Overview of the “Ionic Liquids meet Biomolecules” session at the 19th international IUPAB and 11th EBSA congress

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Room temperature ionic liquids (ILs) (Welton 1999) are a vast class of ionic systems consisting of an organic cation and either an organic or inorganic anion, whose melting temperature falls below the conventional limit of 100 °C, making these compounds liquid at or near room temperature. The thermal and chemical stability of these systems make them the basis of what is called “green chemistry” (Earle and Seddon 2000). Several biochemical studies, however, have highlighted their potential toxicity to organisms, a toxicity which, in turn, is also a measure of their affinity for bio-molecules. This property has stimulated several chemical–physical studies on the interaction between ILs and basic biological systems. In recent decades, it has been observed that selected ILs are able: (1) to kill bacteria and cancer cells while leaving eukaryotic healthy cells almost unaffected; (2) to extract, purify and even preserve DNA at ambient temperature; (3) to stabilize proteins and enzymes; (4) to either favour or prevent protein amyloidogenesis; (5) to penetrate and eventually disrupt biomembranes via extended poration; and (6) to dissolve polysaccharides and cellulose. A recent overview of the subject is reported in two reviews authored by Benedetto and Ballone (2016a, b).

The aim of the “Ionic Liquid meet Biomolecules” session of the IUPAB–EBSA congress was to present an up-to-date overview of this new and intriguing subject of research which has potential applications in several fields, ranging from biomedicine, pharmacology, and material science to biotechnology.

Pannuru Venkatesu (University of Delhi, India) focuses on the interaction between ionic liquids and proteins (Meena et al. 2016; Jha and Venkatesu 2016), arguing that studies of interaction between proteins and different ILs *in aqueous solution* are comparatively more important than those in pure ILs. The results of these investigations suggest that the IL–water–protein interaction is a complex balance of different contributions by the different components, which is not possible to predict *a priori*. There is sufficient evidence in the literature to lead to the conclusion that the interaction between proteins and ILs depends on the protein as well as on the cations and anions present in the ILs.

Antonio Benedetto (University College Dublin, Ireland, and Paul Scherrer Institut, Switzerland) presents results from joint experimental and computational studies on the interaction between ILs and (model) biomembranes (Benedetto 2017; Benedetto et al. 2015, Benedetto et al. 2014). Combining neutron scattering and computer simulations these studies show how it is possible to describe the mechanisms of interaction at the molecular level: IL cations penetrate the biomembrane, finding a preferential location between the tails and the heads of the phospholipids. The penetration is driven by the Coulombic attraction between the IL cations and one of the most electronegative oxygen atoms in the phospholipid heads, and is stabilized by dispersion forces between the lipids and the IL tails. The absorption of ILs shrinks the membrane, changes the diffusion coefficients of both the phospholipids and interfacial

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water and changes the mechano-elasticity of the membrane (probed by atomic force microscopy).

Seema Singh (Sandia National Laboratories, USA) discusses the role of ILs in enabling the bioeconomy and presents IL applications to facilitate the production of liquid transportation fuels from renewable lignocellulosic biomass. She argues that it is important to perform the pretreatment prior to downstream saccharification and fermentation and also discusses how ILs are overcoming existing barriers and enabling scalable and industrially viable technologies (Socha et al. 2014; Xu et al. 2016). In her presentation, Seema Singh provides two specific examples of why it is important to understand biomolecule and IL interactions in the context of advancing the one-pot integrated process that will overcome many of the existing barriers in future lignocellulosic biorefineries, including how imidazolium acetate inhibits the activities of cellulase and microbes and how experimental and computational studies are providing insight into designing engineered cellulase, microbes and designer ILs.

Valentine Ananikov (Russian Academy of Science, Russia) presents recent experimental observations of dynamic interactions made directly in IL media using field-emission scanning electron microscopy (Kashin et al. 2016). He shows that water self-organizes in ILs, leading to the formation of a variety of morphologies, including isolated droplets, aggregates and two-dimensional meshwork, all of which have been experimentally detected and studied (Kashin et al. 2016). The structuring of water in ionic media plays an important role in the process of sustainable biomass conversion. More detailed investigations of this system will provide the valuable driving force for improving the utility of biomass conversion in organic synthesis (Galkin et al. 2016).

Damien Hall (Australian National University, Australia, and Osaka University, Japan) focuses on the amyloidogenesis process in which folded proteins first unfold and then create different aggregates. He presents a new way to describe this process by resorting to a multi-dimensional conformational space and considering a step-by-step scenario. He describes both experimental and statistical mechanical modelling studies of high-order polymeric coacervates formed from heparin and lysozyme. His argument is that the dynamic nature of such coacervates or ‘polymeric ionic liquids’ is important in the formation of amyloids (Hall and Edskes 2012)—whereby amyloid is a fibrous homopolymer constructed from various proteins that is the primary subject of study in many disease states (Hall and Edskes 2009).

Hans-Joachim Galla (University of Münster, Germany) introduces the audience to a new series of lipid-mimic imidazolium-based ILs, and to their interaction with (model) biomembranes. The major characteristic of these ILs is that they have two hydrophobic alkyl chains located at the 4- and 5-positions of the imidazole ring. Interest in this new class of RTILs is increasing due to their significant anti-tumour

activity and cellular toxicity. In comparison with the most active one-tailed imidazolium RTILs, the two-tailed RTILs show approximately a three order of magnitude higher anti-tumour activity. The most intriguing aspect is that their toxicity is negatively correlated with their chain lengths, with C₇Ime·HI having the highest toxicity and anti-tumour activity and C₁₅Ime·HI having the lowest toxicity but still the highest membrane activity (Wang et al. 2015a, b, 2016; Drücker et al. 2017).

Sajal Ghosh (Shiv Nadar University, India) presents his recent X-ray reflectivity study on the interaction between an imidazolium-based IL with a soft supported lipid bilayer that is a well-accepted model for biomembranes (Bhattacharya et al. 2017). In this study, Ghosh and co-workers were able to probe how the structure and the overall stability of the supported lipid bilayer are affected by the interaction with the IL. As a major result, they found that there is a considerable decrease in the bilayer thickness of the order of several angstroms due to the interaction with the IL. Other techniques allowed them to verify that the IL penetrates into the lipid region.

Fig. 1 Photograph of the session speakers and chairs. From left to right: Hans-Joachim Galla, Valentine Ananikov, Sajal Ghosh, Antonio Benedetto, Pannuru Venkatesu, and Damien Hall. Seema Singh is not in the photograph

Compliance with ethical standards

Conflicts of interest Antonio Benedetto and Hans-Joachim Galla declare that they have no conflicts of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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