number of theories have been developed for binary mixtures. These theories are based on either the radial distribution function or on the choice of some suitable physical model. Theories of perturbation type have been extended to
the case of mixtures from the problems of pure liquids where it showed its successful application. Lennard Jones and Devonshire\textsuperscript{10} attempted first to evaluate the thermodynamic functions for a single component fluid in terms of intermolecular energy parameter. They used “free volume” or “cell” model.

I.Prigogine & S.Garikian\textsuperscript{11} extended the above model to the liquid mixture. Random mixing of components was their main assumption that can be used if the molecules have similar sizes. I.Prigogine and A. Bellemi\textsuperscript{12} developed a two fluid versions of the cell model. They got the result that while \( V^E \) was negative for mixtures of molecules of same size but they found large +ve \( V^E \) for solutions with molecules having small difference in their molecular size. D.Cook and Languet-Higgins\textsuperscript{13} gave a new approach with his theory of conformal solutions, which is based on the principle of corresponding states as developed by Pitzer. He used a simple perturbation approach to show that the properties of mixtures could be obtained from the knowledge of intermolecular forces and the thermodynamic properties of the pure components.

A more successful approach is due to Flory, who also made use of certain features of cell theory and assumes an empirical equation for the dependence of energy on volume. Flory & co-workers\textsuperscript{14} have developed a statistical mechanical theory for predicting the excess functions of binary mixtures from the equation of state, properties of pure liquids alongwith adjustable parameters. This theory was developed originally for non-polar liquids only, however, use of adjustable parameters makes it applicable to components whose molecules interact in a specific manner. This is the only theory that can be applied to mixtures of realistic interest in which the component molecules may differ considerably in size & shape.

D.Patterson & G.Delamas\textsuperscript{15} combined both Prigogine & Flory theories and presented a general, unified theory from which one is able to identify various contributions such as free volume, interaction, internal pressure, etc. in the excess thermodynamic quantities. Recently, A.J.Trezczanowicz and G.C.Benzon\textsuperscript{16}, Heintz & co-workers\textsuperscript{17,18}, described the thermodynamic properties of associated mixtures
using, association. The thermodynamic properties were expressed as the sum of chemical term described by an associated model and a physical contribution given by Flory equation of state theory. This model is known as extended real associated solution (ERAS) model.

1.1.3. Ion-Solvent and Ion-Ion Interactions:

It is well known that the thermo-physical properties of liquid systems such as density, viscosity, dielectric constant, refractive index among others, are strictly related to the molecular interactions present in different binary liquid mixtures. The variation of these properties with composition gives us important data about intermolecular interactions and the structure. There is a wide range of possible interactions between the components of a mixture, such as hydrogen bonding, molecular associations, charge transfer, dipole-dipole and dipole-induced dipole interactions. As a consequence of these interactions, deviations occur from ideal behavior of dielectric constant and viscosity. These deviations can be defined by excess dielectric constants and viscosities.

The interaction between liquid-liquid & liquid-solid systems are very important, because it help to understand the interactive forces working among them. Recently\textsuperscript{19} various workers studied the drug released mechanism in mixed solvent system. It is observed that a solid is soluble in one solvent and insoluble in another. But it is fairly soluble or extremely soluble in mixed solvent system. Such behavior\textsuperscript{20} of organic compounds varies from compound to compound and it has to be studied in detail. These studies will also help us to understand the nature of ion-solvent forces which overcome the ion-ion forces holding together the crystals. If the compound is solid or ionic crystal, a solvent reduces the force which hold the ions together. A stage is reached when the cohesive forces are so weakened that the ions, which could only vibrate in solid state, acquire a new degree of freedom, i.e. the freedom of translation motion\textsuperscript{21,22}.

There are various models suggested for the interactions of ions in single solvent system. The Born\textsuperscript{19} model suggest a simple process for calculating the free
energy, $\Delta G$, of ion-solvent interactions. According to this model ion is a charge sphere (of radius $r_i$) bearing a charge $z_i e_o$ & solvent is a continuum & the free energy of ion-solvent interactions is equal to the work of transferring a charge sphere from vacuum into a continuum of dielectric constant, $\epsilon$

$$\Delta G = - \frac{N_A (z_i e_o)^2}{2r_i} \left( 1 - \frac{1}{\epsilon_s} \right) \text{ per mole of ions } , \quad (1.01)$$

Where, $N_A$ is Avogadro's number,

$Z_i e_o$ is the charge present,

$r_i$ is radius of sphere

$\epsilon$ is dielectric constant.

From the free energy expression, the enthalpy change and entropy change can be calculated as,

$$\Delta s_{1-s} = \left( \frac{\delta \Delta G_{1-s}}{\delta T} \right)_P = N_A \left( \frac{z_i e_o}{2r_i} \right)^2 \frac{1}{\epsilon_s^2} \frac{\delta \epsilon_s}{\delta T} \quad \cdots$$

$$\Delta H = - \frac{N_A z_i^2 e_o^2}{2r_i} \left[ 1 - \frac{1}{\epsilon_s} - \frac{T}{\epsilon_s^2} \frac{\delta \epsilon_s}{\delta T} \right] \quad \cdots \quad (1.03)$$

When an ion is present in a polar solvent like water, the structure of water near ion is divided into three regions. In the primary or structure-enhanced region next to the ion, the water molecules are immobilized and oriented by the ionic field, they move as and where the ion moves. Then, there is a secondary or structure-broken region, in which the normal bulk structure of water is broken down to varying degrees. The in-between water molecules, however, do not partake of the translational motion of the ion. Finally, at sufficient distance from the ion, the water structure is unaffected by the ion & displays the tetrahedrally bonded network characteristic of bulk water.

The second model assumes that there is an interaction between ion and dipole of solvent. The solvent molecules interact in such a way that there is minimum interaction energy involved. The enthalpy in such situation is given by
\[ \Delta H = W - \frac{N_A n z_i e^2}{(r_i + r_s)^2} - \frac{N_A(z_i e^2)^2}{2(r_i + 2r_s)} \left[ 1 - \frac{1}{E_s} - \frac{T}{E_s^2} \frac{\delta E_s}{\delta T} \right] \] ...... (1.04)

This \( \Delta H \) is called heat of solvation.

In this theory, the first contribution was considered to arise from the interaction between the ions and water molecules which are members of the primary solvent sheath. The second contribution is due to the interaction between a primary solvated ion and the surrounding solvent. The change in heat content due to the structure breaking around a primary solvated ion constitute the third contribution.

When a non-electrolyte is added to the solvent system its solubility changes due to primary and secondary solvation. The effect can be given by an equation.

\[ \frac{S_0 - S}{S_0} = \frac{n_c c_i}{55.55} + \frac{N_A c_i}{1000} \left[ \frac{4\pi(z_i e^2)^2(\alpha_{\infty} - \alpha_{\infty})}{E_s^2 kT \tau_h} \right] \] ...... (1.05)

There are various examples which affect the solubility of non-electrolytes in presence of ions such as salting out of soap and manufacturing of dyes, detergents, emulsion, polymerization and the concentration of antibiotics and vitamins from aqueous solution, all depend in some parts of their manufacture upon salting in.

Ion-solvent interactions are only part of the story relating ions to its environment. When an ion looks out upon its surroundings, it sees not only solvent dipoles but also other ions. The mutual interactions between these ions constitute an essential part of the picture of an electrolytic solution. The ion-ion interactions are important, because they affect the equilibrium properties of ionic solutions and also because they interfere with the drift of ions, for instance, under an externally applied electric field.

The degree to which these interactions affect the properties of solutions will depend on the mean distance apart of the ions, i.e. on how densely the solution is populated with ions, because the inter ionic fields are distance dependent. This ionic density will in turn depend on the nature of electrolyte, i.e. on the extent to which the electrolyte gives rise to ions in solution. Solutions of most potential electrolytes in water generally contain only small concentration of ions and
therefore, ion-ion interactions in these solutions are negligible; the ions are on the average too far apart. The behavior of such solutions is governed predominantly by the position of the equilibrium in the proton-transfer reaction between the potential electrolyte and water. In contrast, true electrolytes are completely dissociated into ions when the parent salts are dissolved in water. The resulting solutions generally consists only of solvated ions and solvent molecules. The dependence of many of their properties on concentration is determined by interactions between ions and to understand these properties, one must understand ion-ion interaction.

The exact molecular theory of liquids and liquid mixtures still possess problems which make it difficult to apply. These difficulties are accentuated in the assemblies in which interactions are mainly long range forces, e.g. by coulombic forces. The starting point for all conjectures in this field is the relation.

\[
\frac{\partial f_h}{\partial t} + \sum_{i=1}^{n} \frac{\partial f_h}{\partial \mathbf{r}_i} \cdot \mathbf{v}^{(i)} + \sum_{i=1}^{n} \frac{\partial}{\partial \mathbf{v}^{(i)}} (f_h \mathbf{v}^{(i)}) = 0
\]

\[\tag{1.06}
\tilde{n}^{(i)} = \frac{1}{f_h} \int \mathbf{v}^{(i)} \cdot \int \mathbf{g}_h [\mathbf{r}_j^{(i)} \mathbf{n}^{(i)} \mathbf{n}^{(i)}] \, d\tilde{n}^{(i)}
\]

With

\[\tag{1.07}
\]

Where,

- \(f_h\) is the order distribution function determining both velocity & position.
- \(t\) is the time variable,
- \(\mathbf{r}_i\) is the position vector describing the \(i^{th}\) particle,
- \(\mathbf{v}^{(i)}\) is the velocity vector,
- \(\mathbf{g}_h\) is the rate of acceleration vector of its particle.

Equation (1.07) is exact, i.e. its deviation does not involve any serious physical approximations.

The assumption that the intermolecular potential energy may be written in terms of the sum of individual pair potentials \(\Phi\) (rs) i.e. as

\[
\Phi = \frac{1}{2} \sum_{r,s=1}^{N} \Phi(rs)
\]

\[\tag{1.08}
\]
Reduces equation (1.07) to
\[
\frac{\partial \eta_h}{\partial t} + \sum_{i=1}^{h} \frac{\partial \eta_h}{\partial z(i)} \frac{d}{dt} z(i) = \frac{1}{m} \sum_{i,j=1}^{h} \frac{\partial \eta_h}{\partial z(i)} \frac{\partial \phi(i,j)}{\partial z(j)} + \frac{1}{m} \sum_{i=1}^{N} \frac{\partial \phi(i,h+1)}{\partial z(i)} \frac{\partial \eta_h}{\partial z(i)} \frac{d}{dt} z(h+1)
\]
\[
\ldots (1.09)
\]

Eqn. (1.09) is regarded as the BBGKY equation after the names of Bogoliubov\textsuperscript{22}, Born and Green\textsuperscript{24}, Yvon\textsuperscript{25} & Kirkwood\textsuperscript{26}.

Born & Green\textsuperscript{24} have shown that under rather restrictive conditions this equation for \( h=2 \) may be reduced to Boltzman integrodifferential equation from which the theories of transport phenomena of dilute gas start.
\[
\frac{\partial \eta_h}{\partial r(i)} + \sum_{j} \frac{n_j}{K T} \frac{\partial \phi(i,j)}{\partial r(i)} + \int \frac{n_{h+1}}{K T} \frac{\partial \phi(i,h+1)}{\partial r(i)} \frac{d}{dr} r(h+1)
\]
\[
\ldots \ldots (1.10)
\]

Where, \( \eta_h \) is the \( h \)th order position distribution function.

Eqn.(1.10) is called the BGYK equilibrium equation For \( h=2 \), the new famous approximation known as the superposition approximation.
\[
\eta_3 (r_1, r_2, r_3, r_4, \ldots) = \eta_2 (r_1, r_2) \eta_2 (r_3, r_4) \ldots \ldots (1.11)
\]
reduces the equation (1.10) after some manipulation to the Born Green equation.
\[
\ln \frac{n_2(r)}{n^2} + \frac{\phi(r)}{K T} = \frac{3 \pi}{n} \int_0^{\infty} \left( \frac{t+s^2-t^2}{r} \right) \left\{ n_2(t+r) - n^2 \right\} dt n_2(s) \phi(s) dr
\]
\[
\ldots \ldots (1.12)
\]
Relation equivalent to the above were also proposed by Kirkwood & Yvon.

The relevant expression for the different thermodynamics properties of liquids are\textsuperscript{27}
\[
E = \text{internal energy} = \frac{3}{2} N K T + 2 \Pi \nu \int_0^{\infty} n_2(r) \phi(r) r^2 dr
\]
\[
\ldots \ldots (1.13)
\]
Where,
\[
P = \text{pressure} = \frac{N K T}{\nu} \int_0^{\infty} n_2(r) \phi(r) r^3 dr
\]
\[
\ldots \ldots (1.14)
\]
\[
\mu = \text{viscosity} = \frac{2 \pi}{15} \left( \frac{m}{k T} \right)^{\frac{1}{2}} \int_0^{\infty} n_2(r) \phi'(r) r^2 dr
\]
\[
\ldots \ldots (1.15)
\]
\[
v = \text{surface tension} = \frac{\pi}{8} \int_0^{\infty} n_2 (r) \phi(r) r^4 dr
\]
\[
\ldots \ldots (1.16)
\]
\[ \frac{N}{V} = \text{number density} = n \]

\[ m = \text{atomic mass} \]

\[ k = \text{Boltzmann constant} \]

\[ T = \text{temp. in } ^{0}\text{K} \]

One of the most important molecular assembly is the aqueous solution of an electrolyte. Here the intermolecular interactions are mainly coulombic. Debye & Huckel studied this aspect. It correctly predicts the behavior in the limiting case of infinite dilutions. The usual theories of dense gases and fluids are supposed to be inadequate to tackle the coulombic interactions. However, in the hands of Mayer & his associates, the cluster integral formalism for ionic assemblies has reached its culmination and this formalism also pre-supposes assumption (1.08).

The answer to the problem, therefore, must exist elsewhere, one may naturally assume that the solvent-ion interactions are the main controlling factors.

Instead of the assumption (1.08), if we write,

\[ \overline{\Phi} = \sum_{i \neq j} \phi_{ij} \]

\[ \overline{\Phi} = \sum_{i \neq j} \phi_{ij} \] \hspace{1cm} (1.17)

Where, \( \overline{\Phi} \) is the potential energy averaged for all molecules, except for a given pair. Needless to say that \( \phi_{ij} \) is temperature dependent although \( \Phi \) is not. This equation is exact. With this relation BGYK equation can still be derived. The only change is that \( \Phi \) has to be replaced by the average. The BGYK equation also survives, subject to this change.

In summary, the observation is that the equation (1.17) must replace the approximate relation (1.08), may provide the key towards the solution of the problems of long range interactions, because, the deviations from equation (1.08) may then be actually computed by successive integration.

1.1.4. Structure Of Solvent:

Water is a unique solvent in many senses. One of the most remarkable properties of water is the strong and steric solvent structure formed by the hydrogen bonding network. In particular, the solvent structure play a very
important role in the hydrophobic case. If the solute molecule is strongly hydrophobic, the water network around the hydrophobic solute tends to be stronger than of the bulk phase. It is called the hydrophobic hydration. In 1938, Butler et al. found that the dissolution entropy changes of non-polar solutes are negative and heat capacity changes are very large. In 1945, Frank & Evans interpreted this observation by the iceberg hydration model, which is the basic model of the hydrophobic hydration. In 1959, Kauzmann proposed the concept of hydrophobic interaction, and since ~1970, Ben-Naim has developed the concept of hydrophobic hydration. After that many observations and calculations of hydrophobic hydration have been reported. The solvent structure of water has been elucidated by x-ray diffraction, neutron diffraction and several calculations. The hydrogen bond of water molecule can extend to four directions, and the solvent structure is tetrahedral like that of diamond.

Pure water is a polymer, \((\text{H}_2\text{O})_n\), and the value of \(n\) is not known presently. Many theories have been proposed by several workers to deal with the structure of water. All these theories have been explained with theoretical models. Many models have been proposed for the structure of liquid water, but none has been completely verified experimentally. One of the models suggest that liquid water consists of ice-like clusters of water molecules in a labile equilibrium with free water molecules. According to continuum model, although a great majority of hydrogen bonds between water molecules in ice at 0°C remain unbroken, but when ice is melted, they distorted or bent at different angles.

The structural features of liquid water depends primarily on its ability to participate in any number of hydrogen bonds by utilizing its two H-atoms and loan pair of electrons on oxygen. In many structures, water achieves its tetra-coordination. One of the structures which shows this behavior is the ordinary form of ice that exists at 0°C and 1 atmosphere pressure. The ice lattice is open one, accounting lower density than the liquid water at the melting point. When ice melts, there still exist a high degree of H-bonding in the resulting liquid.
Frank & Wen\textsuperscript{41} considered the "flickering cluster concept". They described that the formation of H-bonds in liquid water is a co-operative phenomenon i.e. the bonds are not made and broken singly, but several at a time thus producing a short lived clusters of highly hydrogen bonded regions surrounded by non-bonded molecules. This concept assumes that when bond is formed several will form and when one bond breaks, several will break. However, all these models prove themselves untenable for a complete description of the physico-chemical properties of water and an interpretation of its anomalies.

Liquid water consists both of bound ordered regions of a regular lattice, and regions in which the water molecules are hydrogen-bonded in a random array; it is permeated by monomeric water and interspersed with random holes, lattice vacancies, and cages. There are chains and small polymers as well as bound, free and trapped water molecules. The currently accepted view of the structure of liquid water treats it as a dynamic three-dimensional hydrogen-bonded network, without a significant number of non-bonded water molecules, that retains several of the structural characteristics of ice (i.e. tetrahedral molecular packing with each water molecule hydrogen-bonded to four nearest neighbours), although the strict tetrahedrality is lost. The H-O-H bond angle in vapor phase\textsuperscript{42} and in solid\textsuperscript{43} is 104.35\textdegree{} and 109.28\textdegree{}, respectively. High dielectric constant also support the flickering cluster concept\textsuperscript{44}.

In principle, other hydrogen-bonded solvents should possess similar complicated structures. However, whereas water has been thoroughly studied, the inner structures of other solvents are still less well known.

Alcohols are the compounds with polar character. The dipole-dipole type of Van der Waals forces are present. In addition to dipole-dipole forces, alcohols are hydrogen bonded and thus involves strong intermolecular interactions. The physico-chemical properties of aliphatic alcohols like methanol, ethanol, ..., etc. varies with variation in increasing chain length of alkyl group. Alcohols are the most well known solvents used to study the hydrophobic effects. Alcohols are highly applicable in pharmaceutical industries. In view of their simple molecular
structure, increasing hydrophobic character with increasing chain length and high solubility in polar solvents, most of their physical properties have been extensively studied.

Mixtures of water with aliphatic alcohols are of considerable interest from the viewpoint of the existence of some interaction, such as hydrogen bonding between water which contains an -OH group and can act as a donor- and alcohol molecules, which have one acidic H atom on the -OH group and can act as acceptors.

The assumption of forces of interaction between solvent and solute led, on the other hand, to the century-old principle that “like dissolve like”, where the word “like” should not be too narrowly interpreted. In many cases, the presence of similar functional groups in the molecules suffices. When a chemical similarity is present, the solution of the two components will usually have a structure similar to that of the pure materials (e.g. alcohol-water mixtures).

However, rather than the “like dissolves like” rule, it is the intermolecular interaction between solvent and solute molecules that determines the mutual solubility. A compound A dissolves in a solvent B only when the intermolecular forces of attraction $K_{AA}$ and $K_{BB}$ for the pure compounds can be overcome by the forces $K_{AB}$ in solution.

Intermolecular forces are those which can occur between closed-shell molecules. These are also called Van der Waals forces, since van der Waals recognized them as the reason for the non-ideal behavior of real gases. Intermolecular forces are usually classified into two distinct categories. The first category comprises the so-called directional, induction, and dispersion forces, which are non-specific and cannot be completely saturated (just as Coulomb forces between ions cannot). The second group consists of hydrogen-bonding forces, and charge-transfer or electron-pair donor-acceptor forces. The latter group are specific, directional forces, which can be saturated and lead to stoichiometric molecular compounds. For the sake of completeness, in the following the Coulomb forces between ions and electrically neutral molecules (with permanent dipole
moments) will be considered first, even though they do not belong to the intermolecular forces in the narrower sense.

The term solvation refers to the surroundings of each dissolved molecule or ion by a shell of more or less tightly bound solvent molecules. This solvent shell is the result of intermolecular forces between solute and solvent. For aqueous solutions the term used is hydration. Intermolecular interactions between solvent molecules and ions are particularly important in solutions of electrolytes, since ion exert specially strong forces on solvent molecules.

Solute-solvent interactions play an important role in a variety of phenomena. In bio-physical chemistry, drug interaction is a subject of intensive studies, involving complex molecular mechanisms. Despite years of investigations, many important drug actions and their mechanisms are not fully understood. Structure activity relationship is one of the most common rationale presented for explaining drug reactions. In cases such as certain hormones, antibiotic and peptide actions, amphiphilicity in molecular structure is considered to be a key factor in the overall drug mechanism. Knowledge about mechanism of anesthesia is also clouded in mystery despite years of intensive studies. The role of volume property, however, is considered important in connection with this phenomenon. According to the concept of critical volume of anesthesia, nerve conduction is blocked when drug molecules enter the lipid bilayer and causes expansion in the membrane structure to a critical volume level. The disordering of bilayer structure, resulting from volumetric expansion, causes the disfunctioning of the membrane transport property and the blockage of nerve conduction. An important evidence in favour of this concept is given in terms of the observed reversal of anesthesia under applied pressure.

Since volume is an additive property, gross changes in the volume of a system can be assessed by comparing the volume of the system with those of its components. Moreover, volumetric data often lead to interpretations in terms of molecular interactions within the system. Volumetric data of drugs, lipid bilayers, and membrane proteins can provide clues to the interactions occurring in cellular
 fluids. Recent literature on the volumetric properties of drugs and other materials of biological importance shows increasing interest by a number of workers in this area of study \(^ {45}\).

Anomalous physical properties of alcohol-water mixtures at room temperature have been studied extensively over the year \(^ {46,47}\). Different structures and mechanism for formation of those structures in alcohol-water solutions at low to high alcohol concentrations have been proposed \(^ {46,47}\). Several experimental studies indicate that at low alcohol content, water structure is stronger than that in pure water \(^ {48-50}\). At higher alcohol concentration, however, the water structure breaks down and the characteristic chain like structure of pure alcohol predominates \(^ {50}\). At high water content, at infinitely dilute third component (an ion or a neutral solute) competes with the alcohol molecules to be properly ‘surrounded’ by water structure \(^ {48-50}\). This is dictated by the relative interaction strengths between the solute and the solvent molecules of different species. As a result the structure forming and breaking ability of alcohol in water is modified in presence of an ion or a solute \(^ {48-50}\).

Moreover, specific interactions among these components may favour enriching of one component over the other in the first few solvation shells giving rise to what is known as preferential solvation. In such a situation one would like to ask the following question. First, will there be any preferential solvation and thus non-ideality in the absence of any solute-solvent and solvent-solvent specific interactions ? Second, how solvent size disparity would affect the preferential solvation and thus the non-ideality ? Third, what are the effects of solute size on the non-ideality ? Fourth, can one develop a theoretical formalism which will be simple and analytically tractable yet capable of describing the liquid structure in these complex mixtures, at least qualitatively ?

Recently Hemant Kashyap & Ranjit Biswas \(^ {51}\) extended the mean spherical approximation (MSA) framework in order to investigate answer to these questions. They extended MSA formalism to study the solvent size ratio dependence of non-identity in Born-free energy of solvation of an infinitely dilute ion in two different
types of binary mixtures at different mole fraction of the solvent components, mixtures containing associating (H-bonding) solvents, (ethanol & water) and those made-up of non-associating solvents (DMSO & acetonitrile). The D.M. of water is slightly larger than ethanol, but the size is considerably smaller. This assists water molecules to be perfectly chosen in the first solvation shell and hence the non-ideality is likely to be stronger.

Therefore, larger ions would be able to accommodate the larger solvent components leading to a more 'homogeneous' solvation structure. This in turn, will render the non-ideality weaker. It is to be noted here that the preferential solvation in model binary mixtures have been studied earlier\textsuperscript{52,53} & these studies indicated \checkmark that specific interactions among the components are not crucial for giving rise to non-identity\textsuperscript{52}. The ethanol- water mixtures show greater non-ideality than DMSO-acetonitrile mixture by using MSA framework.

1.1.5. Literature Survey:

N.Adeyinka et.al\textsuperscript{54} applied the reduced 3-suffix solubility equation (R3SSE) to the characterization of solubility in the ethanol-water system. The reduced 3-suffix solubility equation (R3SSE) was developed to predict the solubility of non-polar organic compounds in solvent mixtures\textsuperscript{55}. The equation was shown to be adequate for describing the solubility profiles of the compound tested in ethanol-water and other systems\textsuperscript{56,57}. For a binary solvent mixture, the experimental data needed are the solubility of the compound in each of the pure solvents and the solubility in mixture of solvent. The latter is needed to estimate the solute-solvent interaction constant $C_2$.

Since the solvent-solvent interaction parameters depend only on temperature, once obtained for a mixed solvent system, they are fixed. Therefore at a given temperature, the R3SSE may be reduced to one parameter equation with $C_2$ as the only undetermined parameter. For ethanol-water binary solvent system, the R3SSE is
\[ \ln X_{s_{2,m}} = \ln X_{s_{2,3}} + Z_1 \ln \left( \frac{X_{s_{2,1}}}{X_{s_{2,3}}} \right) - A_1 - 3Z_1Z_3(2Z_1-1)\frac{q_2}{q_1} + A_3 Z_1^2 Z_3 \frac{q_2}{q_3} + C_2 Z_1 Z_3 \]  

(1.18)

Where \( X_{s_{2,m}} \) is the solubility of the solute in the mixed solvent, \( X_{s_{2,1}} \) is the solubility in pure solvent 1 (ethanol); \( X_{s_{2,3}} \) is the solubility in pure solvent 3 (water); \( A_{1,3} \) & \( A_{3,1} \) are the constants characteristic of the interaction between solvent 1 and solvent 3 respectively, and \( Z_1 \) & \( Z_3 \) are the volume fractions of solvent 1 & 3 respectively.

For the ethanol-water system at 25\(^\circ\)C

\[ A_{1,3} = 1.216 \quad q_1 = 58.68 \text{ cm}^3/\text{mol} \]
\[ A_{3,1} = 0.9093 \quad q_3 = 18.07 \text{ cm}^3/\text{mol} \]

Noting that \( Z_3 = 1-Z_1 \) and substituting the values given above, equation (1.18) may be rearranged to give

\[ \ln X_{s_{2,m}} = \ln X_{s_{2,3}} + Z_1 \ln \left( \frac{X_{s_{2,1}}}{X_{s_{2,3}}} \right) + \]
\[ \{[10.080-0.059(1-Z_1)]q_2 + C_2(1-Z_1)Z \} \]

(1.19)

Thus for ethanol-water at 25\(^\circ\)C, the solubility is given by equation (1.19).

Much attention has been paid to the volumetric behavior of dilute aqueous alcohol solutions, where unique changes in many thermodynamic properties are observed. Since the alcohol molecule in water can be regarded as a “soluble alkane”, the interesting volumetric behavior has been usually interpreted in terms of the group-water interactions that is so called iceberg effect or hydrophobic hydration. On the other hand, little attention has been paid to the contributions of the hydrophilic group-water interactions to the volumetric properties. The large negative excess volume observed for aqueous monohydric alcohol system is not due to the hydrophobic effects, but mainly to geometrical factors and hydrophilic interactions.

Thermodynamic properties of binary mixtures of alkanols with polar and non-polar solvents have been described by a number of workers in terms of lattice model theories. In the chemical industry, a knowledge of the
thermodynamic properties of non-electrolyte solutions are essential in the design involving chemical separations, heat transfer, mass transfer & fluid flow. The mixtures of binary non-electrolyte liquids have been studied from different perspective in recent years. Equilibrium & thermodynamic properties are studied very widely for a number of mixtures and statistical theories are developed to correlate these properties with intermolecular forces.

Physicochemical investigations of electrolyte solutions were aimed to have a better understanding of ionic interactions in different solvents. The active interest in the solution chemistry of electrolytes at low concentration region resulted into a primitive model of ions, interacting in a structureless dielectric medium, obeying Coulombs law. On the other hand anhydrous molten salts have also been extensively studied with a view to their use as industrial solvents, electro-winning of metals, high energy-density storage batteries, nuclear reactors, disposal of wastes and vulcanology.

Mixed electrolytes are very important in that they are found in numerous processes in chemical industry. They occur in enormous quantities in water of the oceans and have an important role in the physiological process of body fluids and cell equilibria. Various types of interactions exist between the ions in solutions and of these ion-ion & ion-solvent interactions are of current interest in all the branches of chemistry. These interactions help in better understanding of the nature of solute and solvent. i.e. whether the solute modifies or distorts the structure of solvent.

Solute-solvent interaction studies have been a subject of active interest among physical chemists and mostly the inferences regarding these interactions are drawn from conductance, molar volume data & viscosity data together. Studies in mixed solvents are of considerable interest because peculiar results are obtained in most of the solvent systems. The volumetric, viscometric & acoustical properties of binary liquid-mixtures containing alcohols as a function of molecular size, shape and molecular association of alcohols have been reported.
Most of the drugs are organic molecules with both hydrophobic and hydrophilic groups. These molecules often contain certain groups, which are responsible for their acidic, basic or amphoteric properties. Pharmacological properties\textsuperscript{80,83} of drugs are highly dependent on the solution behavior. These drug molecules show specific interactions with lipid molecules due to hydrophobic groups & electrostatic interactions due to hydrophilic groups. The processes of drug transport, protein-binding, anesthesia are but a few examples where drug & biomacromolecules appear to interact in an important & vitally significant manner. The mechanisms of these molecular processes, however, are not clearly understood.

Fundamental properties such as enthalpy, entropy & Gibb’s free energy represent the macroscopic state of the system as an average of numerous microscopic states at a given temperature & pressure. An interpretation of these macroscopic properties in terms of molecular phenomenon is generally difficult. Sometimes, higher derivatives of these properties can be interpreted more effectively in terms of molecular interactions. For example the partial molar volume, the pressure derivatives of partial molar, Gibb’s energy are useful parameters for interpreting solute-solvent interactions. Various concepts regarding molecular processes in solution, hydrophobic hydration\textsuperscript{84}, micellization\textsuperscript{85} & cosphere overlap during solute-solute interactions\textsuperscript{86} to a large extent, have been derived and interpreted from the partial molar volume data.

The physico-chemical properties play important role in interpreting the molecular interactions occurring among mixed components. As a result there has been renewed interest in the study of physico-chemical properties of liquid-liquid systems\textsuperscript{87-89}. One of the important ways to study molecular interactions in fluids is the use of thermodynamic properties. The first systematic attempt made in this direction was by Young\textsuperscript{90}, who collected a large amount of data on the thermodynamic and mechanical properties of liquid mixtures. The thermodynamic properties are the convenient parameter for interpreting solute-solvent interactions in the solution phase, which ultimately explain the excess properties using different
interaction parameters. The excess thermodynamic properties of mixed system corresponds to the difference between the actual property and the property if the system behave ideally. These properties provide important information about the differences in the intermolecular forces operating among mixed components. The theoretical values of the excess functions depend critically on the assumption about the extent of their interactions, weak or strong, and size. The interactions between the molecules can be established from a study of characteristic departure from ideal behaviour of some of the physical properties like density, viscosity, conductance and refractive index\textsuperscript{91}.

The present theories on liquid, a knowledge about molecular size, molecular structure and polarity are found to be inadequate to predict the properties of a mixture from the nature of its constituents. This is due to the non-availability of the data essential for understanding the nature of interactions among the constituents of the system. The physico-chemical properties involving excess thermodynamic functions has their relevance in carrying out engineering applications in the process industry and in the design of industrial separation processes. The current theories and their results expressed in terms of excess thermodynamic functions, can be successfully checked and utilized if the experimental data for the excess functions are available. The data along with relevance information of the excess thermodynamic functions can be used for development of empirical correlation and also for the improvement of theoretical knowledge.

When a solute, polar or non-polar, dissolved in water, it may break water structure or preserve water structure through interactions. The equilibrium between non-bonded water and bonded water is disturbed due to the addition of a solute in water. Thus solutes or additives can be classified as water structure breakers or water structure makers. Frank & Evans\textsuperscript{29} & Ben & Neim\textsuperscript{92,93} have considered that water consists of distinct species of different densities both monomeric & polymeric forms. When a non-polar or partially polar solute is added to water, the added solute drives the equilibrium towards the species of highest density. Thus the free volume is made available for the accommodation of solute. This volume
may be greater or less than that actually required by solute. The physical chemistry of drug molecules is a subject of study of recent origin and a number of researchers are looking for physical properties of several drugs. The first stage in this process is to study thermodynamic properties of drugs in aq. solution. Literature survey reveals that very few drug molecules are studied on this background.

Tarlok. S. Banipal et.al\textsuperscript{94} determined & reported density, viscosity & apparent molar volume of glycine, DL- α alanine in water & in aqueous solutions of each of potassium chloride, barium chloride, glucose & sucrose. Ramkrishna Pramanik & Sanjib Bagchi\textsuperscript{95} have studied the solvation of 2,6-diphenyl-4-(2,4,6-triphenyl)-1-pyridinium phenolate in ethanol + octan-1-ol binary mixture. The results, indicating preferential solvation of the solute by ethanol, have been analysed in terms of a suitable model to get information about solute-solvent and solvent-solvent interaction.

1.1.6. Density and Viscosity:

Volumetric measurement often yield valuable information regarding molecular interactions in the pure liquids as well as liquid mixtures. A familiar approach is the hypothesis that there is a direct correlation between the viscosity and the thermodynamic behavior of the solution. Very often it is essential to know the viscosity of the liquid mixtures to solve some practical problems.

The physical properties of a binary mixture such as viscosity and density are important from practical and theoretical points of view to understand liquid theory. Their properties are extremely useful for the design of many types of transport (heat, mass, etc.) and process equipments in chemical industries and fluid flow. However, there seems to be no reliable theoretical method to estimate these viscosities. In addition, many viscosity – composition curves are not simple functions of composition. Therefore viscosities of most systems can- not be predicted from theory, but must be determined experimentally. From the survey of literature, it indicates that partial molar volume and viscosity data give valuable information regarding solute-solvent and solute-solute interactions. Studies on
viscosity of ionic solutions are of great help in characterizing the structure properties of solutions.

Poiseuille found that some salts increases the viscosity of water whereas other decreases the viscosity. Sprung appears to have been the first to measure viscosities of solution of BaCl₂ and found that it increased the viscosity of water. Arrhenius made some viscosity measurements on solutions and found that the change in viscosity caused by addition of a salt was roughly proportional to the concentration at low concentrations, but increased more rapidly than the concentration at moderate concentrations (1 normal). He proposed a new formula for the relationship between viscosity and concentration. i.e., \( \eta = A \zeta \), where, \( \eta \) is the relative viscosity compared to that of water at the same temperature and \( A \) is a constant for any given salt and temperature.

Applebey studied dilute solutions (c=0.00724). He made the suggestion that when a salt is dissolved in water there are two different effects on viscosity (1) a depolymerization of triple water molecules, \((H₂O)₃\), to form single molecules, which tend to diminish the viscosity, (2) an increase in viscosity due to the presence of the ions at the salt and the un-ionized molecules of the salt. The work of Merton on cesium nitrate appears to be more accurate and extensive study of a salt which diminishes the viscosity of water. Cox & Wolfenden from the study of the pair of electrolytes KCl-NaCl & KNO₃ - NaNO₃, have found that the difference in the values of ‘B’ of such pairs is connected with the difference in the individual character of the sphere of solvation of the cation & anion. It has already been suggested that in a mixed solvent the number of molecules of each species constituting the sphere of solvation depends not only on the character of the ion, but also on the specific properties of both kind of molecules present in the solvent. P.B.Das, studied the viscosities of magnesium bromide, sodium sulphate etc. in 10,20 & 30% dioxane-water mixture at 35°C.

The value of ‘B’ for different electrolytes differs widely Asmus suggested that the value of B could be determined by the lyotropic number and entropy of hydration. Frank & Evans & Latimer have established the existence of a
solvation sphere of varying nature round of ion & hence ‘B’ varies. Asmus lyotropic number of an ion also varies. So ‘B’ is likely to be dependent on the nature of solvation sphere of ion which in mixed solvents is bound to be formed by both the component of solvent system.

From the point of view of the free volume approach, it is not surprising that those systems that show large positive viscosity deviations, tend also to show large negative deviations from volume additivity. If it is true that free volume is necessary for flow, then shrinking on mixing, which would appear to reduce the free volume, should be associated with an increase in viscosity. Correct use of this argument requires data for all the solutions over a range of temperature, which are not available, for which the relative excess volume, defined as percentage was used by:

\[
\nu^e_r = 100 \left( \frac{V \nu_1 x_1 - \nu_2 x_2}{\nu_1 x_1 + \nu_2 x_2} \right) \\
= 100 \left( \frac{(x_2^3 - 1) M_1 / M_2 + 1}{\rho(x_2^3 - 1) M_1 / M_2 \rho_1 + 1/\rho_2 - 1} \right) \quad \text{.................} (1.20)
\]

where, \( V \) is the molar volume, \( \rho \), \( M \) & \( x \) are density, molecular weight and mole fraction respectively and the subscripts 1 & 2 refer to the two components. Values of the (negative) excess volume are approximately proportional to the product of the mole fractions, \( x_1 x_2 \), as suggested by Biron\textsuperscript{102} or to the product of the volume fractions, \( \phi_1 \phi_2 \) as suggested by Hilbrand and Scott\textsuperscript{103}.

Robert A Staris\textsuperscript{104} studied the viscosity of mixtures of water with a number of organic liquids and of some mixtures of two organic liquids and analysed in terms of its deviation from “ideality”, expressed as

\[
\ln \bar{\eta} = \ln \eta - (x_1 \ln \eta_1 + x_2 \ln \eta_2) \quad \text{.................} (1.21)
\]

It is shown to represent approximately the behavior of the mixtures of two organic liquids. It fails with the water-organic mixtures. The viscosity behavior of dilute aqueous solutions of electrolytes has been studied in detail and numerous empirical relations have been reported\textsuperscript{105,106} to explain the variation of viscosity.
with concentration. The relative viscosity, $\eta_r$, i.e. the viscosity of solution with respect to solvent, is generally used in most of the empirical relations. For dilute solutions ($c \leq 0.1$ M), the theoretical relation of Einstein\textsuperscript{107} gives:

$$\eta_r = 1 + 2.5\phi$$

(1.22)

Where $\phi$ denotes the volume fraction and is equal to $cV$, $V$ being the molar volume of electrolyte in solution. On the other hand the Jones-Dole\textsuperscript{108} semi-empirical relation gives:

$$\eta_r = 1 + A\sqrt{c} + Bc$$

(1.23)

in which the constant $A$ is identified as ion-ion interaction and the constant $B$ is identified as viscosity B-coefficient dealing with ion-solvent interactions in solution. These two relations have undergone considerable modifications for concentrated solutions ($c \geq 0.1$M). In many case it has been seen that the Jones-Dole equation is the most appropriate equation for calculating the viscosity of dilute aqueous solutions of electrolytes. This equation is used for concentrated solutions in the following form\textsuperscript{109}.

$$\eta_r = 1 + Bc$$

(1.24)

Unlike the viscosity behavior of dilute solutions, representation of viscosity at concentrations $> 0.1$M by one general equation becomes difficult. Vand\textsuperscript{110}, Thomas\textsuperscript{111} and Moulik\textsuperscript{112} have extended the limiting extension of Einstein to higher concentrations and have advanced some useful relations which have been tested for their general validity in higher concentrations of limited range by Moulik\textsuperscript{113}. Based on the Eyring\textsuperscript{114} theory of absolute rate for viscous flow of liquids, Goldsack and Franchetto\textsuperscript{115} and Behera\textsuperscript{116} successfully explained the variation of viscosity with concentration for aqueous solutions of electrolytes of alkali metal halides and non-electrolytes respectively. B.Sahu and B.Behera\textsuperscript{117}, developed a general equation to explain the concentration dependence of viscosity of concentrated aqueous solutions of electrolytes of the form

$$\eta_r = 1 + 2.5\phi + k_1\phi^2 + k_2\phi^3 + k_3\phi^4$$

(1.25)

Where $k$’s are constant.
The viscosity B-coefficient of Jones-Dole equation is known to be sensitive to the nature of solute-solvent interactions i.e. it is related to the modification of micro-viscosity of the solvent in the neighborhood of the solute particle as compared to the bulk viscosity. A structure-making solute is expected to have a positive B-coefficient in the given solvent where as a structure-breaker may have a less positive or altogether negative B-coefficient. However, a large solute may always possess a positive B-coefficient (irrespective of the nature of its interaction with the solvent) due to the “obstruction effect”, i.e. a bending of the solvent streamlines round a large solute particle. The sign and magnitude of the temperature coefficient, dB/dT, rather than B, therefore often provides a better index of solute-solvent interactions. This observation is attributed to an increased thermal mobility of water molecules at higher temperature which causes the structure promotion by a solute more difficult (i.e. B is rendered less positive), so that dB/dT becomes negative. A structure-breaker on the other hand, exerts a less disruptive influence on the structure of the solvent (which is already broken) at an elevated temperature and hence the corresponding dB/dT is positive. These considerations are obviously independent of the size of the solute particle. S.K. Mandal & S.K. Sanyal determined viscosity B co-efficient of phenol, resorcinol, p-cresol and benzyl alcohol in aqueous medium at 30, 35 and 40° C.

Several theories have been put forward relating the viscosity of pure components to their mixtures. Eyring’s theory, one of the earliest theories of liquid viscosity is due to Eyring & co-workers that may be written as –

$$\eta = (hN/M) \exp \left( \frac{\Delta G^*}{RT} \right)$$

Where \( \eta \) is viscosity, M is the molecular weight, T is the absolute temperature and h, N & R are Plank’s constant, Avogadro’s number and the gas constant respectively. \( \Delta G^* \) represents the free energy of activation for viscous flow. The excess free energy of activation, \( \Delta G^{*E} \) is given by the difference between the free energy of activation of the mixture and the free energy of activation of the ideal mixture. Thus eqn. (1.26) can be written as,
\[ \Delta^*G^E = RT \left( \ln \eta M - x_1 \ln \eta_1 M_1 - x_2 \ln \eta_2 M_2 \right) \] 

(1.27)

Where \( \eta \) & \( M \) are the viscosity of mixture and the average molecular weight of the components in the mixture respectively \( \eta_1, x_1 & M_1 \) represent the viscosity, mole fraction & the molecular weight of the \( i^{th} \) component.

This theory has provided a foundation for numerous correlations. However, the search for satisfactory analytical correlations applicable generally, or at least to groups of chemical binary systems has, not yet produced the answer. Some semiempirical correlations have been developed with limited sources.

On the basis of the absolute reaction rate theory of Eyring, McAllister derived the following cubic relation for the kinematic viscosity of a liquid mixture.

\[ \ln \eta = x_1^3 \ln \eta_1 + 3x_1^2 x_2 \ln \eta_{12} + 3x_1 x_2^2 \ln \eta_{21} + x_2^3 \ln \eta_2 + D \] 

\[ \text{Where,} \]

\[ D = - \ln \left( x_1 + x_2 M_2 / M_1 \right) + 3x_1^2 x_2 \ln \left( \frac{2}{3} + M_2 / 3M_1 \right) \]

\[ + 3x_1 x_2^2 \ln \left( \frac{1}{3} + 2M_2 / 3M_1 \right) + x_2^3 \ln (M_2 / M_1) \] 

(1.28)

Equation (1.28) is applicable only if the ratio of radii of two components in the mixture is smaller than 1.5. Also, equation (1.28) contain two adjustable parameters, namely \( \ln \eta_{12} \) & \( \ln \eta_{21} \), which could be determined by a least square method. The term \( D \) can be easily calculated from a knowledge of the composition of the mixture and of the molecular weight of the components. The selection of a cubic equation is justified.

The less complex, three parameter Auslander equation has the following form:

\[ X_1(x_1 + B_{12} x_2) (\eta - \eta_1) + A_{21} x_2 (B_{21} x_1 + x_2) (\eta - \eta_2) = 0 \] 

(1.30)

Where,

\( A_{21}, B_{12} \) & \( B_{21} \) are the parameters representing binary interactions & could be calculated from a least squares fit of the experimental data.

Heric proposed the following relation to correlate the binary viscosity data.
\[ \ln \eta = x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_1 \ln M_1 + x_2 \ln M_2 \\
- \ln \left( x_1 M_1 + x_2 M_2 \right) + \Delta_{12} \]  
\[ (1.31) \]

Where, \( \Delta_{12} = \alpha x_1 x_2 \), is a function representing departure from a non-interacting system and \( \alpha_{12} = \alpha_{21} \) is the interaction parameter. Heric expressed \( \alpha_{12} \) or \( \alpha_{21} \) as a linear function of composition.

\[ \alpha_{12} = \beta_{12}' + \beta_{12}'' (x-x_2) \]  
\[ (1.32) \]

The co-efficient \( \beta_{12}' \) & \( \beta_{12}'' \) could be determined from a weighted least square method. Quite often viscosity data were also fitted to an empirical equation of the form

\[ \eta = \eta_1 x_1 + \eta_2 x_2 + x_1 x_2 \left[ a + b(x_1-x_2) + c(x_1-x_2)^2 + \ldots \right] \]  
\[ (1.33) \]

Where \( a, b, \) and \( c \) represent the co-efficient to be evaluated.

T.M. Aminabhav et.al\(^{125}\) determined the density & viscosity for six binary solvent mixtures at 20°c and compared the experimental data with literature values and fitted to several empirical relations. Viscosity of liquid mixtures provide information for the elucidation of fundamental behavior of liquid mixtures, help in correlation of mixture viscosities with those of pure components & provide a basis for the selection of physico-chemical methods of analysis. Fort & Moore\(^{126}\) & Nigam and Mahl\(^{127}\) have shown that the sign & magnitude of excess viscosity, \( \eta^E \) & Grunberg & Nissan characteristic parameter (\( d \)) can be used to predict the degree & the type of interaction.

S.L. Oswal & A. Venkateswara Rao\(^{128}\) reported density & viscosity measurements for six binary liquid mixtures of triethylamine, tripropylamine and tributylamine with cyclohexane & benzene. T.M. Aminabhavi et.al\(^{129}\) reported the densities viscosities & refractive indices in binary mixtures of methyl acetooacetate, with esters such as methyl acetate, ethyl acetate, etc. K. Puma Chandra Rao\(^{130}\) determined viscosities of pure components & binary liquid mixtures of N, N-
Dimethylformamide, & N, N-Dimethylacetamide with ethyl acetate, n-propyl acetate, etc. at 303.13k.

A.B. Bilkis \textsuperscript{131}, S.K. Biswas & M. Alamgir reported the measurements of density and viscosity of binary system of ethylene glycol-water, ethylene glycol-dioxane and ethylene glycol-acetone. B. Vijaykumar \textit{et al.}\textsuperscript{132} reported the measurements of density and viscosity of pure formamide and its binary mixtures with ethylene glycol, diethylene glycol, etc. as a function of composition over the entire range at 35\textdegree~C. P.S. Nikam \textit{et al.}\textsuperscript{133} reported density & viscosity studies of aniline with alcohols (C5-C10) and the effect of chain length of alcohols on these properties of binary mixtures of aniline with alcohols. (C5, C6, C7, C8, C9 & C10). Ramkrishna Pramanik & Sanjib Bagchi\textsuperscript{95} studied and reported the density & viscosity of ethanol and 1-octanol binary system.

It is well known that the reaction medium plays an important role in determining reactivity which is reflected in thermodynamic, transport and spectral properties\textsuperscript{134}. In order to gain insight into the mechanism of such interactions, thermodynamic studies involving one or more solutes in mixed solvent systems are highly useful. Studies on the apparent molar volumes of electrolytes and dependence of viscosity on concentration of solutes and temperature of solutions have been employed as a function of studying ion-ion and ion-solvent interactions\textsuperscript{135}. It has been found by a number of workers\textsuperscript{136} that the addition of electrolyte could break or make the structure of a liquid. Since, the viscosity is a property of the liquid which depends upon the intermolecular forces, the structural aspect of the liquid can be inferred from the viscosity of solutions at different concentration and temperatures.

A. Chaudhari et al.\textsuperscript{137} reported the measurement of density and viscosity data of some mineral salts like ammonium nitrate, potassium nitrate, etc. in 30\% mass tetrahydrofuran and water mixtures at different temperatures. Amalendu Pal and Harish Kumar\textsuperscript{138} reported the viscosities and excess molar volume as a function of composition for binary liquid mixtures of diethylene glycol monomethyl ether and of diethylene glycol monobutyl ether with 1-propanol & 2-propanol. Bhoj
Bahadur Gurung et al.\textsuperscript{139} measured and reported density and viscosity of pure benzene and its binary mixtures with carbon tetrachloride and chloroform as a function of composition over the entire range at different temperatures.

The volumetric \& viscometric studies of electrolytes at infinite dilution in various mixed solvent system have contributed to our knowledge about electrolyte-non-electrolyte-water interactions. By examining the viscosity B co-efficient and $V_0\phi$ of ions as function of size, nature, temperature and composition of the mixed solvent, it is possible to study the effect of these parameters on ion-water interactions, with the hope of obtaining a better understanding of the interactions in solutions.

P.S. Nikam et al.\textsuperscript{140} have determined densities of ammonium sulphate, potassium sulphate and aluminium sulphate in aqueous DMF at different concentrations in the temperature range 298.15 to 313.15K. From these data, apparent molar volumes ($V\phi$) have been derived and analyzed using Masson equation\textsuperscript{141}. The limiting apparent molar volume ($V_0\phi$) and slope ($S_V$) are interpreted in terms of solute-solvent and solute-solute interactions respectively. The structure making/breaking capacities of electrolytes have been ascertained from the equation of L.G. Hepler\textsuperscript{142}. Recently, M.L. Parmar and D.K. Dhiman\textsuperscript{143} have reported studies on the determination of partial molar volumes of some mineral salts from density measurements in aqueous medium at different concentrations and temperatures. The results have been interpreted in terms of ion-solvent and ion-ion interactions.

Reena Gupta and Mukhtar Singh\textsuperscript{144} measured density \& viscosity of ternary systems involving maltose, alkali metal halides and water at different temperatures. The density and viscosity data have been analyzed by applying Jones-Dole equation. The structure making and structure breaking capacities of halides in the presence of maltose have been ascertained from the temperature dependence. Anwar Ali et al.\textsuperscript{145} presented the density, viscosity \& refractive index data for urea and D-glucose in glycine and water mixed solvent as a function of urea/glucose
concentration at 308K. The experimental data obtained was analysed in terms of solute–solute and solute-solvent interactions.

S. Senthil Raja & T.R. Kubendran\textsuperscript{146} reported density & viscosity data for 1,4-dioxane + carbon tetrachloride, carbon tetrachloride + butanol & 1,4-dioxane + butanol at 303.15, 308.15 & 313.15 K. The experimental data was used to calculate deviations in viscosity, and excess molar volume of the mixtures. The viscosity and excess molar volumes have been fitted to Mc- Allister model\textsuperscript{147}, the Krishnan & Laddha model\textsuperscript{148} & the Redlich-Kister\textsuperscript{149} equation. M.L. Parmar & M.K. Guleria\textsuperscript{150} determined relative viscosities for the solutions of oxalic acid & its salts like ammonium oxalate, sodium oxalate & potassium oxalate at different concentration in water and in binary aqueous mixture of tetrahydrofuran. The data have been evaluated using the Jones-Dole equation and the obtained parameters have been interpreted in terms of solute-solute and solute-solvent interactions.

S.K. Lomesh et. al\textsuperscript{151}. reported molar volume, viscosity and molar conductance of copper sulphate in water, aqueous sodium chloride and dextrose from density, viscosity and conductance data. The experimental data obtained was analysed in terms of Jones-Dole equation, Walden product and interpreted in terms of solute-solvent interactions and structure making/breaking behavior of copper sulphate.

A thorough knowledge of transport & thermodynamic properties of multi component liquid mixture is essential in many industrial applications. Therefore, the viscosities of multi component liquid mixtures are required in many chemical engineering calculations. Dominguez and co-workers\textsuperscript{152} have carried out studies relating to thermodynamic and transport properties of binary and ternary mixtures involving butanols, n-hexane, 1-chlorobutane, 1-butylamine at 298.15 & 313.15 K. Surabhi Varshney & Mukhtar Singh\textsuperscript{153} carried out viscometric studies on molecular interactions in ternary liquid mixture of ethane 1,2-diol and pyridine with some polar & non-polar solvents. From the density and viscosity data, the viscosity deviations and the excess thermodynamic properties have been
calculated. On the basis of there values of excess thermodynamic properties, molecular interactions between the mixing components have been discussed.

Physiological & biological activities are medium dependent. Thus study of their interactions and physical characterization is essential. As per molecular modeling data, their interaction with water could influence actual biological processes and hence estimation of parameters such as density, volume and viscosity become necessary. Man Singh measured density and viscosity of citric acid & disodium hydrogen orthophosphate at various strengths and at different temperatures. Varsha Sharma et al. explained viscosity results of uranyl soaps in dimethyl formamide in terms of equations proposed by Einstein, Vand, Moulik & Jones-Dole.

Partial molar volumes of electrolytes provide valuable information about ion-ion, ion-solvent & solvent-solvent interactions. This information is of fundamental importance for understanding the reaction rates and equilibria involving dissolved electrolytes. The structural interactions of non-ionic solutes with ionic ones in different solvents are important in many fields of chemistry. The studies of such interactions of non-electrolytes with electrolytes in solution are very significant and useful for investigating their physico-chemical behavior. Robinson et al. & Vishnu et al. have studied aqueous & non-aqueous ternary system containing polyhydroxy compounds and electrolytes like alkali halides. Vijay Laxmi & Mukhtar Singh measured viscosities & apparent molar volumes of solutions of uni-univalent & bi-univalent electrolytes (NaCl, KCl, NH₄Cl, etc.) and (BaCl₂, MgCl₂) in purely aqueous & aqueous thiourea solutions at different temperatures. These data have been used to calculate the constants of Jones-Dole & Masson’s equations.

Grouping of solvents into classes is often based on the nature of the intermolecular forces, because the manner whereby solute & solvent molecules are associated with one another brings about a marked effect on the resulting properties. After the introduction of the concept of ionization power of solvent much work has been devoted to the solvent effects on the rate and equilibrium
processes. Because of the close connection between liquid structure and macroscopic properties, determination of volumetric and viscometric properties is a valuable tool to learn the liquid state. On the other hand, reliable measurements of solvent properties over a wide range of composition, pressure and temperature is not often feasible; hence, prediction and correlation methods constitute a valuable option to overcome such difficulties.

Ankan Chaudhari et.al. measured and reported the density & viscosity of the binary mixtures of tetrahydrofuran with n-pentane, n-hexane & n-heptane as a function of the composition at 288.15, 293.15 and 298.15K. From these data, excess thermodynamic properties were calculated. The results have been interpreted in terms of possible molecular interactions existing between the component of these mixtures. The study of biomolecules plays a very important role in understanding the thermodynamic behavior of biochemical processes in living cells. Attwood et.al. determined the apparent molar volume & adiabatic compressibility of aq. solution of phenothiazine and chlorpromazine drugs with regard to temperature dependence. Temperature increase caused linear increase in both apparent molar volume and compressibility of chlorpromazine in micellar form.

A.Kumar et.al. measured densities & viscosities of triethylamine with methanol, ethanol & 1-propanol. Gibb’s free energy for the activation flow & Grunberg-Nissan interaction parameters were computed. The results were discussed in the light of intermolecular interactions. Aminabhavi et.al. studied densities, viscosities of binary mixture of methyl acetoacetate with aliphatic alcohols (C₁ – C₈). The variation of various excess properties with chain length & temperature was discussed. In another study, they analyzed the viscosity data using viscosity equations such as McAllister, Auslander & Heric.

Wen-Lu-Weng reported densities & viscosities for the binary mixture of butylamine with aliphatic alcohols (C₄ - C₈). The negative excess molar volumes & viscosity deviations results revealed the presence of molecular interactions of the cross association between the alkanols & amine molecules. Su-chan-ku & Chein-
Hsiun Tu\textsuperscript{175} reported densities & refractive indices of binary mixture of dimethyl ether of a glycol with ethanol at various temperatures.

Iqbal et.al. \textsuperscript{91} studied the partial molar volume of some drugs in water and ethanol solvent system. Their study showed solution behavior constant with the general rules governing the behavior of electrolytic, non polar and amphiphillic solutes in water. The differences in volumes were interpreted as due to hydrophobicity of solutes. The hydrophobicity of these drugs was proposed to play a key role in resulting drug action. The possible mechanism of drug binding with membrane structure was also discussed.

Horsein A. Zarei \textsuperscript{176} reported densities, excess molar volumes & Partial molar volumes of the binary mixtures of acetic acid + alcohols (C$_1$-C$_4$) at 298.15 K. Pavel Hyncica et. al \textsuperscript{177} reported densities & Partial molar volumes of organic solutes in water at the temperature rang 298 to 573 K. Y. Leong et.al. \textsuperscript{178} reported partial molar volumes of acetonitrile + water mixture over the temp range 273.15 to 318.5 K.

Volumetric properties of binary mixtures are complex properties because they depend on only on solute – solute, solvent-solvent and solute-solvent interactions, but also on the structural effects arising from interstitial accommodation due to the difference in molar volume and free volume between components present in the solution. Knowledge of several properties, including densities at different temperature, is required for engineering design and for subsequent operations. R.B. Torres et.al. \textsuperscript{179} measured the densities & reported volumetric properties of binary mixtures of acetonitrile and alcohols at different temperatures.
1.1.7. Conductance:

The study of conductivity behavior of electrolytes in aqueous & non-aqueous media has received considerable importance in recent years due to its varied applications in various electrochemical investigations. Conductivity study is one of the important & simplest tools to understand the transport behavior in general and solvation behavior in specific for the ionic species involved in that electrolytic system under existing conditions\textsuperscript{180}. The behavior of electrolytes in solution can be revealed by conductance\textsuperscript{181} & viscosity investigations\textsuperscript{182}, which makes one to understand in detail about the nature of ion-ion & ion-solvent interactions.

Three types of binary solvent mixture have been generally used in the literature for conductance measurements. Most frequently used are the mixtures of dipolar solvents with atleast one protic solvent\textsuperscript{183,184}. In order to change the dielectric constant of the medium without introducing a second solvating component, mixtures of dipolar solvents with non-polar components have also been used\textsuperscript{185}. Mixtures of dipolar aprotic solvents, however, have rarely been used for the conductance studies of electrolytes\textsuperscript{186} and thus need further investigations.

The effect of sucrose on the conductivity of aqueous electrolyte solutions has been reported by a number of repoters\textsuperscript{187,188}. The conductance data have been analyzed by Kohlrausch's law or Onsagar's limiting law. An increase in the viscosity of medium has been attributed\textsuperscript{189} to large aggregate of sucrose molecules having no effect on the mobility of smaller ions. However, Stokes & Stokes\textsuperscript{190}. While analyzing the conductance data of LiCl, NaCl, KCl, etc. in 10 & 20% sucrose solutions at 25° C have opined that decrease in conductance of the electrolytes is due to the frictional charactor of the medium.

R. G. Mishra & B. Behera\textsuperscript{191} reported the conductance data on NaCl, NaBr & NaI in sucrose solution at 25° C. The data obtained was analysed by Shedlovsk’y method. Solute-solvent interaction studies have been a subject of active interest among physical chemists\textsuperscript{192} & mostly the inference regarding these interactions are drawn from conductance\textsuperscript{193}, molar volume and viscosity data.R.L.
Bokhra & P. C. Verma reported the conductance data for potassium acetate in water and in aqueous methyl acetate at different temperatures. The experimental data have been evaluated from Onsager's plot and with the help of Owen's method.

In recent years, structural interactions in ternary systems comprising electrolyte-solvent-nonelectrolyte are gaining special attention. It has been observed that non-electrolyte moiety interacts with the ions of the electrolytes in solution. Several polyhydroxy compounds are known to interact with electrolytes in solution. Definite adducts of many carbohydrates with salts and hydrated oxides of alkali and alkaline earth metals have also been reported. Measurements of conductance of electrolyte solutions in the presence of nonelectrolytes have been made by several workers. The changes of conductance of carbohydrate-electrolyte solutions was attributed to the obstruction of the electrical migration of ions by the environmental, non-electrolyte entities.

Vishnu & Vidya Sagar Mishra carried out conductance measurement of maltose with alkali metal halides in water & formamide solutions at different temperatures. The transitional behavior in the conductance values was explained in terms of solute-solvent interactions involved in the electrolyte-solvent-nonelectrolyte system. Conductance behavior of hydrogen halides in amphi-protic solvents and their mixtures has been extensively studied. V. Venkateshvara Sastri and C. Kalidas studied the conductance behavior of HCl & HBr in water - propylene glycol mixtures over the entire composition range at 25°C. The data has been analyzed by the Fuoss-Onsagar-Skinner three-parameter equation. The data has been evaluated interms of structural changes in the mixed solvents.

Varaprasad N.S. & Ishwara Bhat J. reported the conductivity of N-chlorosuccinimide & N-bromosuccinimide in water & various compositions of water + dioxane at a temperature range 283 to 323K. From the conductance data free energy, enthalpy and entropy were evaluated and interpreted in terms of ion-ion & ion-solvent interactions in the present system. Extensive studies on electrical conductance in various solvents have been performed in recent years to examine the nature & magnitude of ion-solvent and ion-ion interactions. M.N.Roy &
Anuradha Sinha\textsuperscript{205} carried out conductance measurement for tetramethyl ammonium chloride, tetraethylammonium bromide, etc. in isoamylalcohol at 298.15K. The conductance data have been analyzed by Fuoss equation & the results have been explained in terms of ion-solvent & ion-ion interactions.

V.K. Syal et.al.\textsuperscript{206} carried out conductance studies on the drugs Parvan Spas, Parvodex and Tramacip in ethanol-water mixtures at 25° C in absence and presence of additives viz. electrolytes –sodium chloride, sodium dodecyl sulphate, non-electrolytes – fructose and sucrose. The data obtained was evaluated in terms of specific conductance, equivalent conductance and limiting molar conductance.

Mousumi Das & Mahendra Nath Roy\textsuperscript{207} reported conductance measurement for selected alkali metal chlorides in the binary mixtures of methanol with carbon tetrachloride and 1,4 dioxane at 298.15K. The data was used to evaluate limiting equivalent conductance, the association constant and the Walden product at all the mole fraction of solvent mixtures using the 1978 Fuoss conductance – concentration equation. The results have been interpreted inters of ion-solvent interactions and structural changes in the mixed solvent systems.

\section*{1.1.8. Refractive Index:}

Experimental of physical properties such as refractive index are required for a full understanding of the thermodynamic properties of liquid mixtures as well as for practical chemical engineering work. Some of the important investigations, which contributed to the development of the treatment of refractive index of liquid mixtures have been reported\textsuperscript{208,209}. In order to correlate the refractive index for a binary solution of a specified composition, the mixing rules of Lorentz-Lorenz; Gladstone-Dale, Wiener, Heller & Arago-Biot are most frequently employed. Some of these relations are not suitable when there is a large change of volume on mixing, resulting from physical and / or chemical interactions. The behavior of binary system in a particular mixture is specific and depends on its composition.

Alaksandar Z. et.al\textsuperscript{210} reported the refractive indices for binary system benzene-cyclohexane, acetone-benzene & acetone-cyclohexane at 25° C over the
composition range. These results were used to test the applicability of the Lorentz-Lorenz, Gladstone-Dale, Weiner, Heller and Arago-Biot refractive index mixing rules.

Refractive index & density measurements of binary liquid mixtures are essential for determination of composition of binary liquid mixtures, usually for non-ideal mixtures, where direct experimental measurements are performed over the entire composition range. Most empirical approach for calculating the excess properties is an attempt to explain non-ideality in terms of specific & non-specific molecular interaction. The most widely used rules for predicting refractivity in case of binary liquid mixtures are Arago-Biot\textsuperscript{211}, Gladstone-Dale\textsuperscript{212}, Lorentz-Lorenz\textsuperscript{213,214}, Weiner\textsuperscript{215}, Heller\textsuperscript{216}, Newton\textsuperscript{217}, Oster\textsuperscript{218} & Eyring-John\textsuperscript{219}. Many authors\textsuperscript{220} have applied their properties to study the structure, solvent- solute interactions and the solvation behavior in binary liquid mixtures.

Refraction arises from the presence of extra nuclear electron of atom, tend to follow the oscillation of the electro-magnetic field associated with light. As per Clausius-Mosotti equation, at a particular frequency of light,

\[ [R] = 4\pi \cdot N \alpha /3 \]

Where N is Avogadro's number & \( \alpha \) is electronic polarizability of the molecules of medium, polarizability of medium is sum of polarizabilities of constituent atoms. Refractive index depends on the wave length of light.

Sangita Sharma et.al.\textsuperscript{221} determined density & refractive index for binary liquid mixtures of methyl acetate, ethyl acetate, propyl acetate and butyl acetate with n-butanol and iso-butanol at 303.15, 308.15 & 313.15K. S. Dhillon & Chugh H.S.\textsuperscript{222} measured the refractive indices of mixtures of 1,2-dibromomethane with cyclohexane, benzene, toluene, o-xylene, m-xylene and p-xylene at 303.15K as a function of composition. Molar refractions of the mixture were calculated from refractive index measurement. Jagan Nath & B. Narain\textsuperscript{223} reported the refractive indices for binary liquid mixtures of tetrachloroethylene with benzene, toluene, p-xylene, carbon tetrachloride & cyclohexane. Juan Ortega\textsuperscript{224} measured the refractive
indices of normal alcohols form methanol to 1-decanol in the temperature range from 20 to 80° C.

Since the refractive index can be determined for a small amount of samples sealed in a cell in wide range of temperature & pressure with a high precision, the refractive index method have been used to obtain density of liquids and liquid mixtures. Among many theoretical and empirical equations, the Lorentz-Lorenz formula and the Gladstone-Dale law have been widely employed to evaluate the density of liquids from observed refractive indices. The density derivative of the refractive index for the L-L formula has been found to be Ca 5-10% higher than the observed one. The estimation of the density of binary liquid mixtures from the observed refractive index is affected by another uncertainty caused by the assumption of the additivity rule. It has been known that the experimental values of the molar polarization for various binary mixtures usually do not differ by more than a few parts in a thousand from the values calculated with L-L formula on the basis of additivity rule. From a fractional viewpoint, this small deviation is not serious in the determination of density. However, this uncertainty yields a large error for the excess volume, which reflects the properties specific to binary liquid mixtures. Therefore, the determination of the excess volume with refractive index data requires a careful examination of the additivity rule and equations of refractive index. Heller scrutinized various equations of refractive index by calculating refractive indices from old data for a liquid mixture, although attention was not paid to the excess volume.

Milsuo Nakato and Masao Sakurai reported the refractive indices of binary mixtures of 1-chlorobutane-2-ol, 1-chlorobutane-2-methoxyethanol, and isopropyl acetate-methylethyl ketone. The excess volume obtained from densimetric measurements were compared with the ones calculated from the refractive indices.

Refractive index is one of the physical properties of a solvent which affects the solution of a number of problems in Pharmaceutical and chemical areas. Refractive index values of most of the common solvents are available in literature.
Binary and higher order solvent mixtures were used to overcome a number of practical limitations of mono-solvent systems including poor solubility of a solute &/or insufficient analytical performance of mono solvent systems in chemical analysis. Jimenez et al.\textsuperscript{229} compared these models using refractive index data of 1,2-ethane diol + 1-propanol & 1,2-ethanediol + 1-butanol & found that the accuracy order of the models was as Wiener, Heller, Newton, Gladstone-Dale, Lorentz-Lorenz, Eykman, Arago-Biot & Oster equations. The main limitation of these models is that they correlate refractive index values to the solvent composition as independent variable at a constant temperature & the models could not be used to predict refractive index values at other temperatures. However, refractive index of the solvent depends strongly on temperature & mixed solvent systems at various temperature have been used in many analytical methods where refractive index detectors were used as detection system. It is obvious that by changes in the refractive index of the system, fluctuations appear on the detection output & make noises. To provide a single model to correlate refractive index of mixed solvents at various temperatures Jimenez & co-workers proposed a two independent variables model as—

$$R_{lm,T} = J_0 + J_1 f_1 + J_2 f_1^2 + J_3 (T - 298.15) + J_4 (T - 298.15)^2 + J_5 f_1 (T - 298.15) + J_6 f_1^2 (T - 298.15) + J_7 f_1 (T - 298.15)^2 + J_8 f_1^2 (T - 298.15)^2 \quad \ldots \quad (1.34)$$

Where, $R_{lm,T}$ is refractive index of the mixture at temperature $T$, $J_0$-$J_8$ are the model constants, $f_1$ is the mole fraction of the solvent 1 in the mixture. Lee and co-workers\textsuperscript{230} have used equation (1.35) for computing $R_{lm,T}$ & shown its accuracy using R.I. data of water + 1,3-propanediol at 298-323K.

$$R_{lm,T} = M_0 + M_1 f_1 + M_2 f_1^2 + M_3 T + M_4 f_1 T + M_5 f_1^2 T + M_6 T^2 + M_7 f_1 T^2 + M_8 f_1^2 T^2 \quad \ldots \quad (1.35)$$

Where,

$M_0$ – $M_8$ are the model constants.

The Jouyban-Acree model has been presented for calculating different physico-chemical properties of solvent mixtures at various temperatures including dielectric constants\textsuperscript{231}, surface tensions\textsuperscript{232}, absolute viscosities\textsuperscript{233} & density\textsuperscript{234}. The
adopted model for calculating refractive index of binary solvent mixtures at various temperatures is –

$$\ln RI_{m_1 T} = f_1 \ln RI_{1T} + f_2 \ln RI_{2T} + f_1 f_2 \sum_{j=0}^{2} \left[ \frac{A_j (f_1-f_2)^j}{T} \right]$$

...... (1.36)

Where,

$f_2$ is the volume (mole/weight) fraction of solvent 2 in the mixture, $RI_{1T}$, $T$ & $RI_{2T}$ are the values of solvents 1 & 2 at T, & $A_j$ is the model constant. The performance of the equations for calculating the refractive index of the systems at various temperatures has been tested with 29 systems including aqueous & non-aqueous binary liquid mixtures collected from literature.\textsuperscript{229,230,235,236} The agreements between experimental (RI exp) & calculated (RI cal) refractive indices for the systems were shown in the form of average percentage deviation (APD);

$$\text{APD} = \frac{100}{N} \sum_{1}^{N} \left\{ \frac{RI_{\text{cal}} - RI_{\text{exp}}}{RI_{\text{exp}}} \right\}$$

.................................(1.37)

Where N is the number of data points in each set. The overall APD (OAPD) was defined as –

$$\text{OAPD} = \frac{\sum_{1}^{29} \text{APD}}{29}$$

.................................(1.38)

The refractive index, excess refractive index, etc. are used to explain the nature of solvent-solvent interactions. The refractive index along with density values of mixtures are used to test the accuracy of available refractive index mixing relationships in predicting binary mixture refractive index data.

1.1.9. Present Work:

The recent trend is to correlate physico-chemical properties to the therapeutic effect of drug molecules. Literature survey reveals that very few molecules have been studied on this background. This prompted us to undertake the study of thermodynamic properties of drug molecules in binary solvent system of ethanol-water at 301.15K. Our study aims at selective few new drugs recently introduced in the market and being commonly used. We have selected drugs from
antibacterial, antidepressant, antihistamine, hypoglycemic and antihyperlipoproteinemic therapeutic categories. These drugs were used to determine their density, viscosity, conductance and refractive index in absence and in presence of additive electrolytes and non-electrolyte. The analytical data on solubility & purity of drugs was complying with pharmacopea standards. The basic instruments selected were viscometer, conductometer, refractometer, etc. The experimentally determined values of density, viscosity, conductance and refractive index were further statistically processed for obtaining excess molar volume, excess viscosity, viscosity deviation, Gibb’s excess energy of viscous flow, Gruinsen-Nissan and other excess parameters, etc. The data was further used for interpretation of the intermolecular interaction, testing & development of various existing theories of solution. Following drugs were used for the present study:

i) Sulphamethoxazole  ii) Fluoxetine hydrochloride

ii) Cyproheptadine hydrochloride  iv) Metformin hydrochloride

v) Fenofibrate  vi) Chlorpheniramine maleate.

The structures and properties of these drugs are discussed in chapter 4.
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