Thesis title: **Investigation of Interaction and Dynamics in Complex Liquids: Theory and Computer Simulations**

Index No.: **30/19/Chem./26**

Abstract

This thesis entitled, "**Investigation of Interaction and Dynamics in Complex Liquids: Theory and Computer Simulations**" investigates the structural and dynamical aspects of a variety of liquid systems, ranging from simple to complex, using molecular dynamics simulations. The studied systems include deep eutectic solvents (DES) and binary mixtures, such as, neat molten amide, amide-based ionic DESs, glucose-based naturally abundant DESs (NADESs), binary mixtures of ethylene glycol (EG) and glucose, and choline chloride-based DESs. The molecular arrangements of the systems at the molecular level have been investigated, including discussions on the possible formation of deep eutectic systems of binary mixtures. Additionally, the solubility of drug molecules in DESs was investigated and the importance of non-polar interaction in controlling solubility analysed. A major aspect of this thesis is the comprehensive computation of dielectric relaxation (DR) spectra from molecular dynamics (MD) simulations for a number of ionic and non-ionic DESs, which successfully explained in molecular terms the relevant experimental data. This computational framework was further expanded to study DR in binary mixtures and neat liquids and provide microscopic explanations to experiments. With a focus on exploring the application potential of these liquids in industrial and technological sectors, the simulation protocols have been critically examined for accuracy and validity by extensively comparing the simulated data with those from experiments.

The first part of the thesis deals with a debate over the mega-value of the static dielectric constant of acetamide-based ionic DESs and provides a satisfactory resolution. New dielectric relaxation data measured in the frequency range $0.2 \leq \upsilon/\mathrm{GHz} \leq 50$ suggests a significant electrolyte-induced reduction of the static dielectric constant of the host acetamide (εs), which differ dramatically from earlier experimental data measured in the 0.1 Hz – 100 MHz frequency range. Simulation studies of dielectric relaxation shed light on the origin of the decrease of the static dielectric constant of such ionic systems. Dissection of total dielectric spectra into rotational, translational and ro-translational components indicate major contribution to DR arises from the rotational dynamics of the fluctuating host dipolar solvent molecules. The origin of the ion-induced dielectric decrement was traced to a frustration of the local orientational dipolar order brought out by a partial damage of the H-bond network of acetamide.

The structure and dynamics of a glucose-based NADES have been extensively explored employing temperature dependent MD simulations. Real-space pair correlations, depicted by radial distribution functions (RDFs) and the three-dimensional spatial arrangements, revealed size-dependent interactions between glucose, urea and water. Relaxation times of structural hydrogen bonds get incrementally faster

with temperature. Computation of DR reveals the complex interplay of molecular motions within the system. Component-wise decomposition of total DRS reveals dominant contributions from self- and cross-interactions involving glucose and urea.

Drug solubilization is an important aspect of the potential use of DESs. The solvation efficiency of two choline chloride (ChCl) based DESs where ethylene glycol (EG) and propylene glycol (PG) are the hydrogen bond donors (HBDs) to solubilize a drug- paracetamol, has been extensively investigated. Predicted solubilities from simulations agree well with the experimental results. Roles of hydrogen bonding and non-polar interactions have been studied which may help designing new and more useful DESs for this purpose.

The definition of DES becomes somewhat flaccid when one groups both solid-solid and solid-liquid combinations under one name, that is, DES. An example of a solid-liquid mixture being branded as DES is ChCl-EG DES or ethaline. We have studied mixtures of ChCl and EG at different compositions to look into this problem computationally. We haven't detected any 'magic composition' that accompanies anomalous changes in structural and/or dynamical properties which may indicate formation of a DES.

Beyond DESs, we explored another class of liquids – the cryoprotectants. Sugars and polyols are well-known cryoprotecting agents (CPAs). We have computationally investigated mixtures of glucose (sugar) and ethylene glycol (polyol) at different compositions to monitor the changes in their structural and dynamical properties, with a focus on correlating relaxation processes with the solution structure. The study has revealed that increasing glucose content damages the hydrogen bond network of ethylene glycol while enhancing interactions among glucose molecules. This has a deep implication on the over-all polarization relaxation in the system.

Coordination number analysis indicates a rise in glucose population around both ethylene glycol and glucose. The slowing down of molecular migration and multi-exponential relaxations in reorientational and hydrogen bond correlation functions suggest the formation of a glucose domain, offering insights into the cryoprotection mechanism.

Ranjit Biswas
(signature of guide)
15.04.24

Shrabanjyoti Maji 15/04/2024
(signature of candidate)

DR. RANJIT BISWAS
Senior Professor
Dept. of Chemical, Biological & Macromolecular Sciences
S. N. Bose National Centre for Basic Sciences
Block - JD, Sector-III, Salt Lake, Kolkata - 700 106, India