



## CHAPTER X

### CONCLUDING REMARKS

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In this thesis, I have studied the phenomenal supramolecular “Host-Guest” inclusion complexation of some important molecules, including biomolecules, drugs etc., with  $\alpha$ - and  $\beta$ -Cyclodextrins. Cyclodextrin by the formation of Inclusion complexes are capable to modify the physicochemical properties of guests, such as solubility, particle size, thermal behaviour and thus providing a highly water miscible amorphous forms. The formation, characterisation, stabilisation, solubility, bioavailability, bio degradability of inclusion complexes and also their controlled release without a chemical modification have been explored by various spectroscopical techniques such as NMR, 2D ROESY, FT-IR spectroscopy, UV-Vis spectroscopy, Fluorescence spectroscopy, High Resolution Mass spectroscopy as well as physicochemical techniques such as surface tension, conductance, refractive index, density and viscosity studies, focusing primarily on the encapsulation of the guest molecules into the hydrophobic cavity of cyclodextrins. The encapsulation of the guest molecules inside into cyclodextrin’s cavity and the stoichiometry, association constant and thermodynamic parameters for the complexes thus formed have been determined so as to communicate a set of quantitative data.

In my research work, I have also explored the molecular interaction in different solution systems by means of various physicochemical parameters obtained from density, viscosity, refractive index and conductivity studies along with FT-IR measurements. Various types of interactions exist between the ions in solutions, and of these, ion-ion and ion-solvent interactions are of prime interest. The nature of solute and solvent, or more simply, whether the solute distorts or modifies the solvent structure, can be perceived well by studying these interactions. The inkling of whatever taking place in aqueous medium enhances curiosity to examine the behaviour of electrolytes in aqueous and mixed solvents by investigating solute-solute and solute-solvent interactions at different circumstances. The proper understanding of the ion-ion and

ion-solvent interactions may form the basis for the quantitative interpretation of the influence of solvents and ions in solution and thus pave the way for actual understanding of diverse phenomena associated with solution chemistry.

Nevertheless, the behaviour of solutes in mixed solvents are quite different than in aqueous medium. The ion-ion and ion-solvent interactions can be better studied in mixed solvents because such solvents facilitated the variation of properties. The dependence of electrolyte conductivity upon concentration leads to the derivation of several quantities intensely influenced by solvent properties. Accordingly, a number of conductometric and related studies of different ionic liquids and some lithium salts in non-aqueous solvents, especially mixed organic solvents, have been performed. Therefore, to examine the nature and magnitude of ion-ion and ion-solvent interactions, extensive studies have been done on electrical conductance in mixed organic solvents. Ionic association of electrolytes in solution is influenced by the mode of solvation of its ions, which in turn depends on the nature of the solvent (or, solvent mixtures). Such solvent properties as viscosity and the relative permittivity have been taken into account, since, they help to determine the extent of ion association and the solvent-solvent interactions.

In chapter IV, the outstanding result of the triple-ion formation of the investigated ionic liquid, tetrabutylphosphonium methanesulfonate in methylamine solution ( $\text{CH}_3\text{NH}_2$ ) with the help of conductivity has been obtained. The tendency of the triple-ion formation depends on the size and the charge distribution of the ions, and functional group of the solvents. The qualitative analysis from FTIR spectroscopy has confirmed the same observation.

Chapter V dealt with all-embracing study of conductance of lithium salts ( $\text{CH}_3\text{COOLi}$ ,  $\text{LiNO}_3$ , and  $\text{LiI}$ ) in the binary mixtures of acetonitrile and water leads to the conclusion that, electrolytes associated more in the mixture. Therefore, it can also be seen that in the conductometric studies in the binary mixture of different mass fraction of acetonitrile they probably remains as ion-pairs. The reliable significance of volumetric, viscometric and refractometric studies also suggest that in solution there strong ion-solvent interaction than the ion-ion interaction and these interactions promote

strength at higher molality and with increasing size of lithium salts in the solution media.

In chapter VI, based on the experimental results and derived parameters of the studied binary system *viz.*, {[EMIm]Cl/AlCl<sub>3</sub>)+methanol}, {[EMIm]Cl/AlCl<sub>3</sub>)+ethanol}, {[EMIm]Cl/AlCl<sub>3</sub>)+1-propanol}, and {[EMIm]Cl/AlCl<sub>3</sub>)+1-butanol}, we concluded that the ion-solvent interaction signifying parameters *e.g.*, limiting apparent molar volume, molar refraction, limiting apparent molar isentropic compressibility increases with rising the side chain of the studied alcohols and with increasing temperature. On the other hand, ion-ion interaction indicating parameters ( $S_v$  and  $S_k$ ) decreases with the same. The study also attributed that ion-solvent interactions are dominant over the ion-ion interactions. The molecular interactions occurring between the ionic liquid and solvent molecules are due to the structure-making capacity that causes by intermolecular forces and non-covalent interactions.

Chapter VII concludes characterization of solid state crystal using UV-VIS, FTIR, HRMS, <sup>1</sup>H NMR spectroscopy, and the observed SEM pictures strongly support the formation of stable inclusion complexes. Association constant values obtained from UV-Vis spectroscopic study suggests that both the complexes are formed with strong binding affinity. Evaluation of Job plots and surface tension data shows that in both the cases 1:1 stoichiometric complexes are formed. One of the driving forces for the formation of the inclusion complex is the extrication of the water molecules from the hydrophobic cavity of cyclodextrin to the bulk, leading to an increase in the entropy of the system with a simultaneous decrease in Gibbs free energy. In NMR spectra, the chemical shift corresponding to H5 and H3 protons support that the incorporation occur from wider rim of cyclodextrin. More negative  $\Delta G^0$  value and more shifts in various IR stretching frequencies in case of complexation with  $\beta$ -CD indicate that IC2 is formed more feasibly than IC1. This is further supported by higher shifting of H3 and H5 protons in <sup>1</sup>H NMR spectra for IC2. The bonds to form the ICs thus can be attributed in terms of hydrophobic, H-bonding interactions and other non-covalent interactions.

From the observed results and discussion in chapter VIII, it can be concluded that hydrazinophthalazine molecule is incorporated insight into the truncated cone type hydrophobic cavity of  $\beta$ -cyclodextrin molecule to form 1:1 stoichiometric complex. Evaluation of binding stoichiometry and constants from both the surface tension and

UV-vis spectroscopy demonstrated the same observation that the host-guest inclusion complex formed with great stability. The complex has been formed by replacing the water molecules present into the cavity of cyclodextrin (which make a driving force for incorporation of guest molecule) and becomes stable with non-covalent interaction. The inclusion complex formed balance both surface and bulk properties of solution by adsorption and inclusion phenomena. But the inclusion phenomena are dominant over the surface adsorption.

The comprehensive study in chapter IX describes the inclusion phenomena of N,N-dimethyl-4-phenylenediamine dihydrochloride with  $\beta$ -Cyclodextrin. 1:1 inclusion complex formed between DMPD and  $\beta$ -CD. The solid complex was found to be freely soluble in water. The stoichiometry of the complex was established by UV-Vis, conductance and surface tension study.  $^1\text{H}$ NMR data reveal the mode of inclusion where the hydrophobic aromatic part of the guest molecule was incorporated. The reliable value of association constant and free energy stands for the stability of the inclusion complex. The complexation is occurring by the binding between DMPD and  $\beta$ -CD with non-covalent bonds, where H-bonding interactions played a significant role.

So, this work is an attempt to explore the supramolecular “Host-Guest” inclusion complexation of some noteworthy molecules by various physicochemical and spectroscopic methods and to make them more bioavailable by increasing their solubility and controlled release without any chemical modification. All the studies fruitfully support the formation of inclusion complexes which are stabilised by Van der waals forces. In addition, H-bonding interactions sometime provides extra stability to the inclusion complexes.

Beside, in this thesis, I have also tried to investigate solution behaviour of some important solutes in some aqueous and industrially important non-aqueous solvents in terms of various interactions like solute-solute, solute-solvent and solvent-solvent interactions. Molecular interactions have been examined with the help of thermodynamic and transport properties of solutions. Such study will find significance in chemical engineering areas particularly to understand the mixing behaviour of different components in the mixture.

More extensive studies of the different thermodynamic and transport properties of the electrolytes will be of sufficient help in understanding the nature of the ion-solvent interactions and the role of solvents in different chemical processes. However, it is necessary to remember that molecular interactions are very complex in nature. There are strong forces existing in the molecule and it is not really possible to separate them all. Nevertheless, upon careful judgement, valid conclusions can be drawn in many cases relating to degree of structure and order of the system.

In the near future we must endeavour to extend our research work with more ionic liquids and biomolecules, and I hope, this will certainly complement our present findings.