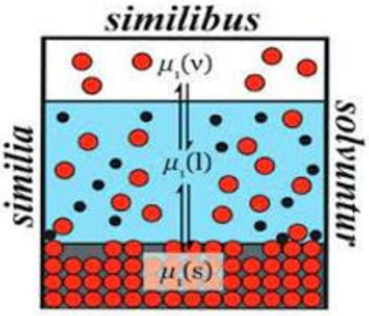


21st IUPAC International Symposium on Solubility Phenomena and Related Equilibrium Processes (ISSP21)

Book of Abstracts

Novi Sad, Serbia, September 9 – 13, 2024

Title of the publication:	21st IUPAC International Symposium on Solubility Phenomena and Related Equilibrium Processes (ISSP21) Book of Abstracts
Editors:	Prof. Dr. Slobodan Gadžurić Prof. Dr. Sanja Belić MSc Nikolet Cako Baganj
Published by:	University of Novi Sad, Faculty of Sciences Trg Dositeja Obradovića 3, Novi Sad, Serbia
For publisher:	Prof. Dr. Milica Pavkov Hrvojević, dean University of Novi Sad, Faculty of Sciences
Printed by:	Electronic material
Published at:	https://issp2024.pmf.uns.ac.rs/

CIP - Каталогизација у публикацији
Библиотеке Матице српске, Нови Сад

54(048.3)(082)(0.034.4)

INTERNATIONAL Symposium on Solubility Phenomena and Related Equilibrium Processes (21 ; 2024 ; Novi Sad)

Book of Abstracts [Elektronski izvor] / 21st IUPAC International Symposium on Solubility Phenomena and Related Equilibrium Processes, Novi Sad, Serbia, September 9 – 13, 2024 ; [editors] Slobodan Gadžurić, Sanja Belić, Nikolet Cako Baganj. - Novi Sad: Prirodno-matematički fakultet, 2024

Sistemski zahtevi nisu navedeni. - Način pristupa (URL): https://issp2024.pmf.uns.ac.rs/ - Nasl. sa naslovnog ekrana dana 2. 9. 2024.

ISBN 978-86-7031-667-6

а) Хемија -- Апстракти -- Зборници

COBISS.SR-ID 151303177

Table of contents

Preface *ii*

Committees *iii*

Conference partners *iv*

Sponsors *v*

General information *vi*

Conference topics *viii*

Plenary lectures 1

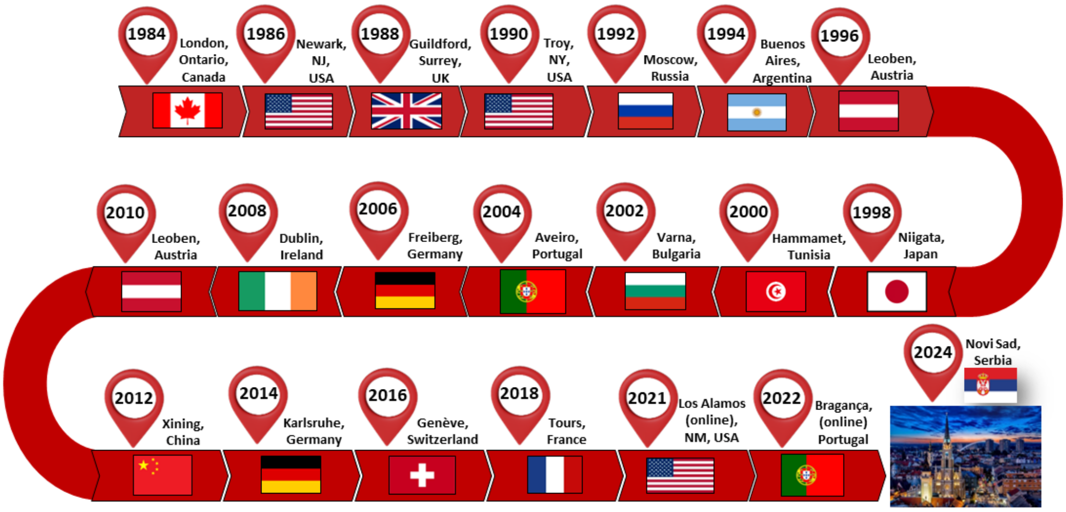
Invited lectures 6

Oral lectures 14

Posters 35

Dear colleagues and friends,

It is a great pleasure for us to organize the 21st IUPAC International Symposium on Solubility Phenomena and Related Equilibrium Processes (ISSP21) in Novi Sad, Serbia, from 9th to 13th September 2024. ISSP became a traditional conference initiated in 1984, and the first event took place in London, Ontario Canada. It is a biennial symposium organized by the IUPAC Subcommittee on Solubility and Equilibrium Data committed to gather international experts on solubility and associated properties, to exchange scientific research and technological applications within the academic, scientific, and technical communities. It addresses the general importance of these phenomena in a variety of settings ranging from green chemistry to nuclear waste disposal, always envisaging applications for sustainable development.



After two successful online conferences organized by Los Alamos National Laboratory, USA in 2021 and Instituto Politécnico de Bragança, Portugal in 2022, ISSP21 including a Workshop on Data Analysis is organized in-person and will continue to celebrate creativity, diversity, and friendship among its participants, promoting the exchange of ideas and fruitful interactions. Traditionally, Franzosini Prize will be given in recognition of outstanding and sustained contributions to the field of critical evaluation of data in solubility and related chemical equilibria and memorializes the contributions to this field by the late Paolo Franzosini, Professor of Physical Chemistry at the University of Pavia. Also, the newly established Balarew Award will be awarded for the first time in the history of ISSP to an outstanding young scientist working in the field of critical evaluation of solubility and related chemical equilibria.

We are proud that ISSP21 is organized by the Faculty of Sciences University of Novi Sad in Serbia in the year when the Solubility Data Project celebrates 50 years, the Solubility Data Series, and the creation of the IUPAC Commission V.8 on Solubility Data 45 years, and 40 years since the first ISSP has been held in London, Ontario. City of Novi Sad, the second largest city in Serbia and the European capital of culture in 2021 has been selected for the conference venue. With rich cultural heritage, traditions, multinational diversity, six official languages, youthful vibrancy, and creativity, we are sure that Novi Sad will impress you and make this event memorable.

Let us come together to share our thoughts and shape the future in this field. Welcome to Serbia, welcome to Novi Sad.

Slobodan Gadžurić, Chair of ISSP21

International Advisory Board

1. Dr. Marcus Altmeier, Karlsruhe Institute of Technology, Germany
2. Dr. Ala Bazyleva, National Institute of Standards and Technology, USA
3. Dr. Magdalena Bendova, Institute of Chemical Process Fundamentals, Czech Republic
4. Dr. Alex De Visscher, Concordia University, Canada
5. Dr. Olga Ferreira, Instituto Politécnico de Bragança, Portugal
6. Dr. Montserrat Filella, University of Genève, Switzerland
7. Dr. Slobodan Gadzuric, University of Novi Sad, Serbia
8. Dr. Maria Gonzalez-Miquel, Universidad Politécnica de Madrid, Spain
9. Dr. Johan Jacquemin, Mohammed VI Polytechnic University, Morocco
10. Dr. Glenn Hefter, Murdoch University, Australia
11. Dr. Clara Magalhães, Chair of Program Committee, Portugal
12. Dr. Selva Pereda, Universidad Nacional del Sur, Argentina
13. Dr. Simão P. Pinho, Instituto Politécnico de Bragança, Portugal
14. Dr. David G. Shaw, University of Alaska, USA
15. Dr. Ana Soto, Universidade de Santiago de Compostela, Spain
16. Dr. Michael Steiger, Hamburg University, Germany
17. Dr. Wolfgang Voigt, Technische Universität Bergakademie Freiberg, Germany
18. Dr. Earle Waghorne, University College Dublin, Ireland (Conference Editor)
19. Dr. Dewen Zeng, Central South University, China

Local Organizing Committee

1. Dr. Slobodan Gadžurić, University of Novi Sad, Serbia – Chair
2. Dr. Sanja Belić, University of Novi Sad, Serbia
3. Dr. Jasmina Anojčić, University of Novi Sad, Serbia
4. Dr. Milan Vraneš, University of Novi Sad, Serbia
5. Dr. Snežana Papović, University of Novi Sad, Serbia
6. Dr. Sanja Armaković, University of Novi Sad, Serbia
7. Dr. Suzana Apostolov, University of Novi Sad, Serbia
8. Dr. Jovana Panić, University of Novi Sad, Serbia
9. Dr. Sanja Mutić, University of Novi Sad, Serbia
10. Nikolet Cako Baganj, University of Novi Sad, Serbia
11. Teona Teodora Borović, University of Novi Sad, Serbia
12. Dajana Lazarević, Vinča Institute of nuclear Sciences, University of Belgrade, Serbia
13. Jelena Jovanović, Vinča Institute of nuclear Sciences, University of Belgrade, Serbia
14. Andrijana Bilić, University of Novi Sad, Serbia
15. Andrija Vukov, University of Novi Sad, Serbia

Conference partners

UNIVERSITAS STUDIORUM NEOPLANTENSIS
MCMLX

FACULTY OF SCIENCES NOVI SAD
1969
SERBIA

IUPAC
INTERNATIONAL UNION OF
PURE AND APPLIED CHEMISTRY

Sponsors

We would like to thank our sponsors for their support.

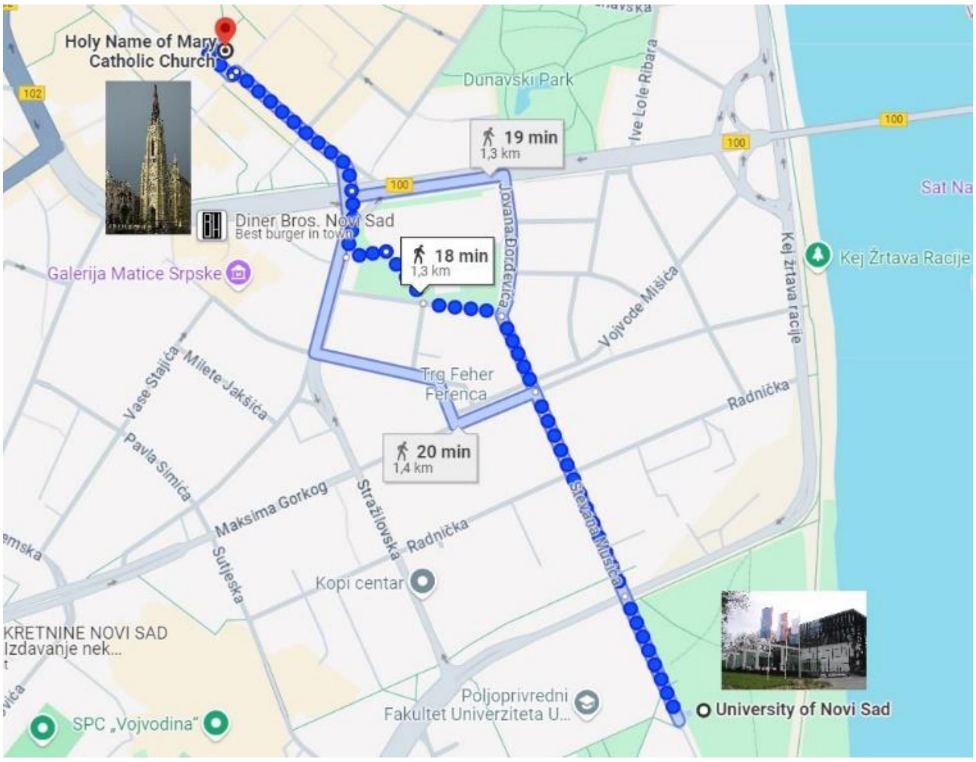
ANALYSIS
LABORATORY EQUIPMENT

processes
an Open Access Journal by MDPI

General Information

Venue
University of Novi Sad, Rectorate, dr Zorana Đinđića 1, Novi Sad Serbia

University of Novi Sad, Rectorate, address: dr Zorana Đinđića 1, Novi Sad Serbia. Our lectures are organized in the Amphitheatre on the ground floor of the building. The venue is within walking distance (about 15 minutes, 1 km) from the city center.



Registration

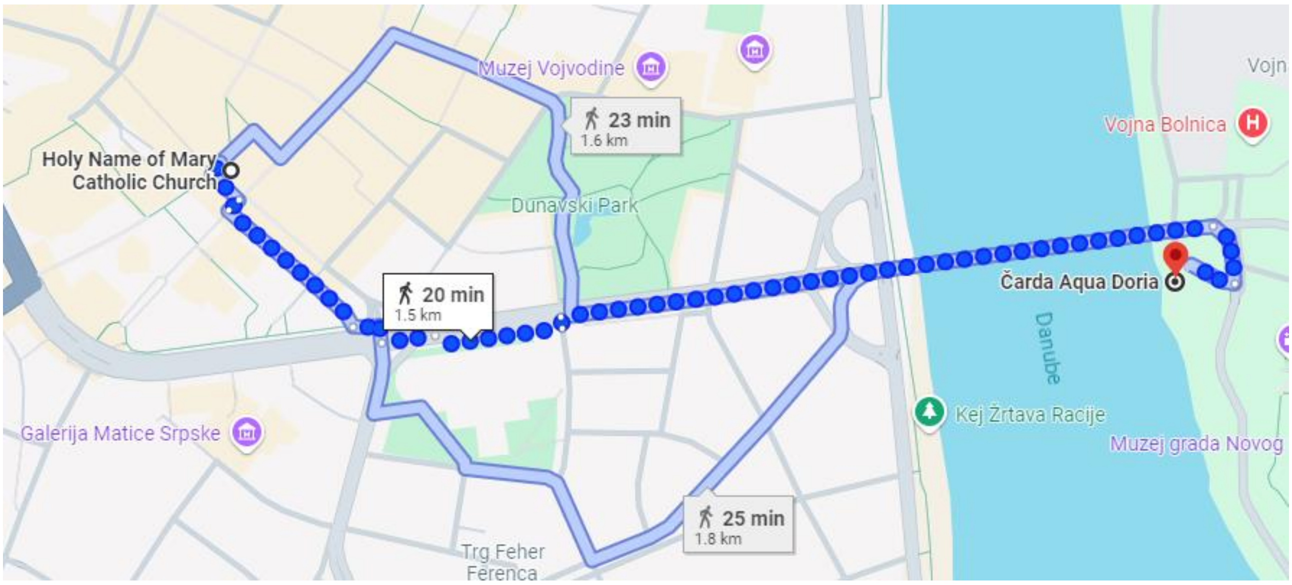
The registration desk will be open on Monday, September 9, 2024, from 8:00 am to 5:00 pm and every day during the conference from Tuesday to Friday from 9:00 am in front of the Amphitheater. Due to security reasons, participants must wear conference badges as their identification to enter the venue.

Conference tour
Novi Sad city tour with wine tasting

The city tour is scheduled for Wednesday, September 11, 2024, in the afternoon for all participants. We will start our tour from the plateau in front of the Rectorate at 13:30 h directly after lunch. During the tour, we will have a tasting of the regional wines organized in the Museum of Vojvodina province. One of the wines will be a dessert wine that is a specialty of Fruška Gora wine region in northern Serbia. It was originally intended for medicinal purposes, but later it was produced for regular consumption. It is usually served as a dessert wine, but can also be served as an aperitif, much like Vermouth. However, *Bermet* is produced in a different manner than Vermouth, through maceration of 20 different herbs and spices. It can be made of red or white grapes, but the exact recipe is secret and held by only a handful of families in the town of Sremski Karlovci. According to some documents, *Bermet* was served on the Titanic, as well as in the Vienna royal palace as one of the most favorite wines of Austrian sovereign Maria Theresa. The end of the city tour is expected around 17h.

Conference dinner
Aqua Doria restaurant, Kamenički put bb, 21000 Petrovaradin, Serbia

The conference dinner will be held on Thursday, September 12, 2024, at 20:00 in the traditional Aqua Doria Restaurant where you can enjoy traditional Serbian cuisine and music. The restaurant is located in one of the most attractive places in Novi Sad, at the foot of Petrovaradin Fortress on the bank of the Danube River (next to the bridge). You can take a taxi or just walk to the restaurant from the city center (20 min).



Topics

Aqueous Solutions

Biofuels

Computer Assisted Equilibrium Calculation

Deep Eutectic Solvents

Environmental Equilibrium Processes and Applications

Fluid Phase Equilibria

Molten Salts

Ionic Liquids

Nuclear Wastes

Solution Chemistry Complex Equilibria

Solubility Phenomena in Pharmaceutical Applications

Book of Abstracts

21st IUPAC International Symposium on Solubility Phenomena and Related Equilibrium Processes

PL1

Calorimetric and phase equilibrium data: from design of measurements methods to assessment of uncertainty and critical evaluation

Zdeněk Wagner

Department of Aerosol Chemistry and Physics, Institute of Chemical Process Fundamentals, CAS, v.v.i.
Rozvojová 135, 165 02 Prague 6 – Suchdol, Czech Republic

Presenting author email: wagner@icpf.cas.cz

Measurement is just one part of experimental scientific work in many branches including but not limited to physics and chemistry. A measured value is not much useful if its quality and reliability are not assessed. Data analysis is thus an important complement to experimental work. Mathematical analysis should often be employed even before the real measurement starts. The quality of the results of measurement techniques can be affected by settings of various parameters. For instance, the quality of the continuous measurement of heat capacity depends on the heating rate used. The optimum value should be selected by mathematical analysis of preliminary measurements.

Measurements can be affected by various types of errors. Each type of error requires its own methodology of analysis. We will limit our attention to measurement precision which is defined as closeness of agreement between indications of measured quantity values obtained by repeated measurements on the same or similar objects under specified conditions. It is also known as a repeatability as well as a random error because it behaves unpredictably but it is not necessarily a random variable in the statistical meaning of the word.

The final task is the comparison with literature values and critical evaluation. The aim is to find whether a subset of available values is possibly subject to a systematic error and after discarding them to provide a recommended value of the measured quantity. It is well known that experimenters sometimes assign to their measurements an uncertainty that is lower than reality. On the contrary, compilers of databases and other collections sometimes assign an uncertainty that is too high. Published values of uncertainty thus cannot be relied upon. The mathematical tools that are nowadays in use cannot reliably distinguish between poor precision (i.e. high scatter) and systematic deviation because there is no statistical model of systematic errors. A different approach is therefore needed.

The lecture will demonstrate the application of modern robust non-statistical methods of data analysis based on mathematical gnostics to all three interconnected parts of experimental work on real measurements of calorimetric and phase equilibrium data. Advantages, disadvantages, and limitations will be discussed.

PL2
Using the available pKa data in non-aqueous solvents

Ivo Leito, Ivari Kaljurand, Sofja Tshepelevitsh, Agnes Kütt, Märt Lõkov, Jaan Saame, Agnes Heering, Elisabeth Parman, Sigrid Selberg, Andre Leesment, Merili Tammiste, Helerin Roomet and Carmen Kesküla

University of Tartu, Institute of Chemistry, Ravila 14a, 50411 Tartu, Estonia

Presenting author email: ivo.leito@ut.ee

The acid and base strengths, typically expressed as pKa values, depend on the solvation of the proton, as well as of the neutral and ionized forms of the acid/base [1]. Every solvent has different solvation properties. Thus, the pKa values for the same acid/base in different solvents are also different (often dramatically different). In principle, whenever using pKa values for predicting or rationalizing chemical processes, the pKa values determined in the same solvent should be used. Two main problems arise:

1. In some solvents, e.g. water, DMSO or acetonitrile large bodies of pKa data exist, while in most solvents either very few pKa values are available or none at all.
2. Reliably measuring pKa values in non-aqueous solvents is difficult.

Thus, the pKa data in the literature is often unreliable. This presentation addresses both of these problems. The problem 1 can often be solved by estimating pKa values in one solvent from the data in other solvent(s) [2,3]. An overview to what extent such estimates can be usefully done, highlighting both successes and failures. Concerning the reliability of the non-aqueous pKa data a brief overview will be given of the IUPAC project 2015-020-2-500 “Critical compilation of acid pKa values in polar aprotic solvents" [4].

[1] A. Kütt, S. Selberg, I. Kaljurand, S. Tshepelevitsh, A. Heering, A. Darnell, K. Kaupmees, M. Piirsalu, I. Leito, *Tetrahedron Lett*. 2018, **59**, 3738.
[2] S. Tshepelevitsh, A. Kütt, M. Lõkov, I. Kaljurand, J. Saame, A. Heering, P. G. Plieger, R. Vianello, I. Leito, Eur. *J. Org. Chem*. 2019, **40**, 6735.
[3] A. Kütt, S. Tshepelevitsh, J. Saame, M. Lõkov, I. Kaljurand, S. Selberg, I. Leito, *Eur. J. Org. Chem*. 2021, **9**, 1407.
[4] Critical compilation of acid pKa values in polar aprotic solvents, IUPAC project 2015-020-2-500, https://iupac.org/project/2015-020-2-500, 2024.

PL3

Exploring the potential: design strategies and applications of deep eutectic solvents

Mirjana Minceva

Biothermodynamics, Technical University of Munich, Maximus-von-Imhof-Forum 2, Freising, 85354, Germany

Presenting author email: mirjana.minceva@tum.de

Deep eutectic solvents (DES) represent a promising class of designer solvents with diverse applications across various fields. DESs are eutectic mixtures of two or more compounds with a melting temperature significantly lower than that of the pure constituents. The DES physicochemical properties can be tuned by selecting its constituents. However, due to the large number of potential compounds that can be used to form DES, the design of these solvents is challenging. Therefore, understanding the DES formation is essential for selecting the constituents and defining their molar ratio to tune the solvent properties accordingly.

This talk will discuss approaches for designing DES and tailoring their compositions for specific applications. The importance of the solid-liquid equilibria (SLE) as a starting point in the DES design will be elaborated. Applications of DES in separation processes with a focus on extraction and chromatography, as well as current limitations and challenges, will be presented. The presentation aims to inspire further research and innovation in exploring DESs´ full potential as powerful solvents.

PL4
Thirty years of ionic liquids

Andrea Mele

Department of Chemistry, Materials and Chemical Engineering, Politecnico di Milano,
Piazza L. da Vinci 32, 20133 Milano, Italy

Presenting author email: andrea.mele@polimi.it

The history of ionic liquids (ILs) began with a chance discovery, the scientific implications of which were not understood at the time. Ethylammonium nitrate, prepared by Walden in 1914, was viewed as an academic oddity, a salt with a melting point so low that it remained liquid at room temperature. The world wasn't yet ready to grasp the exceptional potential of room-temperature liquid salts.

It took about 80 years to arrive at the first class of compounds -the alkylimidazolium salts- which we rightfully consider the forerunners of modern ionic liquids, organic salts with melting points below the ordinary boiling point of water.

The number of publications indexed with the keyword "ionic liquids" grew from 323 in 1992 to over 7,500 in 2022, reflecting the incredible success of this class of compounds.

In this presentation, we will trace the milestones in the study of ionic liquids through five pillars:

- Local structuring
- Gas absorption
- Interaction of ILs with biomacromolecules
- Use of IL with biomass
- Ionic liquids and energy storage devices

The central theme of the presentation is the close interconnectedness between the fundamental understanding of intermolecular interactions within ionic liquids and the innovative and diverse applications that characterize this class of compounds today.

PL5
Chemistry in art and art in chemistry

Clara Magalhães

School of Biological, Earth & Environmental Sciences, UNSW Sydney, NSW 2052, Australia
LEAF, Linking Landscape Environment Agriculture and Food Research Centre, Associate Laboratory TERRA, Instituto Superior de Agronomia, University of Lisbon, Lisbon, Portugal

Presenting author email: mclara@ua.pt

Chemistry is the science of materials, their properties and transformations. Art is a human activity that uses a variety of languages combining color, space, image, movement, words, sound and volume. Combining Chemistry and Art the interested basic elements are color, image, space and volume. The interest lies in drawing, painting, photography, sculpture and architecture.

Chemistry appears in art, fundamentally in painting and drawing, long before its creation as a science, as many of the objects and methods are inherited from alchemy. Art has been used to disseminate the scientific knowledge. Nowadays, new substances, materials and structures can be used to built new artworks.

In today's world, with changes in the atmosphere, all of this heritage is subject to much more energetic solar radiation and intense climatic conditions. It is not only the outer atmosphere that has been changing but also the inner atmospheres. There are more and more visitors to exhibition sites (museums, caves, art galleries) with a strong impact on the indoor environment. How do these changes influence artworks?

Chemistry can help to restore damaged art pieces as well as in the rehabilitation of old buildings facing specific problems. Analytical techniques are very important to identify artworks, by studying the composition of the materials, their origins and also the artist techniques. Analytical techniques can help to determine the authenticity of an artwork and to identify forgeries.

Artists must know the materials they work with. Accidents can happen and should be minimized. Artists, like chemists, must know the safety procedures when using different materials.

IL1

Modeling the dependence of stability constants on medium and ionic strength. The pure water model

Clemente Bretti[1], Concetta De Stefano[1], Sofia Gama[2], Claudia Granata[1], Gabriele Lando[1], Salvatore Raccuia[1] and Demetrio Milea[1]

[1] Dipartimento di Scienze Chimiche, Biologiche, Farmaceutiche ed Ambientali, CHIBIOFARAM, Università degli Studi di Messina, Viale F. Stagno d'Alcontres 31, 98166 Messina, Italy.
[2] C2TN - Centro de Ciências e Tecnologias Nucleares, Instituto Superior Técnico, Universidade de Lisboa, Estrada Nacional 10 (km 139.7), 2695-066, Bobadela LRS, Portugal.

Presenting author email: dmilea@unime.it

The dependence of stability constants (and activity coefficients) on medium, ionic strength and temperature can be modelled by several approaches. The most common (e.g., Davies, Bromley, Pitzer, Specific ion Interaction Theory – SIT) can be considered as evolutions of the (Extended) Debye-Hückel theory/equation. All models and theories have pros and cons, so that none can be considered better than others [1]. Between the '80s and '90s, the group of Prof. Silvio Sammartano from the University of Messina proposed, with the precious support of colleagues from the Italian Universities of Torino, Catania and Palermo, a model [2] (with the relative equation), for the ionic strength (and temperature) dependence of formation constants, based on three simple assumptions:

[H1]: It is possible to express the dependence on ionic strength of formation constants by a simple equation, independently of the type of reactants and products, and only dependent on the type of reaction.

[H2]: All the deviations from the predicted behavior are ascribed to weak complex formation between components and/or species under study and the background ions (e.g., the ionic medium). This implies that "pure water" is considered as reference state, and some ions as non-interacting with the reactants and/or products involved in the studied equilibrium.

[H3]: Perchlorate does not interact with cationic species, tetraethylammonium cations (and higher tetraalkylammonium analogues) do not with O-donor ligands, and Na^+ and K^+ do not with N-donor ligands.

Evidences collected during more than half a century in those universities demonstrated the validity of this "pure water model", and showed the potential of this approach to model the speciation of several multicomponent complex systems in a very simple way. This contribution describes the main features of the pure water model through some examples, highlighting the theoretical and practical aspects of this approach in the speciation modeling of systems of different complexity, including real systems.

Acknowledgements: We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 1409 published on 14.9.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU– Project Title Efficient Sequestration of Metal Ions from Aqueous Systems for Green and Sustainable Applications - AquaGreen – CUP J53D23014430001- Grant Assignment Decree No. 1409 adopted on 14/09/2022 by the Italian Ministry of Ministry of University and Research (MUR). This contribution is dedicated to the memory of Prof. Silvio Sammartano, for the unquestionable impact he had in developing research in this and related fields.

[1] L. Castellino, E. Alladio, S. Bertinetti, G. Lando, C. De Stefano, S. Blasco, E. García-España, S. Gama, S. Berto, D. Milea, *Chemometr. Intell. Lab. Syst.* 2023, **239**, 104860.
[2] P.G. Daniele, A. De Robertis, C. De Stefano, S. Sammartano, in *Miscellany of scientific papers in honour of Enric Casassas, professor of Analytical Chemistry*, S. Alegret, J.J. Arias, D. Barcelò, J. Casal, G. Router, Eds., Universitat Autonoma de Barcelona, Bellaterra, Spain, 1991, 121.

IL2

Thermodynamics of aqueous solutions of menthol-basedchiral ionic liquids from the macroscopic and molecularviewpoints

Magdalena Bendová[1,2], Joanna Feder-Kubis[3], Jan Heyda[1], Zdeněk Wagner[2], Jakub Polák[1] and Martin Melčák[1]

[1] University of Chemistry and Technology, Prague, Technická 5, 166 28, Prague 6, Czech Republic
[2] Institute of Chemical Process Fundamentals, Rozvojová 135/1, 165 02, Prague 6, Czech Republic
[3]Wrocław University of Science and Technology, Faculty of Chemistry, Wybrzeże Wyspiańskiego 27, 50-370, Wrocław, Poland

Presenting author email: bendovam@vscht.cz

Even though squeous solutions of organic and inorganic compounds, including of ionicliquids, are some of the most studied systems in physical chemistry, we still lack some understanding of the solute-solvent interactions of ionic liquid ions with water at the molecular level. In addition, such systems have an increasing practical relevance, as the properties of ionic liquids may be modified not only in terms of their structure, but also by adding suitable molecular solvents. Water seems to be one of the obvious choices, due to its availability and low toxicity. To better understand its interaction with ionic liquids, wepropose an experimental and molecular dynamic simulation study of physicochemical properties and phase behaviour of these systems [1]. Experimental volumetric, osmometric, thermal and transport properties provide us with a fair amount of data on solution chemistry of aqueous solutions of ionic liquids in their own right. MD simulations then allow for an even deeper insight into the molecular structure of ILs in water, while estimates of bulk volumetric and transport properties by simulations can be validated by the corresponding experiments.

In this contribution, this approach will be illustrated by examples of studies of volumetric, transport and osmometric properties in aqueous solutions of conventional and chiral ionic liquids (e.g. in 1-alkyl-3-[(1R,2S,5R)-(–)-menthoxymethyl]imidazolium chlorides) by means of experiments and MD simulations. In addition to binary aqueous solutions, octanol-water partitioning of the studied ILs will be discussed.

Acknowledgements: Specific university research (A1_FCHI_2022_002), the Czech Science Foundation (grant 20- 24155S), MEYSe-INFRA CZ (ID:90140) and National Science Centre, Poland (Grant No. UMO-2020/37/B/NZ9/04201) are greatly acknowledged.

[1] M. Bendová, J. Heyda, Z. Wagner, J. Feder-Kubis, J. Polák, T. Tankam, et al., *J. Mol. Liq.* 2023, **378**, 121591.

IL3

Solute aggregates in solution and the crystallization of organic molecules

Ricardo Simões

Departamento de Química e Bioquímica, Universidade de Lisboa, Centro de Química Estrutural, Institute of Molecular Sciences, Faculdade de Ciências, Campo Grande, Lisboa, 1749-016, Portugal

Presenting author email: rasimoes@fc.ul.pt

Crystallization from solution remains one of the most widely used, and yet poorly understood, methods for the preparation and purification of solid materials. Control over the crystallization process is often challenging, as even small variations in experimental conditions can lead to the production of different solid forms of a compound (polymorphism). As each polymorph displays unique physical properties (such as fusion temperature, colour, conductivity, or solubility), crystallization control is an important issue in many industries, with an impact on the reproducible manufacture, and safe use, of a product (e.g., variations in the solubility of pharmaceutical compounds changing their bioavailability).

It is generally assumed that crystal formation occurs through a mechanism of nucleation and growth. As the solution reaches a metastable state (supersaturation), small nuclei of the new phase begin to form, growing into macroscopic crystals by incorporating further solute molecules. Recent studies, however, have highlighted that stable aggregates of solute molecules are often already present in solution, even before reaching conditions of supersaturation. The role of these prenucleation clusters in the crystallization process is now being investigated [1].

The impact of solute aggregation on the precipitation of different solid forms is here explored for the crystallization of 4’-hydroxyacetophenone (HAP, Figure 1), from water. HAP is known to adopt two anhydrous polymorphs as well as three hydrated forms. When crystallized from water, the obtained solid form is highly sensitive to the experimental conditions. Indeed, two of the hydrates (H2, and H3) and the anhydrous form I can be selectively produced, through cooling crystallization of aqueous HAP solutions, simply by varying the initial concentration of the solute [2]. Variations in the solution structure, as a function of the temperature and composition, were assessed by combining volumetric and acoustic measurements with molecular dynamics simulations.

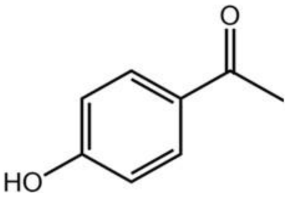


Figure 1. Molecular structure of 4’-hydroxyacetophenone.

Acknowledgements: Centro de Química Estrutural is a Research Unit funded by Fundação para a Ciência e Tecnologia (FCT) through projects UIDB/00100/2020 (https://doi.org/10.54499/UIDB/00100/2020) and UIDP/00100/2020 (https://doi.org/10.54499/UIDP/00100/2020). Institute of Molecular Sciences is an Associate Laboratory which is funded by FCT through project LA/P/0056/2020 (https://doi.org/10.54499/LA/P/0056/2020). This work was further supported by the FCT project 2021.03239. CEECIND (https://doi.org/10.54499/2021.03239.CEECIND/CP1650/CT0003). R. G. Simões gratefully acknowledges the FCT grant SFRH/BPD/118771/2016.

[1] D. Gebauer, P. Raiteri, J.D. Gale, H. Cölfen, *Am. J. Sci.*, 2018, **318**, 969.
[2] C.E.S. Bernardes, M.E. Minas da Piedade, *Cryst. Growth Des.*, 2012, **12**, 2932.

IL4
The intricate role of salts and sugars in biomolecular complexation

Miha Lukšič and Matjaž Simončič

Faculty of Chemistry and Chemical Technology, University of Ljubljana, Večna pot 113, SI-1000, Ljubljana, Slovenia

Presenting author email: miha.luksic@fkkt.uni-lj.si

The balance between attractive and repulsive interactions between protein and a synthetic polyelectrolyte (PE) in aqueous solutions determines the formation of protein-PE complexes. The strength of the interactions for a given protein-PE system and their modulation strongly depend on the PE charge density, the heterogeneous charge distribution of the protein surface, the pH and ionic strength of the solution, the presence of co-solutes, etc. and can lead to phase separation. Complexation is often initiated at pH values where both macromolecules have the same charge sign (so-called complexation on the "wrong side" of the isoionic point of the protein) [1]. Understanding how other components (such as salts, buffers, sugars, etc.) influence the onset of complexation is critical given its importance in numerous applications, including protein purification, drug delivery systems, biomaterials and biosensors.

We have investigated the modulating role of salts (NaCl, NaBr, NaI) and sugars (sucrose, sucralose) on complexation between a globular protein, bovine serum albumin (BSA), and a synthetic polyelectrolyte, sodium polystyrene sulfonate (NaPSS), at pH values above the isoionic point of BSA using a combination of experimental techniques and molecular modelling. The electrostatic attraction between positively charged patches on the BSA surface and the overall negatively charged NaPSS is responsible for the onset of BSA-NaPSS complex formation. Salt ions screen attractive electrostatic interactions and hinder complex formation in a concentration-dependent manner. Ion-specific effects have been observed (NaI > NaBr > NaCl) [1]. The effect of sugars on complex formation is less pronounced: sucrose showed no significant effect, while its chlorinated analogue, sucralose, prevented phase separation. The differences in the effect of these two sugars are due to their water-structuring capabilities [2,3]. Consistent with the so-called *preferential exclusion mechanism*, sucrose does not interact directly with the protein surface, whereas sucralose adheres to the BSA surface (*preferential interaction mechanism*) and can hinder contact between BSA and NaPSS.

Acknowledgements: financial support from the ARIS is acknowledged (research core funding no. P1-0201)

[1] M. Simončič, J. Hritz, M. Lukšič, *Biomacromolecules*, 2022, **23**, 4412.
[2] M. Simončič, M. Lukšič, *Polymers*, 2022, **14**, 1245.
[3] M. Simončič, M. Lukšič, *J. Mol. Liq.*, 2021, **326**, 115245.

IL5
Insight into the impact of ionic liquids on forming aqueous biphasic systems

Tatjana Trtić-Petrović[1], Milan Vraneš[2] and Slobodan Gadžurić[2]

[1]Vinča Institute of Nuclear Sciences, National Institute of the Republic of Serbia, University of Belgrade, Belgrade, Mike Petrovića Alasa 12-14, 11351, Belgrade, Serbia
[2]Department of Chemistry, Biochemistry and Environmental Protection, University of Novi Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia

Presenting author email: ttrtic@vin.bg.ac.rs

Aqueous biphasic systems (ABS) are formed when two water-soluble components are mixed in water at specific concentrations. Due to the negligible volatilities of the phase-forming constituents and the high water content, ABS are environmentally friendly and biocompatible alternatives to traditional liquid-liquid extraction methods. Rogers et al. [1] introduced ionic liquids (ILs) into the formation of ABS, spurring extensive research into IL-based ABS. The inherent advantages of ABS can be combined with the biocompatibility and favorable characteristics of ILs, including their tunability and wide solubility for both polar and non-polar compounds. Various combinations of ILs with inorganic and organic salts, alcohols, carbohydrates, and polymers have been reported to form ABS. The properties of ILs, such as density, viscosity, and surface tension, significantly influence the phase behavior in ABS. The potential of IL-ABSfor the extraction, separation, and enrichment of diverse classes of compounds, including biomolecules,metal ions, pharmaceuticals, and dyes, has been extensively explored. Three major types of IL-based ABS have been extensively studied: IL-inorganic salt ABS, IL- carbohydrate ABS, and IL-polymer ABS. The formation and stability of IL-based ABS are influenced by the structure of the ILs, temperature, pH, and the nature and functionality of the other phase-forming components such as the charge density of the salts, the structure of the carbohydrates and the molar mass andfunctionality of the polymers. Firstly, the impact of the IL cation structure (such as alkyl chain length and substituents at the N-1 and N-3 positions of the imidazolium cation) and anion on forming ABS with inorganic salts was investigated. It was found that the ability to form ABS increases with the alkyl chain length on the imidazolium cation. Additionally, ILs with an ethyl group at the N-3 position form ABS more effectively compared to those with a methyl substituent, attributed to the increased hydrophobicity of the ILs and their lower affinity for water. Secondly, the formation of ABS based on symmetric imidazolium ILs, such as 1,3-dibutylimidazolium and 1,3-diethylimidazolium combined with phosphate and citrate salts, was examined. It was found that the ABS based on 1,3-dibutylimidazolium dicyanamide exhibited an exceptionally large biphasic area, requiring avery low amount of salt (~2%) to induce phase separation. Thirdly, the effect of naturally derived anions (such as acetate, lactate, pyruvate, taurate, and nicotinate) in choline-based ILs on forming ABS with polymers was studied. The salting-out aptitude of these ILs is directly related to the hydration capacity of their ions. Since all the ILs share a common cation, choline, more hydrophilic anions with higher charge density, like acetate, exhibit greater hydration ability and stronger salting-out effects. To better understand the impact of ILs on ABS formation efficiency, computer simulations were conducted.

Acknowledgements: This work was supported by the Ministry of Science, Technological Development and Innovation, Republic of Serbia (contract number 451-03-66/2024-03/200017).

[1] K.E. Gutowski, G.A. Broker, H.D. Willauer, J.G. Huddleston, R.P. Swatloski, J.D.Holbrey, R.D. Rogers, *J. Am.Chem. Soc.*, 2003, **125**, 6632.
[2] A. Dimitrijević, N. Zec, N. Zdolšek, S. Dožić, A. Tot, S. Gadžurić, M. Vraneš, T. Trtić-Petrović, *J. Ind. Eng. Chem.*, 2016, **40**, 152.
[3] A. Dimitrijević, A. Jocić, N. Zec, A. Tot, S. Papović, S. Gadžurić, M. Vraneš, T. Trtić-Petrović, *J. Ind. Eng. Chem.*, 2019, **76**, 500.
[4] A. Dimitrijević, A.P.M. Tavares, M.R. Almeida, M. Vraneš, A.C.A. Sousa, A.C. Cristóvão, T. Trtić-Petrović, S. Gadžurić, M.G. Freire, *ACS Sustain. Chem. Eng.*, 2020, **8**, 5683.

IL6

Ionic liquids in organic synthesis: mechanistic aspects in Knoevenagel reactions

Caroline D'Oca[1], Kahlil Salome[2], Elise Rios[1], Uenifer Rodrigues Couto,[3] Giuliana Pavanelli[1] and Claudio Tormena[3].

[1] Agrochemical and Medicinal Organic Synthesis Research Group, Chemistry Department, Federal University of Parana, Curitiba, 81531-980, Brazil
[2]NMR Laboratory, Chemistry Department, Federal University of Parana, Curitiba, 81531-980, Brazil.
[3]Institute of Chemistry, University of Campinas, 13083-970, Brazil

Presenting author email: carolinedoca@ufpr.br

Knoevenagel reaction, also known as Knoevenagel condensation, is a classical transformation between a carbonyl compound (aldehydes or ketones) and an activated methylene compound, such as a 1,3-dicarbonyl compound, with ammonia or other amines as catalysts in organic solvents, to obtain the Knoevenagel condensation product, a dicarbonyl α,β-unsaturated compound [1]. In spite of your 128 years old, this reaction remains a powerful tool to form new C-C bonds, employed as key-step in many synthetic strategies to afford complex structural compounds in linear or multicomponent processes [2-5].

In recent years, ionic liquids (ILs) have emerged as a greener alternative to commonly used organic solvents and catalysts. Their green characteristics, combined with their low volatility, non-inflammable nature, thermal stability, and capacity for reuse as catalysts, have made ILs an environmentally friendly option for organic synthesis [6]. However, a few studies have reported the use of ILs for both their solvent and catalytic functions; ILs have been used most commonly as solvents in the presence of another catalyst/promoter system or as catalysts in the presence of a solvent.

In this work, the use of Pyrrolidinium ionic liquids **3-5** (PyrrILS) as solvent and catalyst in the Knoenevagel reactions is described, using several classic 1,3-dicarbonyl compounds **2** (β-ketoesters, 1,3-diketones, Meldrum's acid, and malonates) with aliphatic aldehydes **1**, in a solvent-free media (Figure 1). Besides, the mechanistic aspects are discussed, supported by NMR experiments.

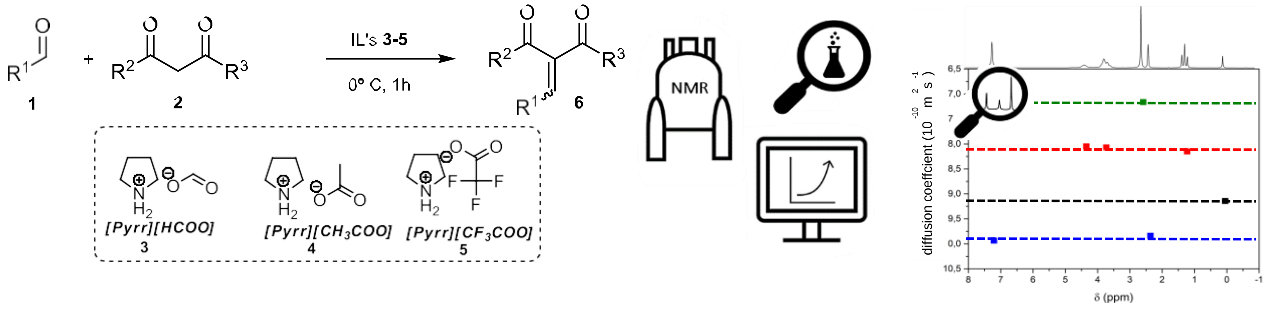


Figure 1. Mechanistic studies in Knoevenagel reaction and Ionic Liquids.

[1] E. Knoevenagel, *Dtsch. Chem. Ges.*1894, **27**, 2345.
[2] R.V. Hangarge, D.V. Jarikote, M.S. Shingare, *Green Chem*., 2002, **4**, 266.
[3] D.Z. Xu, Y.J. Liu, S. Shi, Y.M. Wang, *Green Chem.*, 2010, **12**, 514.
[4] S.H. Zhao, X.J. Wang, L.W. Zhang, *RSC Adv*., 2013, **3**, 11691.
[5] A. Al Otaibi, C.P. Gordon, J. Gilbert, J.A. Sakoff , A. McCluskey, *RSC Adv*., 2014, **4**, 19806.
[6] S.K. Singh, A.W. Savoy, *J. Mol. Liquids*, 2020, **297**, 112038.

IL7

Study of oxides solubility in fluoride molten salts

Blanka Kubíková, František Šimko, Michal Korenko, Jarmila Mlynáriková,
Zuzana Vasková and Miroslav Boča

Institute of Inorganic Chemistry, Slovak Academy of Sciences, Dúbravská cesta 9, Bratislava, 84536, Slovakia

Presenting author email: blanka.kubikova@savba.sk

Research on molten salts, especially fluoride systems, has experienced a significant renaissance in last decade. This focus is mainly on special applications that have the potential to replace old ones, while obtaining various benefits such as environmental, economic and, of course, functional. From a relatively wide range we can highlight in particular:

- use in metallurgy (e.g. solvent of electroactive component in electrolytic production of metals)
- use in energy applications: i) in Generation IV reactors; (ii) in the field of solar energy storage
- use in other areas: e.g. i) preparation of single crystals with desired physical properties (piezoelectrics, optical transparency, ion conductors ...), ii) preparation of substances serving as standards for various analytical methods, iii) preparation of substances with defined spectral properties (e.g. photoluminescence).

The recycling seems to be the efficient way how to reduce the dependence on imports of raw materials, reduce the volume of waste and how to increase the sustainable development. Molten salt electrolysis is an industrial method for metals or alloys production from corresponding mixtures, including oxides. It is known that the solubility of oxides is not high but the presence of fluorides increase the solubility, especially in the case of rare earth elements.

We have mainly used thermal analysis method and XRD analysis for investigation of oxides solubility. Oxides solubility differ from used fluoride molten salts.

Acknowledgements: This work was supported by Slovak grant agency: VEGA 2/0083/24.

[1] https://eur-lex.europa.eu/legal-content/SK/TXT/?uri=CELEX:52020DC0474

IL8
Drug solubility enhancement: from buffer complexes formation to acid-base supersolubilization

Tatjana Verbić[1], Olivera Marković[2], Miloš Pešić[1], Igor Topalović[1], Mladen Đurđević[3], Martin Kuentz[4], Alex Avdeef[5] and Abu Serajuddin[6]

[1]University of Belgrade, Faculty of Chemistry, Studentski trg 12-16, Belgrade, 11158, Serbia
[2]University of Belgrade, Institute of Chemistry, Technology and Metallurgy – National Institute of the Republic of Serbia, Njegoševa 12, Belgrade, 11000, Serbia
[3]University of Belgrade – Faculty of Pharmacy, Vojvode Stepe 450, Belgrade, 11221, Serbia
[4]University of Applied Sciences and Arts Northwestern Switzerland, School of Life Sciences, Institute of Pharma Technology, Hofackerstrasse 30, Muttenz, 4132, Switzerland
[5]*in*-ADME Research, 1732 First Avenue, New York, NY 10128, USA
[6]St. John's University, College of Pharmacy and Health Sciences, 8000 Utopia Parkway, Queens, NY 11439, USA

Presenting author email: tatjanad@chem.bg.ac.rs

A majority of the new chemical entities (NCE) that emerged as potential drug candidates in pharmaceutical development during the past 2-3 decades are practically insoluble solids consisting of ionizable molecules [1]. Class II BCS drugs (Biopharmaceutics Classification System) exhibit poor bioavailability due to insufficient absorption in the gastrointestinal tract with slow drug release from the dosage forms and low solubility as the limiting steps for their absorption [2]. Thus, detailed and precise study of compound solubility and the possibilities to increase solubility and dissolution rate, are at the core of the development of bioavailable drug dosage forms and clinically effective pharmaceutical products that would dissolve in gastric and intestinal fluids after oral administration or not precipitate in the blood after intravenous administration. A *white paper* on consensus recommendations for improving data quality in equilibrium solubility measurement of ionizable drugs [3] emphasizes the importance of precise solubility measurements. As a part of solubility studies of a group of tricyclic antidepressants (TCAs) we have shown the influence of competing counterions, such as buffering agents, complexing agents, salt coformers, tonicity adjusters, and solid-phase transformations on the aqueous solubility of studied drugs [4-5].

A variety of methods to increase solubility and/or dissolution rate, and thereby increase their bioavailability, have been developed. Still, most of them, like particle size reduction, salt formation, conversion to amorphous form, solid dispersion, and solubilization in lipids or lipid-surfactant mixtures have their own limitations. To mitigate some of the above limitations, a novel method of drug solubilization in aqueous media by acid–base interactions has been developed [6]. This novel approach of greatly increasing the solubility is based on interactions of a model low-soluble basic drug in an aqueous medium with acidic species that would not normally form salts with it. Although quite successful, the proposed model still needs additional work and some fine-tuning with additional low-soluble drugs to establish it as a widely accepted method for increasing solubility, dissolution rate and bioavailability of poorly water-soluble drugs. Our research team is working on it.

Acknowledgements: This research has been financially supported by the Ministry of Science, Technological Development and Innovation of Republic of Serbia (Contract No: 451-03-66/2024-03/200168, 451-03-66/2024-03/200026, 451-03-65/2024-03/200161, No 451-03-66/2024-03/200161).

[1] C.A. Lipinski, *J. Pharmacol. Toxicol. Methods*, 2000, **44**, 235.
[2] C.A.S. Bergström, R. Holm, S.A. Jørgensen, S.B.E. Andersson, P. Artursson, S. Beato, A. Borde, K. Box, M. Brewster, J. Dressman, K-I. Feng, G. Halbert, E. Kostewicz, M. McAllister, U. Muenster, J. Thinnes, R. Taylor, A. Mullertz, *Eur. J. Pharm. Sci.*, 2014, **57**, 173.
[3] A. Avdeef, E. Fuguet, A. Llinàs, C. Ràfols, E. Bosch, G. Völgyi, T. Verbić, E. Boldyreva, K. Takács-Novák, *ADMET&DMPK*, 2016, **4**, 117.
[4] O.S. Marković, N.G. Patel, A.T.M. Serajuddin, A. Avdeef, T.Ž. Verbić, *Mol. Pharmaceutics*, 2022, **19**, 710.
[5] O.S. Marković, M.P. Pešić, A.V. Shah, A.T.M. Serajuddin, T.Ž. Verbić, A. Avdeef, *Eur. J. Pharm. Sci.*, 2019, **133**, 264.
[6] S. Singh, T. Parikh, H.K. Sandhu, N.H. Shah, A.W. Malick, D. Singhal, A.T.M. Serajuddin, *Pharm. Res.*, 2013, **30**, 1561.

OL1
My adventures with the solubility data

On the occasion of the Franzosini Prize

Cezary Gumiński

Department of Chemistry, University of Warsaw, Pasteura 1, 02093 Warszawa, Poland

Presenting author email: cegie@chem.uw.edu.pl

The present speaker is co-author of 10 volumes [1-10] published within the IUPAC-NIST Solubility Data Series. He has been a four dacades member of the Solubility Data Commission and later the Subcommittee for Solubility and Equilibrium Data.

Preparation of the volumes for this series is really a time consuming process that needs a very systematic activity. Primary materials must be completed as much as possible. Some subjects need inspection of such rare sources as U.S. Atomic Energy Commission Reports, conference materials, rare journals and reports from Russia and China (not in English). After preparation of data sheets for every experimental study, critical evaluations of selected systems are prepared. Finally, authors of the critical evaluations select the best or recommended solubility data set to be further used by scientific as well as technical community. Therefore, the solubility volumes should not be treated as a kind of reviews where authors are not obliged for detailed assessment and a selection of recommended values.

This author was involved in elaboration of two kinds of systems: where liquid mercury or alkali metals (at elevated temperatures) were the solvents and where rare earth metal salts were dissolved in various aqueous media. Critical evaluations for a part of them were complicated by significant scatter of the solubility results. The most frequent reasons of the divergences were: purity of components of a systems being investigated, slow kinetics of an real equilibrium approach and side chemical reactions connected with solubility process.

[1] Z. Galus, C. Gumiński, Metals in Mercury, 1986, C. Hirayama, Ed., Pergamon, Oxford.
[2] Z. Galus, C. Gumiński, Intermetallic Compounds in Mercury, 1992, J. Osteryoung, M. Schneider, Eds., Pergamon, Oxford.
[3] H.U. Borgstedt, C. Gumiński, Metals in Liquid Alkali Metals, 1996, Oxford University, Oxford.
[4] H.U. Borgstedt, C. Gumiński, Metals in Liquid Alkali Metals,, 1996, Oxford University, Oxford, 1996.
[5] H.U. Borgstedt, C. Gumiński, *J. Phys. Chem. Ref. Data*, 2001, **30**, 835.
[6] H. Miyamoto, R. Miyamoto, C. Gumiński, M. Salomon, *J. Phys. Chem. Ref. Data*, 2008, **37**, 933.
[7] T. Mioduski, C. Gumiński, D. Zeng, , *J. Phys. Chem. Ref. Data*, 2008, 37, 1765.
[8] T. Mioduski, C. Gumiński, D. Zeng, H. Voigt, *J. Phys. Chem. Ref. Data*, 2012, **41**, 013104.
[9] T. Mioduski, C. Gumiński, D. Zeng, *J. Phys. Chem. Ref. Data*, 2014, **43**, 013105.
[10] C. Gumiński, L.Sh. Wang, T. Mioduski, Rare Earth Metal Sulfates in Water and Aqueous Systems, in preparation.

OL2
Enhancing acetaminophen solubility in aqueous solutions with hydrotropes

Aline Zambom[1,2,3], João Santos[1,2,4], Priscilla S. Gaschi[4], Mónia A. R. Martins[1,2], João A. P. Coutinho[3], Olga Ferreira[1,2]and Simão P. Pinho[1,2]

[1]Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253, Bragança, Portugal
[2]Laboratório para a Sustentabilidade e Tecnologia em Regiões de Montanha, Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253, Bragança, Portugal
[3]CICECO–Aveiro Institute of Materials, Department of Chemistry, University of Aveiro, 3810-193, Aveiro, Portugal
[4]Departamento de Engenharia Química, Universidade Tecnológica Federal do Paraná, 84016-210, Ponta Grossa, Brazil

Presenting author email: aline.z@ua.pt

Hydrotropes are compounds capable of enhancing the solubility of sparingly soluble molecules in aqueous media, thereby expanding their effective use in many applications [1]. Typically, these compounds exhibit amphiphilic properties, characterized by both hydrophilic and hydrophobic domains within their molecular structure. And while an increase in solubility indicates hydrotrope efficiency, it also holds significance for water activity. In fact, the addition of hydrotropes is known to alter the free water within the system, potentially impacting its activity in pharmaceutical formulations [2,3]. Within the pharmaceutical industry, several traditional hydrotropes are commonly used to enhance the solubility of poorly water-soluble drugs, namely sodium-based salts like benzoate or salicylate, short alkylbenzene sulfonates, and selected small organic compounds such as urea or nicotinamide [2].

Acetaminophen (ACP), a widely used analgesic recognized as an essential medicine by the World Health Organization, remains surprisingly understudied in the hydrotropy field. Previous works have explored the use of organic solvents, biomolecules, salts, ionic liquids, and eutectic mixtures. Due to its significance as a model compound, ACP has been selected as the subject of study to explore different types of hydrotropes under similar conditions, aiming to establish connections between hydrotropes molecular structure and the increase in solubility.

The main goal of this study is to investigate the effect of several hydrotrope families (traditional organic compounds, ionic liquids, and organic or inorganic salts) at different concentrations on the solubility of ACP. New solubility data in aqueous solutions of sixteen hydrotropes were experimentally measured at 298.2 K using the shake-flask method coupled to UV-Vis spectroscopy or gravimetry as analytical techniques. The COSMO-RS model was used to analyze the hydrotrope effect on the solubility increase, through the determination of the hydrotrope charge density (the donor DF, apolar AF, and acceptor AcF factors). Experimental water activity data at 298.15 K for some specific organic salts are also included to better understand if the hydrotrope-induced depression of water activity is related to the solubility increase. Overall, the findings showed that among the tested hydrotropes, organic compounds (acetone or ethanol) had the highest potential for increasing solubility, followed by salts and ionic liquids. In general, according to COSMO-RS, compounds with higher AF values tend to increase solubility more effectively. Besides that, in the aqueous solutions of salts that promoted the highest ACP solubility increase, the highest water activity was observed. These findings provide a deeper understanding of the critical role of hydrotropes in improving drug solubility, with significant implications in the development of pharmaceutical formulations.

Acknowledgements: The authors are grateful to the Foundation for Science and Technology (FCT, Portugal) for financial support through national funds FCT/MCTES (PIDDAC), CIMO (UIDB/00690/2020 and UIDP/00690/2020), SusTEC (LA/P/0007/2021) and CICECO-Aveiro Institute of Materials, UIDB/50011/2020, UIDP/ 50011/2020 & LA/P/0006/2020. A. Zambom is thankful to FCT for her Ph.D. grant (UI/BD/154740/2023).

[1] D.O. Abranches et al., *Chem. Commun*. 2020, **56**, 7143.
[2] J.J. Booth et al., *Phys. Chem.* 2015, **17**, 8028.
[3] S. Shimizu et al., *Phys. Chem*. 2013, **15**, 20625.

OL3

Revealing the solubility enhancement of active pharmaceutical ingredients through eutectic mixtures formation: A parameter study

Sahar Nasrallah, Ahmad Alhadid, and Mirjana Minceva

Biothermodynamics, TUM School of Life Sciences, Technical University of Munich, Maximus-von Imhof-Forum 2, Freising 85354, Germany

Presenting author email: sahar.nasrallah@tum.de

The poor water solubility of active pharmaceutical ingredients (APIs) poses a significant challenge in pharmaceutical development, impacting their bioavailability and therapeutic efficacy. Enhancing API solubility in solvents through the formation of eutectic mixtures with excipients is a feasible approach. However, despite the experimental simplicity of this method, its exploration from a thermodynamic perspective remains relatively limited.

This study explores the influence of parameters on enhancing the solubility of an API with poor solubility in water through eutectic mixture formation. A hypothetical ternary system comprising an API, excipient, and water is considered. The investigation focuses on the impact of excipient melting properties and intermolecular interactions within the liquid solution on API solubility. The liquid phase nonideality is modeled using the two-suffix Margules equation.

The study finds that the eutectic point in a ternary phase diagram consistently represents the maximum solubility enhancement factor for the API. The position of the eutectic point is influenced by the melting properties of the compounds and their molecular interactions. Additionally, the investigation reveals that excipients with low melting temperatures and small melting enthalpies can increase the solubility enhancement factor of the API in water and affect the composition of the constituents at the eutectic point.

Stronger API-excipient interactions, compared to API-water interactions, significantly improve API solubility in the liquid solution. Conversely, if excipient-water interactions are favored over API-excipient interactions, the solubility enhancement of the API in the solution decreases.

The optimal scenario for enhancing API solubility involves selecting an excipient that strongly interacts with the API while maintaining moderate interactions with the solvent.

The current study could serve as a valuable tool in advancing pharmaceutical formulation science by aiding the design of effective drug delivery systems and the development of novel therapeutics with improved solubility and bioavailability.

OL4
Determination and modelling of solubilities in aqueous vanadate solutions

Mikael Manninen, Tuomas Vielma, and Ulla Lassi

Research Unit of Sustainable Chemistry, University of Oulu, Pentti Kaiteran katu 1, Oulu, 90570, Finland

Presenting author email: mikael.manninen@oulu.fi

Aqueous solutions of vanadium (V) salts are in the center of many trending research topics such as hydrometallurgical vanadium recovery processes [1] and vanadium redox-flow batteries [2]. Despite this, physically sound models even for the simplest of binary vanadate salt – water systems that could describe their thermodynamic properties with reasonable accuracy have not appeared in the literature. It can be argued that currently the most important factor hindering the development of such models is the lack of experimental data which is needed in model fitting and validation.

Currently, the thermodynamic information available for aqueous V(V) systems is mainly limited to equilibrium constant, density, and solubility data [3-4]. However, in the case of $NaVO_3$ there seems to be some ambiguities in the solid phase for which solubility data is reported. Furthermore, many publications do not report sufficient details to allow reliable estimation of uncertainties in the reported solubilities. This is a common issue and there is currently an IUPAC project [5] ongoing with the aim of providing investigators working with solubility determinations with guidelines for good practices in uncertainty assessment.

A detailed investigation of solubility in the binary systems $NaVO_3$–H_2O and NH_4VO_3–H_2O was performed by conducting new experimental measurements and a review of previous literature [6]. The guidelines discussed by Hibbert [7] were followed in an attempt to provide reasonable uncertainty estimates. The capability to predict the solubility of the sparingly soluble NH_4VO_3 at 298.15 K based on presently available thermodynamic data was also briefly investigated. Although the magnitude of the solubility could be correctly predicted, considerable deficiencies in the models and the lack of data needed to improve them were recognized. The present work is part of the PhD studies of the first author focusing on the determination and modelling of thermodynamic properties of aqueous V(V) systems.

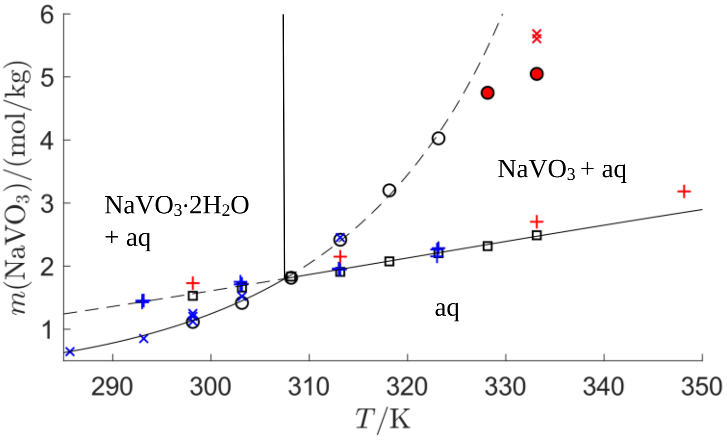


Figure 1. Solubility of $NaVO_3$ in water. Circles and squares: [5], Crosses: literature data, Red: rejected data, Curves: fitted correlation equations.

Acknowledgements: Finnish Cultural Foundation and Towards Fossil-Free Steel project are acknowledged for providing funding for this work.

[1] K. Kurniawan, S. Kim, M. Bae, H. Lee, J. Lee, *Min. Proc. Ext. Met. Rev.*, 2023, 1.
[2] C. Roth, J. Noack, M. Skyllas-Kazacos, *Flow Batteries*, 2023, **22**, 507.
[3] N. McCann, M. Wagner, H. Hasse, *Dalton Trans*. 2013, **42**, 2622.
[4] K. Mazurek, S. Drużyński, *J. Chem. Eng. Data*, 2014, **59**, 1468.
[5] IUPAC project 2022-002-2-500, https://iupac.org/project/2022-002-2-500.
[6] M. Manninen, T. Vielma, U. Lassi, *J. Chem. Eng. Data*, 2023, **68**, 2500.
[7] D.B. Hibbert, *J. Chem. Thermodyn*. 2019, **133**, 152.

OL5

Having fun with sulfate complexes

Glenn Hefter[1] and Cezary Gumiński[2]

[1]Chemistry Department, Murdoch University, Murdoch WA 6150, Australia
[2]Department of Chemistry, University of Warsaw, 02093, Warsaw, Poland

Presenting author email: G.Hefter@murdoch.edu.au

A critical evaluation of the experimental data in the literature for the stability constants and related thermodynamic parameters of metal-ion/sulfate complexes is being conducted under IUPAC auspices. Such quantities are important for modelling natural and industrial water systems as sulfate is a significant constituent of ocean, estuarine, fresh, and waste waters. Metal-ion/sulfate complexes are also found in biological fluids such as blood plasma, in geochemical liquids and atmospheric aerosols, and are present in vast quantities in extractive metallurgy.

Because of its importance, this review began with the protonation of sulfate:

$$H^+ \text{ (aq)} + SO_4^{2-} \text{ (aq)} \rightleftharpoons HSO_4^- \text{ (aq)}$$

Approximately 400 references containing quantitative information about this equilibrium were obtained from the literature, including databases and technical reports. About 60% were rejected outright for various reasons, such as inadequate specification of the measurement conditions, inconsistency with other studies, or because they didn't contain original experimental data. The values so obtained for the stability constants, enthalpies, entropies, and heat capacities for the protonation equilibrium will be discussed. Areas where the database needs further experimental investigation will be identified.

Current work in this project is focused on the *s*-block cations of Groups I and II of the Periodic Table. The database for the sulfate complexes of these ions varies enormously, with some systems (eg, Rb^+, Ba^{2+}) hardly studied while others (eg, Na^+, Mg^{2+}) have been comprehensively investigated. Progress on the evaluation of these apparently 'simple', yet diverse, systems will be presented.

OL6

T-dependent Pitzer model for carbonates and CO_2 in the THEREDA-database for aqueous geochemistry up to high ionic strengths

Wolfgang Voigt

Institute of Inorganic Chemistry, TU Bergakademie Freiberg, Leipziger Str. 29, Freiberg, 09596, Germany

Presenting author email: Wolfgang.Voigt@chemie.tu-freiberg.de

The THEREDA-Database [1] represents a thermodynamic database providing ready-to-use downloads for widely used geochemical codes as PHREEQC and GWB. A particular feature of this database represents the Pitzer model of the oceanic salt system H^+, Na^+, K^+, Mg^{++}, Ca^{++} // Cl^-, SO_4^{--}, OH^- - H_2O, which enables one to calculate the solubility equilibria in multicomponent solutions for a temperature range of 0 – 100 °C. Recently, solubility constants of carbonates of sodium, potassium, magnesium and calcium have been implemented as well as the Pitzer interaction coefficients of CO_3^{2-} and HCO_3^- with all the other ions [2]. With the extended database the solubility of CO_2 and its interaction with the salt components can be calculated up to moderate pressures (see Figure 1).

In the contribution the data situation of the carbonates in respect to solubility at varying temperature, pH and partial pressure of CO_2 is discussed. At selected examples the description of experimental data by the model is demonstrated. Thereby, the uncertainty of experimentally determined solubilities of important minerals as magnesite, hydromagnesite or dolomite is discussed. The literature study revealed also that solubility data of these minerals in natural brines are nearly absent.

The incorporation of the solid-solution model of Königsberger and Gamsjäger [3] for magnesian calcites in a modified form allows the calculation of the equilibrium uptake of magnesium by calcium carbonate in magnesium salt containing solutions.

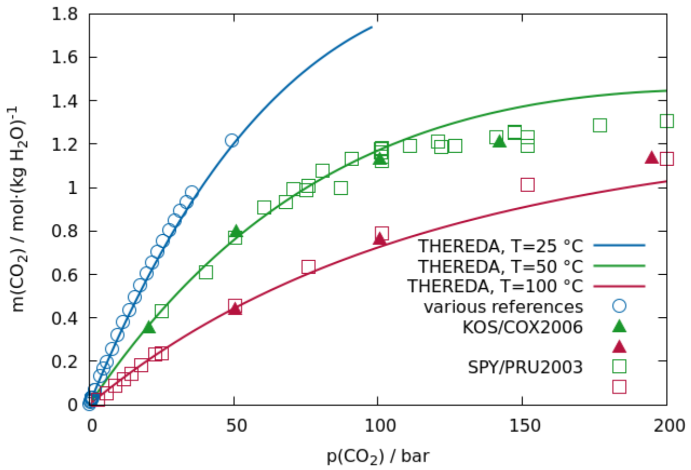


Figure 1. Solubility of CO_2 in water; comparison model (lines) and experimental data (symbols).

[1] https://www.thereda.de/de
[2] W. Voigt, *THEREDA Journal*, 2023.
[3] E. Königsberger, H. Gamsjäger, *Geochim. Cosmochim. Acta*, 1992, **56**, 4095.

OL7
The conversion of lithium carbonate to lithium hydroxide

Pál Sipos, Judit Papp and Bence Kutus

Department of Molecular and Analytical Chemistry, University of Szeged, 7–8 Dom ter,
Szeged, H-6720, Hungary

Presenting author email: kutusb@chem.u-szeged.hu

Lithium carbonate, Li_2CO_3, is an important precursor for the preparation of mixed-oxide cathodes in the production of Li-ion batteries [1]. Li_2CO_3 is then converted to the more precious lithium hydroxide, LiOH, also used for batteries, as a CO_2 sequestrant, and as starting material for various lithium salts. Conventionally, LiOH is produced by reacting the carbonate salt with $Ca(OH)_2$, which generates the sparingly soluble $CaCO_3$ [1,2]. Despite slaked lime being readily available, it needs to be of very high purity and more importantly, the overall process yields low conversions when using concentrated $Li_2CO_3/Ca(OH)_2$ mixtures, with a maximum attainable alkali concentration of 3.5 wt% [1–3]. However, the reason for low conversions has remained elusive; some suggested that is due to decreased solubility of either Li_2CO_3 or $Ca(OH)_2$ [1,3], while others observed the formation of an intermediate solid phase [2]. To shed light on the underlying mechanism of this reaction, we studied its time-dependence and equilibrium properties, analysing both the liquid and solid phases.

We performed all experiments at (30±1) °C. First, conductometric measurements showed that most of the initial amount of Li_2CO_3 transforms to LiOH after 2 hours of contact time (using 10 g L^{-1} Li^+ and an equivalent concentration of $Ca(OH)_2$). Second, we performed conversion experiments varying both the amount of Li_2CO_3 (5–30 g L^{-1} Li^+) and the $Ca(OH)_2$:Li_2CO_3 molar ratio (25–200%), applying 2 hours of reaction time. We found the conversion ratios to be $\leq$96% for 5 and 10 g L^{-1} Li^+, indicating that the process is essentially quantitative. However, for more concentrated suspensions, we indeed observed a dramatic decrease in yields, corresponding to an upper limiting concentration of LiOH of ~1.5 mol dm^{-3} or 3.5 wt%. For suspensions of 30 g L^{-1} Li^+, both sequential addition of the reactants and the order of their addition result in the same final concentration, suggesting that this is an equilibrium process and that heterogeneous reactions obey Le Chatelier's principle, similarly to liquid-phase reactions. Furthermore, no solid phase other than the starting materials and $CaCO_3$ is discernible on the powder diffractograms, supporting the equilibrium nature of the reaction and hence there is no need to assume intermediate phases.

In addition, concentration of CO_3^{2-} in the supernatants were unexpectedly high which on the one hand can be explained by the solubility of Li_2CO_3. However, given the very low solubility of $CaCO_3$, most of the soluble CO_3^{2-} exist probably as $LiCO_3^0$ ion-pair.

In the second set of experiments, we investigated the backward reaction, starting from calcite and concentrated LiOH of 4.2 mol dm^{-3} (which otherwise could not be prepared from Li_2CO_3 and $Ca(OH)_2$). As expected from a true thermodynamic equilibrium, we now obtained Li_2CO_3 and $Ca(OH)_2$ as products. Strikingly, the final LiOH concentration was ~2.2 mol dm^{-3}, contradicting the one obtained from the forward process (1.5 mol dm^{-3}). However, when starting from freshly precipitated $CaCO_3$, we again obtained a LiOH solution of 1.5 mol dm^{-3}. Since this solid contained vaterite to a significant degree, this apparent contradiction may be resolved by assuming that in situ forming $CaCO_3$ always contains some vaterite as opposed to phase-pure calcite. The corresponding equilibrium constant, consisting of the solubility products of Li_2CO_3, $Ca(OH)_2$ and $CaCO_3$, will then be different, depending on which polymorph of $CaCO_3$ is considered to govern the equilibrium. In turn, assuming different polymorphs will give rise to different equilibrium concentrations of LiOH.

In conclusion, all experimental results suggest that the low conversion for concentrated suspensions stem from the decreased solubility of the Li_2CO_3 and $Ca(OH)_2$ in concentrated LiOH solution, and this can be quantified by an equilibrium constant.

[1] B. Yuan, et al., *Particuology*, 2017, **34**, 97.
[2] M. Grágeda et al., *Energy*, 2015, **89**, 665.
[3] K.J. Kim, *Sep. Sci. Technol*, 2008, **43**, 420.

OL8

Thermodynamic modelling of $CuSO_4$-H_2SO_4-H_2O system from 273.15 K to 353.15 K

Hannu Sippola, David Sibrani and Daniel Lindberg

Aalto University, School of Chemical Engineering, Metallurgical Thermodynamics and Modelling Research Group, Espoo 02150, Finland

Presenting author email: hannu.sippola@aalto.fi

Modelling the solubility of copper sulfate in aqueous sulfuric acid is important for the development and optimization in hydrometallurgical processes for copper electrowinning and recycling.

A thermodynamic model for $CuSO_4$-H_2SO_4-H_2O system was developed covering temperature range from 273.15 to 353.15 K and concentration range up to ten molal sulfuric acid solutions. Pitzer model was used to describe the non-ideal behaviour of aqueous solution. The parameters for binary systems were obtained from literature. During the assessment the available solubility data of copper sulfate in sulfuric acid as well as activity of water data were critically evaluated.

Several Pitzer parameter sets for the system was also critically evaluated. It was found that following Pitzer parameters for the system $CuSO_4$-H_2SO_4-H_2O is required for Cu^{2+}/HSO_4^- interaction: $\beta(0)$, β (1) and C^ϕ as well as ternary interaction ψ for $Cu^{2+}/H^+/SO_4^{2-}$. Total number of temperature depend terms in parameters were 3, 2, 2 and 2, respectively, from the following set of terms: a, bT and f/T. Calculated solubility versus experimental data at 298.15 K is shown in Figure 1.

The model was verified against electrochemical cell data and solubility of trihydrate.

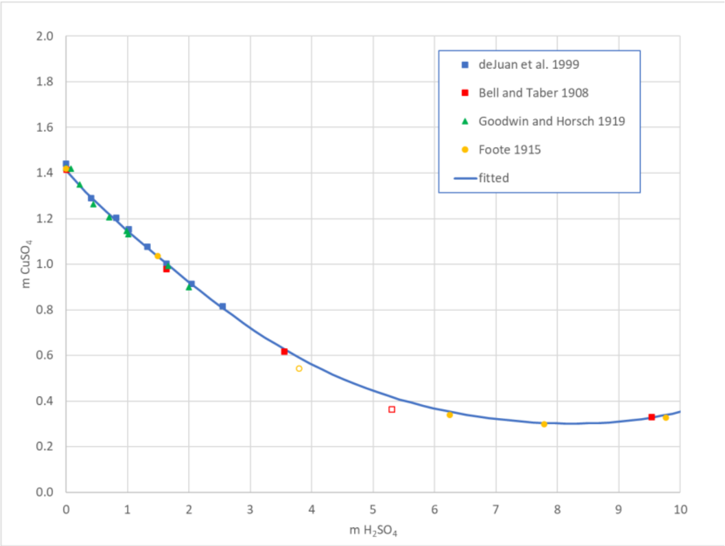


Figure 1. Experimental and fitted solubility of copper sulfate pentahydrate at 298.15 K. Open symbols was not included in the assessment.

OL9
Deliquescence of salt mixture: from water film to bulk liquid

Shaoheng Wang[1], Sebastiaan Godts[2] and Michael Steiger[1]
[1]Department of Chemistry, University of Hamburg, Martin-Luther-King-Platz 6, Hamburg, 20146 Germany
[2]Royal Institute for Culture Heritage (KIK-IRRA), Jubelpark 1, Parc du Cinquantenaire 1, Brussels, 1000, Belgium

Presenting author email: shaoheng.wang@uni-hamburg.de

Deliquescence is a first-order phase transition from solid to solution at a certain relative humidity (DRH), and it widely influences the process of aerosol formation, heritage conservation, the Martian water cycle, etc. [1-3]. In the mixture, the solid-solution transition humidity would be lower than each component, which impacts the physical stability of the salt mixture system. The dynamic mechanism that water sorption on salt surfaces has attracted a lot of attention. Many studies focused on predeliquescence of single salt have been reported [4-6], and raise the mechanism that there is nanoscale thickness water film forming before deliquescence, which leads to the salt's full dissolution at DRH. However, little understanding is gained of how the deliquescence starts in the salt mixture at a humidity that is lower than the DRH of each component.

In this work, we compare the water sorption curves of single salt NaCl, KCl, and the mixture NaCl + KCl. It is indicated that the deliquescence humidity of the mixture is lower than single salt. Subsequently, *in-situ* observation of the water vapor sorption was performed in an optical microscope that cooperated with the environment chamber, as seen in Fig. 1a, 1b. We found the water condensation starts at the interface of salt particles, then the dissolution spreads to bulk salts at deliquescence humidity. We propose that the deliquescence initially takes place in the nanoscale hole generated by the rough surface of particles, where the water condensation pressure is much lower than the bulk system [7]. Then the solution film from each side, i.e. NaCl and KCl, converge in the interfacial gap, shown in Fig. 1c. This confluence is a crucial step for mixture deliquescence since it produces the saturated solution containing both salts, where the water activity or vapor pressure theoretically is lower than the single salt. When the environment humidity reaches the vapor pressure of the saturated solution, this interfacial reaction would extend to the whole system, until one of the components is depleted.

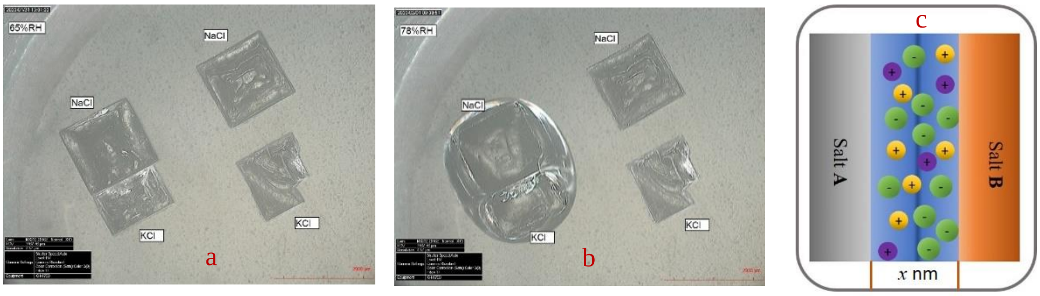


Figure 1. Water vapor sorption of single salts and their mixture.

[1] B. Finlayson-Pitts. *Chem. Rev.* 2003**, 103**, 4801.
[2] D. Li, Y.Y.S. Zhao, P.Y. Meslin, et al. *Commun. Earth Environ.* 2022, **3**, 15.
[3] M. Steigr, K. Linnow, et al. *Environ. Geol*. 2007, **52**, 317.
[4] G.E. Ewing. *Chem. Rev.* 2006, **106**, 1511.
[5] D.A. Bruzewicz, et al. *J. Chem. Phys.* 2011, **134**, 044702.
[6] J.J. Lin, et al. *Atmos. Chem. Phys.*,2021, **21**, 4709.
[7] M. Steiger, T. Talreja-Muthreja, et al. *Langmuir* 2022, **38**, 36, 10963.

OL10
Calcium phosphate precipitation in zwitterionic polymer solutions

Diana Rabadjieva[1], Kostadinka Sezanova[1], Rumiana Gergulova[1], Konstans Ruseva[2], Marin Simeonov[2], Pavletta Shestakova[3] and Alexander Bonchev[4]

[1] Institute of General and Inorganic Chemistry, Bulgarian Academy of Sciences, Sofia 1113, Bulgaria
[2] Faculty of Chemistry and Pharmacy, University of Sofia, Sofia, Bulgaria
[3] Institute of Organic Chemistry with Centre of Phytochemistry, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria
[4] Faculty of Dental Medicine, Medical University, 1431 Sofia, Bulgaria

Presenting author email: didiarab@svr.igic.bas.bg

Zwitterionic polymers have found a wide range of applications due to their unique properties, which include high water solubility, biocompatibility, and resistance to fouling and protein adsorption. They can be incorporated into dental adhesives and restorative materials to improve their adhesion to tooth structure, preventing water infiltration that can lead to restoration failure over time.

The biomimetic precipitation of calcium phosphates in a physiological medium containing either polycarboxybetaine (PCB) or polysulfobetaine (PSB) was investigated in this study. PCB and PSB contain both positive and negative-charged functional groups within their structure, leading to interactions between the polymer and calcium and phosphate ions in the solution. Furthermore, the precipitation of calcium phosphate can be influenced by various factors, including pH, temperature, concentration of calcium and phosphate ions, etc. Several synthesis routes, differing in the mixing sequence of the starting solutions, amount of polymer, and pH were studied to elucidate their effect on the type of the pre-nucleation clusters and thus on the solid phases formed. The changes in pH and the concentration of Ca^{2+} ions during the syntheses were followed in polymer-free systems, in systems with PSB, and in systems with PCB to explore the effect of betaine zwitterionic functionality. Solid state NMR spectroscopy was used to identify the calcium phosphate phases formed as a function of the different synthesis conditions.

The results show that when the pH is not kept constant, and Ca-solution was added to the P-solution, HPO_4^{2-} ions dominate at the beginning, and the formation of $Ca(HPO_4)_3^{4-}$ pre-nucleation clusters is expected to prevail over other ones. The starting pH is 8.9, which results in the formation of amorphous calcium phosphate with common formula $Ca_x(HPO_4)_y(PO_4)_z$ and Ca/P = 1.1-1.6. In the second case (P-solution was added to Ca-solution), Ca^{2+} ions prevail in the initial solution. pH was 4.5 for the system with PSB, 5.7 for the system with PCB, and 6.3 for the polymer-free system. Thus, it was more probable that $CaHPO_4^0$ pre-nucleation clusters which are structural units of dicalcium phosphate dehydrate (DCPD) to be dominant. As a result, a mixture of octacalcium phosphate (OCP) and dicalcium phosphate dihydrate (DCPD) in different ratios was identified depending on the sequence of initial solution mixing and the type of negative functional group of the polymer used. The more acidic character of the sulfo group in PSB than the carboxy one in PCB determines the dominance of acidic solid phases, namely the acidic amorphous phase or DCPD. In the presence of PCB, the formation of ACP with acicular particles arranged in bundles with the same orientation was observed.

When the pH is kept constant, it is a dominant factor in the solid phase formation. Regardless of the amount of polymer and the method of reagent mixing the nano-crystalline hydroxyapatite with a Ca/P ratio of 1.63-1.71 was observed as a mineral phase in all systems.

The polymer type affects also the final microstructure and mineral particle size being thinner and smaller in the synthesis performed using PCB than using PSB. The final intermolecular interaction of the calcium phosphates was demonstrated to be stronger with PCB than with PSB.

The preliminary comparative study of the remineralization potential of the different prepared hybrid materials gives preference to that consisting of PCB.

Acknowledgments: The authors thank the Bulgarian Ministry of Education and Science for the financial support under the project KP-06-H49-6/2020. In this investigation, we used the research equipment of Distributed Research Infrastructure INFRAMAT, part of the Bulgarian National Roadmap for Research Infrastructures, supported by the Bulgarian Ministry of Education and Science.

OL11

Terpene-based green solvents for the dissolution of plastics

Mónia Martins[1,2], Adomizete Rosário[1,2], Ana M. Ferreira[3], João Coutinho[3],
Olga Ferreira[1,2] and Simão Pinho[1,2]

[1]Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança,
Campus de Santa Apolónia, 5300-253 Bragança, Portugal
[2]Laboratório Associado para a Sustentabilidade e Tecnologia em Regiões de Montanha (SusTEC), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal
[3]Department of Chemistry, CICECO − Aveiro Institute of Materials, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

Presenting author email: moniamartins@ipb.pt

Plastics have become an integral part of our daily lives, offering cost-effective solutions that enhance food preservation, medical advancements, and other benefits. However, this convenience has led to an overreliance on these materials, contributing to a global crisis of plastic accumulation.

Despite the alarming production rate, which approaches 400 million tons per year, only 10% of plastics are currently recycled. Hence, there is an urgent need to develop more efficient and accessible recycling processes while ensuring the quality of recycled polymers.

Among the recycling processes, dissolution/precipitation stands out as a particularly promising option. Traditional organic solvents have been the most common choice for this method, but the quest for new solvents capable of efficiently dissolving and depolymerizing plastics under mild conditions and with high selectivity for valuable products has gained attention.

Eutectic solvents are promising alternatives in this endeavour. These are mixtures of pure compounds characterized by significant melting point depressions compared to those of the pure constituents. In the plastic dissolution field, natural terpene-based eutectic solvents have recently gained significant attention due to their dissolution potential.

Terpenes are a well-known class of natural compounds with important applications in various fields. Among them, limonene is a well-known solvent for different applications, and it has been reported as an attractive alternative for polystyrene solubilisation. Also, turpentine, a mixture of monoterpenes derived from the pine industry, has been used as a solvent for polyethylene and polypropylene.

This project aims to optimize dissolution/precipitation methods using environmentally friendly terpene-based biosolvents (and their mixtures) derived from industrial by-products like turpentine. Predictive tools such as the COnductor-like Screening MOdel for Realistic Solvents (COSMO-RS) and the Hansen solubility parameters are first used to identify the most promising systems, based on the chemical interactions between different polymers and solvents. Then, experimental solubility studies are carried out using an isothermal analytical methodology.

The findings gathered here are important contributions to revolutionizing plastics recycling, significantly reducing environmental pollution and fostering a more sustainable future.

Acknowledgements: This work was supported by national funds through FCT/MCTES (PIDDAC): CIMO, UIDB/00690/2020 (DOI: 10.54499/UIDB/00690/2020) and UIDP/00690/2020 (DOI: 10.54499/UIDP/00690/2020); and SusTEC, LA/P/0007/2020 (DOI: 10.54499/LA/P/0007/2020). AMF acknowledges FCT for the research contract CEECIND/00361/2022 (DOI: 10.54499/2022.00361.CEECIND/CP1720/CT0020) under the Scientific Stimulus – Individual Call.

OL12

Intermolecular interactions and sustainability: a pathway to exploring hydrophobic eutectics and eutectogels

Maria Enrica Di Pietro, Giselle de Araujo Lima e Souza, Valeria Vanoli, Alberto Mannu, Grazia Isa Carla Righetti, Franca Castiglione, Francesco Briatico Vangosa and Andrea Mele

Department of Chemistry, Materials and Chemical Engineering “G. Natta”, Politecnico di Milano, Piazza Leonardo da Vinci 32, Milano, 20133, Italy

Presenting author email: mariaenrica.dipietro@polimi.it

Hydrophobic non-ionic eutectic solvents (HES) have recently garnered attention amidst the array of (deep) eutectic solvents, (D)ES [1], thanks to their low viscosities, chloride-free nature, and water-immiscibility. A unique option to expand the design space of HES involves their immobilization within a jelly matrix to yield hydrophobic non-ionic eutectogels (HEG) [2].

While significant strides have been made in comprehending intermolecular interactions and mobility within conventional hydrophilic (D)ES, very little is known for HES, and even less so for HEG.

Here we demonstrate the pivotal role of a multifaceted investigation at the molecular level for unraveling the intricate interplay among H-bond, dispersive forces and steric factors, which drives the formation of HES and rules their peculiar properties [3].

A screening and ranking tool is proposed, which combines spectral descriptors of the intermolecular network that are easy to determine and of effective practical use, along with safety descriptors based on the hazards of the individual components.

We also show that non-ionic HES can be incorporated in stable and homogeneous supramolecular gel scaffolds using the low molecular weight gelator 1,3:2,4-dibenzylidene-D-sorbitol (DBS) at minimal loading, with a simple one-pot preparation process ranked as “excellent” in the EcoScale metrics [4]. A multidisciplinary approach is applied again to shed light on the structure and dynamics of both liquid and semi-solid systems, proving that the liquid-like nature of the hydrophobic mixture is retained upon gelation. Noteworthy, we observe an unexpected increase of the translational motion of the HES components under confinement compared to pure HES, with the effect of the gelator inversely proportional to the strength of pre-existing interactions.

Figure 1. Sketched representation of the combined approach based on molecular properties and safety aspects for screening, ranking and investigating hydrophobic eutectic solvents (HES) and eutectogels (HEG).

Acknowledgements: A portion of this work has been funded by European Union – Next Generation EU in the framework of the PRIN 2022 PNRR project POSEIDON - P2022J9C3R.

[1] D.O. Abranches, J.A.P. Coutinho, *Curr. Opin. Green Sustain. Chem.*, 2022, **35**, 100612.
[2] G. de Araujo Lima e Souza, M.E.Di Pietro, A. Mele, *RSC Sustainability*, 2024, **2**, 288.
[3] M. Busato, G. Mannucci, L. A. Rocchi, M. E. Di Pietro, A. Capocefalo, E. Zorzi, P. Casu, D. Veclani, F. Castiglione, A. Mele, A. Martinelli, P. Postorino, P. D’Angelo, *ACS Sustain. Chem. Eng.*, 2023, **11**, 8988.
[4] G. de Araujo Lima e Souza, M.E. Di Pietro, V. Vanoli, W. Panzeri, F. Briatico-Vangosa, F. Castiglione, A. Mele, *Mater. Today Chem.*, 2023, **29**, 101402.

OL13
The role of atomistic calculations in modeling solvent effects

Stevan Armaković

Department of Physics, University of Novi Sad, Trg Dositeja Obradovića 4, 21000 Novi Sad, Serbia

Presenting author email: stevan.armakovic@df.uns.ac.rs

The rapid advancement of computational technologies has fundamentally transformed the landscape of molecular and material discovery, making these processes more accessible and efficient than ever before. Just over a decade ago, researchers were limited by the computational capabilities of standard desktop computers, which restricted them to relatively simple calculations. More complex tasks, such as quantum-mechanical modeling, require specialized hardware, often associated with high costs and limited availability. Today, the power of modern desktop computers, combined with significant improvements in modeling software, allows researchers to perform a range of calculations on molecules of various sizes and complexities.

Incorporating solvent effects into these calculations is essential for accurately modeling molecular interactions, as solvents play a critical role in influencing the behavior, stability, and reactivity of molecules. By accounting for solvent environments, researchers can achieve a more realistic representation of molecular systems. This inclusion is particularly vital in applications such as pharmaceutical design (Figure 1), where solvent interactions can significantly impact the efficacy and binding of pharmaceutical compounds, as well as in materials science, where solvent effects can alter the properties and performance of new materials.

Investigation of solvent effects at the molecular level is now possible thanks to the emergence of state-of-the-art codes for atomistic calculations, such as ORCA [1] and xtb [2]. However, using a command prompt can be challenging for beginners or users with an experimental focus. In such cases, the graphical user interfaces provided by the Atomistica.online project (available at https://atomistica.online [3]) can be helpful in bridging the gap. These tools enhance our understanding of molecular behavior in realistic environments and provide accessible resources for researchers.

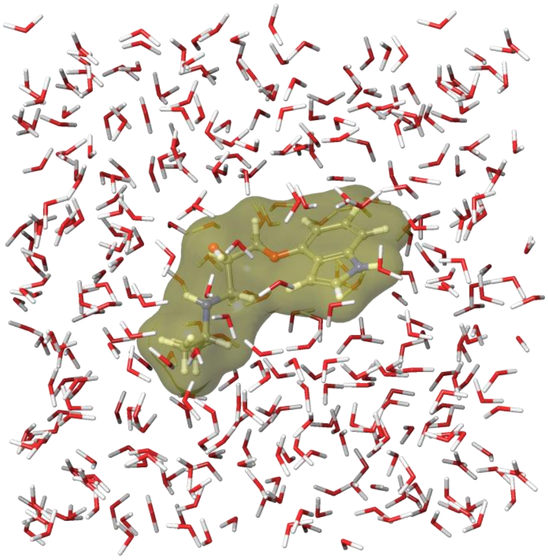


Figure 1. Molecular dynamics simulation of a pharmaceutical molecule solvated in water

Acknowledgments: The authors acknowledge the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No. 451-03-66/2024-03/ 200125 & 451-03-65/2024-03/200125)

[1] F. Neese, F. Wennmohs, U. Becker, C. Riplinger, *J. Chem. Phys.*, 2020, **152**, 224108.
[2] C. Bannwarth et al., *Wires Comput. Mol. Sci.*, 2021, **11,** 1493.
[3] S. Armaković, S. J. Armaković, *Mol. Simulat.*, 2024, **50**, 560.

OL14

Recovery of pure lithium from salt lake brines at low temperatures: Parametrization of thermodynamic models and proposal of a novel extraction method

Julia Sohr and Wolfgang Voigt

Department of Inorganic Chemistry, TU Bergakademie Freiberg, Lessingstraße 45, Freiberg, 09599, Germany

Presenting author email: julia.sohr@chemie.tu-freiberg.de

One of the main challenges in the recovery of lithium from salt lake brines lies within the separation of lithium and magnesium salts. A thorough literature study revealed the potential of fractional crystallization at low temperatures as an effective method for the separation of magnesium salts.

Basic processes in the salar chemistry can be described within the quaternary reciprocal system $2Li^+$, Mg^{2+} || $2Cl^-$, SO_4^{2-} - H_2O. In order to estimate capabilities of the low temperature approach and to design respective processes, the knowledge of solubility equilibria in this system at temperatures below 25°C is essential.

The goal of the present work was to construct the phase diagram and describe equilibria down to about -30°C. For this purpose a PITZER model [1] has been parametrized in such a way that linear dependencies of the parameter allow for a reliable temperature extrapolation.

In the sulfate-free chloridic sub-system, $LiCl$-$MgCl_2$-H_2O, low water activities allow for the additional parametrization of a modified BET model according to Ally and Braunstein [2]. Though based on a completely different calculation approach, the BET model was able to validate the results of the Pitzer model. Also experimental solubility data and cooling experiments of salt brines confirm the model results.

Based on the model predictions, a process for direct crystallization of pure lithium chloride from highly concentrated lithium chloride - magnesium chloride mixed solutions between + 9 °C and - 20 °C could be proposed. Chemical analyses and mass balances from crystallization experiments in pilot scale were in good agreement with model calculations.

[1] K. Pitzer, *Activity coefficients in electrolyte solutions*, 1991, CRC Press Inc., Boston, London.
[2] M.R. Ally, J. Braunstein, *J. Chem. Thermodyn.*, 1998, **30**, 49.

OL15
Exploring green solvent for lupin debittering via *in silico* COSMO-RS predictive screening

Mónia Martins[1,2], Nathan Barbosa[1,2], Filipe Sosa[3], João Coutinho[3], Olga Ferreira[1,2] and Simão Pinho[1,2]

[1]Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal
[2]Laboratório Associado para a Sustentabilidade e Tecnologia em Regiões de Montanha (SusTEC), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal
[3]Department of Chemistry, CICECO – Aveiro Institute of Materials, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

Presenting author email: moniamartins@ipb.pt

Andean lupins have been widely cultivated in the Andean highlands for the enrichment of the soil, animal feeding and as a food crop. Their seeds are nutrient-rich in terms of their high content of protein (about 50%) and oil (about 20%). However, the presence of toxic quinolizidine alkaloids, including sparteine, lupanine, and 13-OH-lupanine, in the seeds limits their industrial applications.

Several ionic liquids (ILs) and eutectic systems (ESs) have been reported in the literature to extract alkaloids from plant materials with the advantages of sustainability, biodegradability as well as adjustable polarity to dissolve polar and non-polar compounds. However, identifying an optimal IL or ES from the large number of possible combinations is quite challenging. To address this issue, the COSMO-RS (COnductor-like Screening MOdel for Real Solvents) model has emerged as a reliable computational tool that can screen numerous compounds or mixtures based on different thermodynamic properties.

The current study demonstrates the dissolution behaviour of quinolizidine alkaloids in ILs and ES using the COSMO-RS model. Several combinations were attempted and evaluated by predicting the activity coefficients ate infinite dilution (γ_{13}^{∞}) of typical quinolizidine alkaloids (sparteine, lupanine, 13-OH-lupanine, and lupinine) in conventional solvents, ionic liquids and natural-based eutectic solvents.

Through this research, we aim to develop a novel separation method based on the use of green solvents, to debitter the Andean lupin beans, i.e., to remove the toxic alkaloids, and to unveil efficient and environmentally conscious strategies for maximizing their use in the food industry.

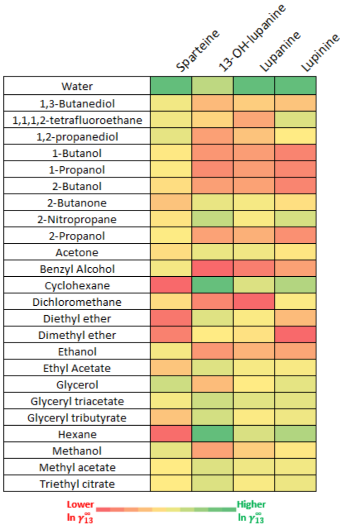


Figure 1. Preliminar results on the ln γ_{13}^{∞} of quinolizidine alkaloids in different pure solvents at 298.15 K.

Acknowledgements: This work was supported by national funds through FCT/MCTES (PIDDAC): CIMO, UIDB/00690/2020 (DOI: 10.54499/UIDB/00690/2020) and UIDP/00690/2020 (DOI: 10.54499/UIDP/00690/2020); and SusTEC, LA/P/0007/2020 (DOI: 10.54499/LA/P/0007/2020).

OL16

Interaction and aggregation behavior of rhodamine B dye in water, ethanol and aqueous solutions of ionic liquids

Imran Khan[1], Aafaq Tantray[2] and Mustafa Nasser[2]

[1]Department of Chemistry, College of Science, Sultan Qaboos University, Muscat, Oman
[2]Gas Processing Center, College of Engineering, Qatar University, Doha, Qatar

Presenting author email: imrank@squ.edu.om

Xanthene dyes are the most widely investigated class of luminescent dyes, because of their special characteristics which make them useful for many applications. One of the most used xanthene dye is rhodamine B emitting in the red region of visible spectrum. Rhodamine dyes are used extensively in biotechnology applications such as fluorescence microscopy, flow cytometry and fluorescence correlation spectroscopy Dye aggregation in ionic liquid-based solutions is a crucial topic because dyes and these ecologically friendly designer solvents have a wide range of applications. The self-association or aggregation of rhodamine B (Rh B) in aqueous and aqueous.

The self-association or aggregation of rhodamine B in water, ethanol and aqueous solutions of Ionic liquids (ILs) has been studied by using spectrophotometry. The concentration ranges from ~1×10^{-5} M to ~3×10^{-4} M were selected to avoid the formation of higher aggregates such as trimer, tetramer etc. For instance, bathochromic J-aggregation can be easily distinguished from hypsochromic H-aggregation using UV/vis light spectroscopy. The impact of ILs namely tetramethylammonium Mercaptopropionate [TMA][MPA] and tetramethylammonium indole 3 acetate [TMA][IAA], a water-miscible room-temperature IL, on the behavior of an aggregation of dyes is evaluated. The addition of ~0.5M ILs resulted in the precipitation of Rh B dye from the solution. The results have been explained in terms of bonding between dye molecule and solvents which affects the arrangement of molecules there by affecting extent of aggregation.

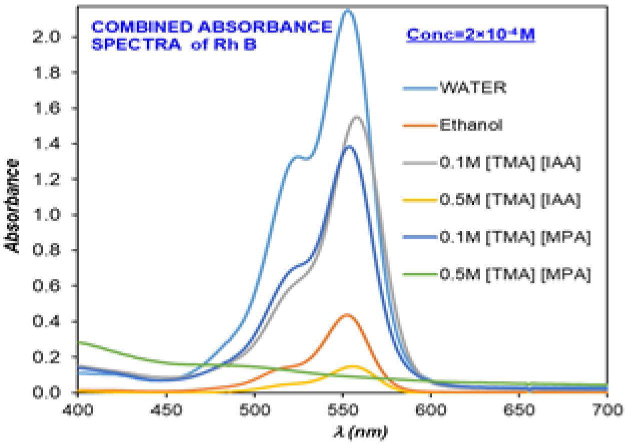


Figure 1. Absorbance spectra of RH B in water, ethanol and aqueous solutions of ILs (2×10^{-4} M) at room temperature

Acknowledgements: We gratefully acknowledge financial support from International collaborative grant Sultan Qaboos University (SQU) and Qatar University (QU) for collaborative SQU-Qatar grant (CL/SQU-QU/SCI/22/01).

[1] I. Khan, M. Taha, P. Ribeiro-Claro, S.P. Pinho, A. João, P. Coutinho, *J. Phys. Chem. B.*, 2014, **118**, 10503.
[2] S. Terdale, A. Tantray, *J. Mol. Liq.*, 2017, **225**, 662.

OL17
Residual volume approach as a tool for prediction of biological activity of ionic liquids

Gergana Letkarska, Savina Stoyanova and Milen Bogdanov

Faculty of Chemistry and Pharmacy, Sofia University St. Kliment Ohridski, 1, Jammes Bourchier, blvd.,
Sofia, 1164, Bulgaria

Presenting author email: mbogdanov@chem.uni-sofia.bg

Enzymes are large protein biomolecules responsible for many chemical reactions that are necessary to sustain life. They are an integral part of any living organism, providing its proper functioning by regulation of processes such as growth, healing, digestion, reproduction, to name just a few [1].

This study examines how various hydrophilic ionic liquids (ILs) affect the diphenolase activity of mushroom tyrosinase, an enzyme responsible for the pigmentation of mammals' skin and hair, and involved in the molting process of insects and the browning of fruits and vegetables, as a model enzyme. It also aims to investigate the potential for predicting the biological activity of these ILs using The Residual Volume Approach (RVA), an empirical model originally developed for predicting IL properties such as density, viscosity, surface tension, etc [2-4].

The ILs studied were based on various cations and anions such as N,N,N',N',N'',N''-hexaalkylguanidinium {$[N22N33N3ngua]^+$}, 1-alkyl-3-methylimidazolium {$[CnC1im]^+$}, N,N,N,N-tetralkylammonium {$[CnCnCnCnN]^+$} or N,N-dialkylpyrrolidinium {$[CnCnpyrr]^+$} cations, coupled with anions such as chloride ($Cl^–$), bromide ($Br^–$), acetate {$[AcO]^–$}, trifluoroacetate {$[TFA]^–$}, thiocyanate {$[SCN]^–$}, dicyanamide {$[dca]^–$}, saccharinate {$[Sac]^–$} and acesulfamate {$[Ace]^–$}.

The wide range of ILs used allowed several generalizations for their effect to be drawn: (i) ILs can be considered as potent tyrosinase inhibitors; (ii) guanidinium ion ensures the highest inhibitory activity; (iii) increase in the alkyl side chain length enhances the inhibitory effect; (iv) anion is of immense importance toward high inhibitory activity. Kinetic analysis was also performed to establish the inhibitory mechanism for the most active compounds.

These findings offer valuable insights into the interactions between hydrophilic ionic liquids and enzymes, providing a foundation for further research. Moreover, the RVA correlations demonstrated that this approach could be successfully applied to predict the enzyme-inhibitory, and possibly other biological activities of ILs.

[1] G. Letkarska, M.G. Bogdanov, *Encyclopedia of Ionic Liquids*, 2019, Effect of Ionic Liquids on Activity and Stability of Enzymes, Springer Singapore.
[2] M.G. Bogdanov, W. Kantlehner, *Z. Naturforsch*. 2009, **64b**, 215.
[3] M.G. Bogdanov, B. Iliev, W. Kantlehner, *Z. Naturforsch.* 2009, **64b**, 756.
[4] M.G. Bogdanov, D. Petkovaa, S. Hristevaa, I. Svinyarova, W. Kantlehnerb, *Z. Naturforsch.* 2010, **65b**, 37.

OL18
Separation of cobalt from nickel via polymer inclusion membrane with ionic liquid [P$_{66614}$][Dec]

Anđela Kovačević, Jose Alejandro Ricardo Garcia, Martina Sanadar, Marilena Tolazzi and Andrea Melchior

Polytechnic Department of Engineering, Chemistry Laboratories, University of Udine, via del Cotonificio 108, Udine, 33100, Italy

Presenting author email: kovacevic.andela@spes.uniud.it

It is estimated that more than 1.2 million tons of batteries enter the European Union each year, with global demand predicted to grow considerably over the next five years [1]. As a result, the demand for Co is projected to increase 20 times by 2050 [2]. Proper disposal of used LIBs is essential to manage resources effectively and prevent environmental pollution from toxic materials [3]. LIBs contain Critical Raw Materials (CRMs) like cobalt, lithium, and graphite, which have high supply risks and price variability [4]. Recent research has focused on sustainable methods for recovering materials from spent LIBs, with hydrometallurgical recycling gaining attention for its low energy and resource use and high metal purity. Liquid-liquid separations using ionic liquids (ILs) have attracted interest due to their potential selectivity and superior characteristics compared to volatile organic solvents (VOCs), such as low volatility, safety, chemical and thermal stability, and recyclability [5]. Immobilizing ILs into polymer inclusion membranes (PIMs) reduces IL volumes which reduces the price, enables extraction and stripping in a single step which makes PIMs suitable for scaled-up processes [6].

In this work we prepared and characterized a PIM membrane based on PVC and IL [P$_{66614}$][Dec] for separation of Ni and Co. Salts of cobalt and nickel were dissolved in 100 ml of HCl acid and used as a Feed phase in reactor shown in Figure 1. The best conditions (temperature, acid molarity, strip phase composition) were determined for metal separation. Metal content in Feed and Strip phase for kinetics and separation study was determined by ICP-OES, and absorption spectra was collected by UV-VIS.

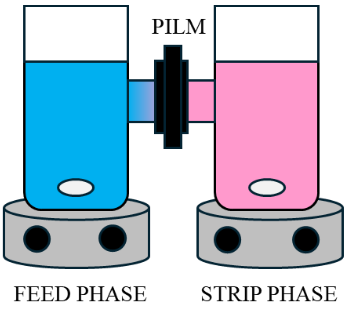


Figure 1. Setup for separation of cobalt from nickel. The volume of each compartment is 100 ml, contact surface with the membrane 28.27 cm^2, stirring speed 700 rpm.

Acknowledgements: AM&AK acknowledge the PhD programme on Green topics (Action IV.5, DM 1061/2021, cycle XXXVII) carried out with co-financing from the European Union - ESF REACT-EU, PON Research and Innovation 2014-2020, UniUD. MT&MS acknowledge the Italian Ministry for University and research for funding: PRIN2022 "Wastezilla" (2022HYH95P).

[1] Y. Zhao, O. Pohl, A.I. Bhatt, G.E. Collis, P.J. Mahon, T. Rüther, A.F. Hollenkamp, *Sustain. Chem.*, 2021, **2**, 167.
[2] A. Tisserant, S. Pauliuk, *J. Econ. Struct.*, 2016, **5**, 4.
[3] T. Or, S.W.D. Gourley, K. Kaliyappan, A. Yu, Z. Chen, *Carbon Energy*, 2020, **2**, 6.
[4] European Commission, Study on the critical raw materials for the EU **2023** – Final report https://data.europa.eu/doi/10.2873/725585, 2023.
[5] Z. Lei, B. Chen, Y.M. Koo, D.R. Macfarlane, *Chem. Rev.*, 2017, **117**, 6633.
[6] A.T.N. Fajar, F. Kubota, M.L. Firmansyah, M. Goto, *Ind. Eng. Chem. Res.*, 2019, **58** (49), 22334.

OL19

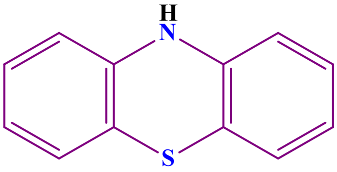
Solubilization of aqueous-insoluble phenothiazine drug in Triton X-100 micellar media

Ajmal Pulikkal and Jacqueline Lalthlengliani

Department of Chemistry, National Institute of Technology Mizoram, Chaltlang, Aizawl 796012, India

Presenting author email: ajmal.chem@nitmz.ac.in

The solubilization of poorly soluble drug phenothiazine (PTZ) in triton X-100 (TX-100) micellar aqueous media at physiological pH and the interaction of cationic surfactants, viz., tetradecyltrimethylammonium bromide (TTAB), hexadecyltrimethylammonium bromide (CTAB), cetylpyridinium chloride (CPC) and cetylpyridinium bromide (CPB) in presence of drug PTZ in TX-100 are discussed. The interaction of surfactants in PTZ–TX-100 media has been studied using conductometric technique at three temperatures. The conductometric results reveal the sequence of critical micelle concentration (CMC) values of surfactants as TTAB > CPC > CPB > CTAB. UV-vis spectroscopy studies were used to learn the interactions of surfactants with the drug PTZ in TX-100 aqueous media (at 303.15 K and pH 7.4) which suggest the interactions are highly feasible (change of Gibbs energy; $\Delta G_b < 0$) and greatly improve beyond the CMC values of corresponding surfactants. Fluorescence technique has been employed to study the aggregation number of TTAB/CTAB in PTZ–TX-100 systems at 303.15 K.



(a) PTZ

Figure 1. Molecular structure phenothiazine drug (PTZ).

OL20
Relative pK_a measurements in non-aqueous solvents

Märt Lõkov

University of Tartu, Institute of Chemistry, Ravila 14a, 50411 Tartu, Estonia

Presenting author email: mart.lokov@ut.ee

Acids and bases are widely used in organic synthesis, chemical analysis, electrochemical processes, and the pharmaceutical industry. The pK_a value used to describe the strength of acids and bases is one of their most important properties. The strength of acids or bases affects their reactivity in chemical reactions, bioactivity, absorption and distribution in living organisms, etc. Accurate pK_a values in water have been determined for a myriad of compounds, but because a significant degree of the usage of acids and bases takes place in non-aqueous solvents, it is crucial to have reliable acidity and basicity data also in these solvents. There is significantly less acidity and basicity data available in non-aqueous solvents because of difficulties in pK_a measurements in such solvents. Moreover, although a significant amount of pK_a values have been determined, e.g. in acetonitrile (MeCN), dimethylsulfoxide (DMSO) and dimethylformamide (DMF), their quality is sometimes doubtful. For instance, in some cases, even simple and widely used carboxylic acids have published pK_a values in the literature that differ by more than an order of magnitude between different authors. For this reason, a reevaluation and revision of pK_a values in MeCN, DMSO and DMF is needed.

We have established measurement capability for pK_a measurements in non-aqueous solvents on the basis of a spectrophotometric method of measuring relative acidity/basicity (ΔpK_a) values. The main advantages of the relative pK_a measurement method are that there is no need to measure pH values and a number of uncertainty sources cancel out, either partially or fully.[1] The most prominent result that we have obtained are extensive self-consistent pK_a scales for acids[2] and bases[3] in acetonitrile (MeCN), each containing over 230 compounds. Because of the nature of the measurement method, involving a number of check and continuous cross-validation, the quality of the results is considered high. Determining high-quality pK_a values also in other solvents (e.g. DMSO and DMF) is underway.

This presentation will describe the principle of our relative pK_a measurement method and show its advantages. A short overview of our recent results and ongoing research will also be provided.

OL21
Uncertainty analysis of solution chemistry data

Christian Ekberg

Department of Chemistry and Chemical Engineering, SE 41296 Göteborg, Sweden

Presenting author email: che@chalmers.se

Uncertainty and sensitivity analysis is an invaluable tool for any modelling attempt, be it a simple chemical speciation calculation to far more complex analyses such as transport of radionuclides from a repository for used nuclear fuel. The founding principle is that we cannot determine anything precisely even of the level of precision may vary. Thus, all measured entities will be encumbered with uncertainties and as these values are subsequently used in e.g. modelling attempt also these results will be uncertain. It is therefore clear that in order to have any reliability in any results a through uncertainty analysis must be done and described together with the determined entity. In this presentation some techniques for uncertainty analysis of solution chemistry data will be given together with an analysis of these results in some modelling attempts.

P1

Physicochemical investigation of ionic additives for improved lithium-ion battery performance and reliability

Nikolett Cakó Bagány[1], Jovana Panić[1], Teona Teodora Borović[1], Mirzet Ćuskić[2], Marija Bešter-Rogač[2] and Snežana Papović[1]

[1]Faculty of Sciences, University of Novi Sad, Novi Sad, 21000, Serbia
[2]Faculty of Chemistry and Chemical Engineering, University of Ljubljana, Ljubljana, 1000, Slovenia

Presenting author email: nikolet.cakobaganj@dh.uns.ac.rs

The development of high-energy density, safe, affordable, and environmentally friendly energy storage devices is crucial for the energy transition. Lithium-ion batteries (LIBs) currently dominate the global energy storage market, but their safety, cost, and environmental impact are significant concerns. The highly flammable and toxic state-of-the-art electrolytes used in LIBs are a major concern, as they can pose a risk to both people and the environment.

The safety issues associated with LIBs are closely linked to their high energy density and the use of volatile and flammable organic-solvent-based electrolytes. As such, improving the thermal stability of electrolytes and enhancing the safety of LIBs is a key priority for our research.

To address this challenge, we are developing electrolytes that can perform multiple functions simultaneously, including stabilizing electrode materials and functionalizing electrodes. In this context, we conducted a comprehensive study involving physicochemical, thermal, and electrochemical testing to evaluate the stability of an electrolyte containing newly synthesized zwitterionic compounds as additives.

Our study utilized 1.0 M $LiPF_6$ in a 50/50 mixture of ethylene carbonate and diethyl carbonate (EC/DEC) as our battery-grade electrolyte solution. We compared the electrochemical performance of the electrolyte with additives to commercially used electrolytes to assess their effectiveness.

Overall, our research aims to develop safer and more environmentally friendly energy storage devices by improving the thermal stability of electrolytes and exploring alternative additive compounds that can enhance the performance of lithium-ion batteries.

Acknowledgments: The authors are grateful for the financial support of the Cost Action CA18202 “NECTAR - the Network for Equilibria and Chemical Thermodynamics Advanced Research.” This research was supported by the Science Fund of the Republic of Serbia, #11036, The new ionic additives for safer and durable electrolytes in lithium-ion batteries - SafeLi.

[1] M. Armand, P. Axmann, D. Bresser, M. Copley, K. Edström, C. Ekberg, D. Guyomard, B. Lestriez, P. Novák, M. Petranikova, *J. Power Sources*, 2020, **479**, 228708.
[2] G.G. Eshetu, J.-P. Bertrand, A. Lecocq, S. Grugeon, S. Laruelle, M. Armand, G. Marlair, *J. Power Sources*, 2014, **269**, 804.
[3] Q. Wang, P. Ping, X. Zhao, G. Chu, J. Sun, C. Chen, *J. Power Sources*, 2012, **208**, 210.

P2

Residual volume approach as a tool for prediction densities of ionic liquids at different pressures and temperatures

Nikolay Lazarov and Milen G. Bogdanov

Faculty of Chemistry and Pharmacy, Sofia University St. Kliment Ohridski, 1, Jammes Bourchier, blvd.,
Sofia, 1164, Bulgaria

Presenting author email: mbogdanov@chem.uni-sofia.bg

A new method has been developed to predict the densities of ionic liquids (ILs) at higher temperatures and pressures. This method is based on an adjusted linear regression equation using the Residual Volume Approach (RVA). The method relies on the linear density dependency on the organic residue's molar volume. The correlation between density and molecular volume has been studied, and adjusted equations have been proposed to accommodate the effects of increased temperature and pressure. These newly defined equations depend on eight coefficients calculated from observed changes in the density of N-alkyl-N-methylimidazolium bis(trifluoromethylsulfonyl)imide type of ILs, as well as the combined effect of changes in molecular volume, temperature, and pressure. These equations can be used with acceptable accuracy. Additionally, a simplified equation requiring only five coefficients is presented. It is also possible to customize the equations to a specific type of cation-anion IL pair by following the method used herein to yield more accurate results. Using eight constants dependent only on residual volume, temperature, and pressure eliminates the need to know IL-specific coefficients, such as isobaric expansivity or isothermal compressibility, which are widely used in similar equations from literature.

The approach proposed can also be used to calculate the properties of other combinations of ions. The calculated results are more accurate when the nature of the IL pair is similar to that of the original. It is possible to fine-tune the equations by adjusting the parameters to accommodate the specific ionic pair, provided that enough density points are available while the equations retain their original form.

[1] M.G. Bogdanov and W. Kantlehner, *Z. Naturforsch*. 2009, **64b**, 215.
[2] M.G. Bogdanov, B. Iliev, and W. Kantlehner, *Z. Naturforsch.* 2009, **64b**, 756.
[3] M.G. Bogdanov et al., *Z. Naturforsch.* 2010, **65b**, 37.

P3

Physicochemical characteristics and antimicrobial activity of nicotine-based ionic liquids with different length alkyl chains

Andrija Vukov[1], Milica Živković[2], Teona Teodora Borović[1], Snežana Papović[1], Jovana Panić[1], Nikolet Cako Baganj[1], Sanja Belić[1], Slobodan Gadžurić[1], Marija Bešter-Rogač[3], Milana Rakić[2], Milan Vraneš[1,4]

[1]Department of Chemistry, Biochemistry and Environmental Protection, University of Novi Sad, Faculty of Sciences, Novi Sad, 21000, Serbia
[2]Department of Biology and Ecology, University of Novi Sad, Faculty of Sciences, Novi Sad, 21000, Serbia
[3]University of Ljubljana, Faculty of Chemistry and Chemical Engineering, Ljubljana, 1000, Slovenia
[4]University of Novi Sad - Faculty of sports and physical education, Novi Sad, 21000, Serbia

Presenting author email: andrija.vukov@dh.uns.ac.rs

Nicotine is a pyridine alkaloid widely known for its recreational use as a stimulant and anxiolytic in the form of tobacco products and e-cigarettes. Nicotine causes addiction in humans and can lead to increased health risks and even cancer [1]. However, nicotine is a natural compound found in a large array of plant species. It is widely believed that the role of this secondary metabolite is that of a pesticide, due to its ability to bind to acetylcholine receptors in the nervous systems of animals, exhibiting harmful effects. For this reason it was used as an agricultural pesticide [2].·

Due to nicotine's structure (Figure 1a) the tertiary nitrogen atom is susceptible to alkylation. The increase of an alkyl side-chain has shown to lead to, among other effects, the increase in antimicrobial activity and toxicity of a substance. Further, ionic liquids (ILs), ionic compounds with melting points below 100°C, are also known to have high biological activity [3]. Due to potential synergistic effects of the base substance, an added alkyl side-chain and the form of an IL, we synthesised four nicotine-based ionic liquids with varying alkyl chain lengths: N-octylnicotinium bromide (Figure 1b), N-decylnicotinium bromide (Figure 1c), N-dodecylnicotinium bromide (Figure 1d) and N-tetradecylnicotinium bromide (Figure 1e).

In order to understand the behaviour of these newly synthesised nicotine-based ILs, density, viscosity and sound velocity measurements of their water solutions were performed in a concentration range from 0.02 to 0.12. mol·kg^{-1} and in a temperature range from 293.15 to 313.15K. The gathered data was further used to determine, among others, apparent molar volume, apparent molar volume at infinite dilution, *Jones-Dole* viscosity coefficient *B*, apparent molar compressibility and apparent molar compressibility at infinite dilution. The values gained are further discussed in terms of solute-solute and solute-solvent interactions. The antimicrobial activity of these ILs and nicotine was also tested against several strains of gram-positive and gram-negative bacteria, yeasts and molds and compared. It was found that all nicotine-based ILs have significantly higher antimicrobial activity than nicotine, for all examined species (Figure 1f).

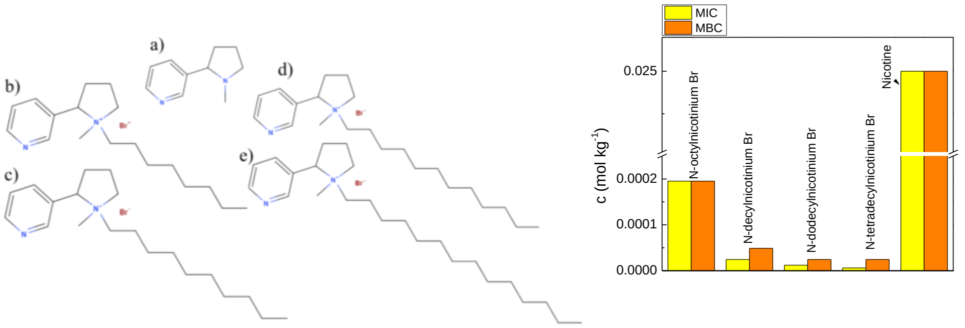


Figure 1. Structures of a) nicotine and nicotine-based ILs: b) N-octylnicotinium bromide c) N-decylnicotinium bromide d) N-dodecylnicotinium bromide e) N-tetradecylnicotinium bromide and f) a graph showing antimicrobial activity of these substances *Escherichia coli* bacteria

[1] A. Mishra, P. Chaturvedi, S. Datta, S. Sinukumar, P. Joshi, A. Garg, *Indian J. Med Paediatr Oncol.*, 2015, **36**, 24.

[2] A. Steppuhn, K. Gase, B. Krock, R. Halitschke, I.T. Baldwin, *PLOS Biology.*, 2004, **2**, e382.

[3] T. Guo, X. Wang, Y. Shu, *J. Mol. Liq.*, 2021, **339**, 116835.

P4

Impact of the environmental conditions on the resilience of bioregulators in the aquatic environment

Andrijana Bilić[1,2], Maria Savanović[1,2], Stevan Armaković[2,3], Mladen Kalajdžić[4], Predrag Božović[4],
Dragoslav Ivanišević[4], Sanja Armaković[1,2]

[1]Department of Chemistry, Biochemistry and Environmental Protection, University of Novi Sad, Faculty of Sciences, Trg Dositeja Obradovića 3, Novi Sad, 21000, Serbia
[2]Association for the International Development of Academic and Scientific Collaboration (AIDASCO), Sutjeska 2, Novi Sad, 21000, Serbia
[3]Department of Physics, University of Novi Sad, Faculty of Sciences, Trg Dositeja Obradovića 4, Novi Sad, 21000, Serbia
[4]University of Novi Sad, Faculty of Agriculture, Trg Dositeja Obradovića 8, Novi Sad, 21000, Serbia

Presenting author email: andrijana.bilic@dh.uns.ac.rs

Bioregulators encompass natural and synthetic compounds utilized directly on plants to enhance agricultural yields. Among the synthetic variants, Globaryll (G) and Ormoroc (O) stand out, aiding in regulating plant growth and development. However, their prolonged presence may lead to environmental accumulation at diminishing concentrations, potentially posing risks as organic pollutants [1].

We investigated the photolytic stability of G and O in a mixture of higher (100 and 20 mg/dm^3, respectively) and lower (50 and 10 mg/dm^3, respectively) concentrations in ultrapure (UPW) and stream water (SW) to understand their environmental stability and behavior. After applying bioregulators in the field, higher concentrations of both substances can be found in the natural environment. However, as the plant partially absorbs the bioregulators over time, their concentrations decrease. Therefore, it is essential to study the stability of bioregulators in both scenarios. The degradation efficiency of G in higher concentrations resulted in 38% degradation observed in UPW (Fig. 1a) and 55% in SW (Fig. 1b). In contrast, G in lower concentrations showed consistently high photolytic stability, whereby 8% in UPW (Fig. 1a) and 2% in SW was degraded (Fig. 1b). On the other hand, O showed high stability for both concentrations. In UPW, 4% degradation was observed for lower and 5% for higher concentrations. The degradation efficiency of O significantly increased in SW, with 13% degradation in lower concentration and 50% in higher concentration, likely due to additive or synergistic effects facilitated by the presence of inorganic ions.

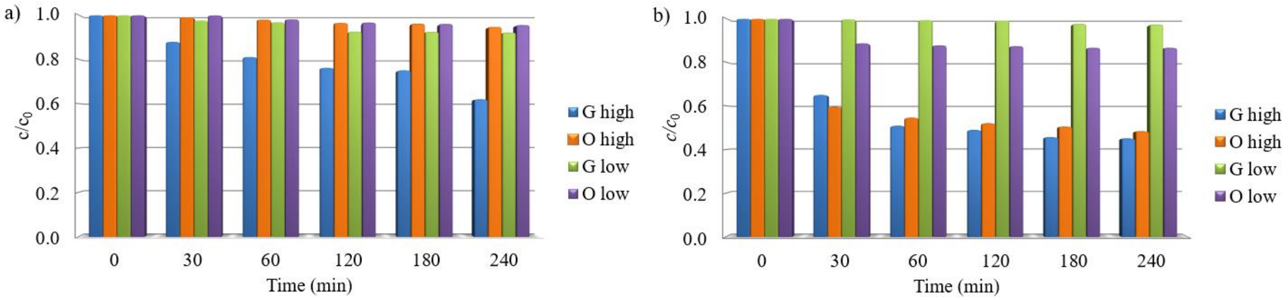


Figure 1. Direct photolysis of Globaryll (G) and Ormoroc (O) in a mixture of higher (100 and 20 mg/dm^3, respectively) and lower (50 and 10 mg/dm^3, respectively) concentrations in (a) UPW and (b) SW.

Acknowledgements: This work is supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No. 451-03-66/2024-03/200125 & 451-03-65/2024-03/200125) and Association for the International Development of Academic and Scientific Collaboration (AIDASCO).

[1] M. Savanović et al., *J. Mol. Struct.*, 2023, **1289**, 135908.

P5

The behavior of hydroxyapatite ceramics in the mimic de- and remineralization solutions

Radost Ilieva[1], Ivalina Avramova,[1] Marin Simeonov[2] and Diana Rabadjieva[1]

[1]Institute of General and Inorganic Chemistry, Bulgarian Academy of Sciences, Sofia 1113, Bulgaria
[2]Faculty of Chemistry and Pharmacy, University of Sofia 1113, Sofia, Bulgaria

Presenting author email: radipl@mail.bg

The compositional and structural similarity of hydroxyapatite to solid tissues makes it suitable for bone reconstruction in the form of ceramic materials, coatings of metal devices, etc. When placed in the body, hydroxyapatite interacts with the body fluids, and depending on the environment, processes of dissolution (demineralization) or reverse deposition of mineral crystals (remineralization) can occur.

The behavior of hydroxyapatite ceramics in the mimic de- and remineralization solutions from the oral cavity was investigated in this study. Dense ceramic tablets from monophasic hydroxyapatite were prepared by pressing and sintering at 1000ºC of nanocrystalline carbonate apatite. The precursor was synthesized via wet precipitation method from 1M solution of $Ca(NO_3)_2$ and 0.6M solution of $(NH_4)_2HPO_4$ at a Ca/P ratio of 1.67, pH 12 (keeping with NH_4OH), open-air atmosphere and continuous stirring. The resulting precipitate was matured for 24 h, centrifuged, washed, and dried at 90°C for 15 h. A solution containing 0.1 mM of lactic acid, 2.2 mM $CaCl_2$, and 2.2 mM NaH_2PO_4 was chosen as a demineralizing agent with pH 4.5. It mimics the conditions in the oral cavity at the bactericidal decomposition of sugars producing lactic acid. Remineralization was examined in the presence of artificial saliva after biostimulating the tablet surface with a solution containing polycarboxybetaine (PCB). PCB is a zwitterionic polymer with unique properties – it creates conditions for mineral nucleation and can serve as an antifouling coating. The experiments were carried out under such conditions as to avoid mineral deposition resulting from sedimentation.

The results of X-ray photoelectron spectroscopy (XPS) reveal that in the initial ceramic tablets, Ca, P, O, and C are the main elements present on the surface in the form of hydroxyapatite and calcium carbonate. The element concentrations are close to the one in the tooth email. Insignificant amounts of Na, Cl, and Si were also found. During the demineralization process, no significant changes were observed in the state of the main elements, except for an increase in the amount of carbonate-type carbon and absorbed water and the appearance of less than 3% nitrogen. The quite noticeable surface change was detected after the remineralization procedure of the sample staying for 12 hours in a demineralizing solution. All peaks become asymmetric indicating a new microenvironment on the surface originating from the components of artificial saliva, namely the appearance of C–N and Na-P-O bonds and increasing the amount of hydroxy and carboxylic groups, which may serve as centers of mineralization.

The images from scanning electron microscopy show a difference in the surface morphology after 6 and 12 h exposure to demineralization respectively. During the first hours, the dissolution proceeds in a spiral fashion, with a greater rate in the center and a lower rate in the periphery. As a result, pits on the grain surface and holes at the grain boundary are formed. As time increases, the concentration of Ca^{2+} ions in the solution increases, the driving force of dissolution decreases, and the two rates equalize. Thus, after 12 h of stay in a demineralizing environment, the surface is smoother, without sharp boundaries between individual hydroxyapatite crystals.

After the remineralization procedure, crystal grains are covered with a diaper due to the deposition of the newly formed mineral phase. The Ca/P ratio of 1.58 - 1.71 reveals apatite type mineral phase in which Na^+ ions are included. The C–N bond, detected by XPS analysis is due to the absorbed organic compounds from the artificial saliva.

In conclusion, hydroxyapatite ceramic obtained by us reveals de and remineralization behavior similar to the tooth enamel and could be used both for tooth restoration and as a primary model for enamel research.

Acknowledgments: The authors thank the Bulgarian Ministry of Education and Science for the financial support under the project KP-06-H49-6/2020. In this investigation, we used the research equipment of Distributed Research Infrastructure INFRAMAT, part of the Bulgarian National Roadmap for Research Infrastructures, supported by the Bulgarian Ministry of Education and Science.

P6

Graphitic carbon nitride and tetrabutylammonium chloride modified carbon paste electrode for efficient electrochemical sensing of carbamazepine

Jasmina Anojčić[1], Sanja Mutić[1], Slađana Đurđić[2], Sandra Petrović[3], Pavol Gemeiner[4]
and Dalibor Stanković[2,5]

[1]Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 3, Novi Sad, 21000, Serbia
[2]Faculty of Chemistry, University of Belgrade, Studentski trg 12-16, Belgrade, 11000, Serbia
[3]Faculty of Pharmacy, Bijeljina University, Pavlovića put 024, Bijeljina, 76300, Bosnia and Herzegovina
[4]Department of Graphic Arts Technology and Applied Photochemistry, Faculty of Chemical and Food Technology, Slovak University of Technology in Bratislava, Radlinského 9, Bratislava, 812 37, Slovakia
[5]Department of Radioisotopes,"Vinča" Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, Mike Petrovića Alasa 12-14, Belgrade, 11000, Serbia

Presenting author email: jasmina.anojcic@dh.uns.ac.rs

Carbamazepine (CBZ) is an anticonvulsant, antiepileptic and mood stabilizing drug used primarily in the treatment of epilepsy and bipolar disorder [1]. As a result of its widespread use, CBZ determination in biological and pharmaceutical samples is of great importance. Different analytical methods are reported for CBZ determination, whereby there is an increasing interest in the development of electrochemical methods for determining CBZ due to their advantages such as simplicity, portability, reliability, and cost-effectiveness. Although CBZ direct electrochemical measurement is possible at different electrodes, researchers mostly used carbon-based electrodes in their modified form [2]. Ionic liquids (ILs) draw attention in electroanalysis as modifiers of carbon paste electrodes (CPE) because of their specific features, such as possible catalytic activity, wide electrochemical window, electron-transfer acceleration and high conductivity [3]. Additionally, IL modified electrodes showed an excellent electroanalytical performance in detection of electroactive species by enhancing faradaic responses and consequently the signal-to-noise ratio [4].

This study utilizes the preparation of CPE bulk-modified with a type of two-dimensional conjugated polymer, i.e., graphitic carbon nitride (g-C_3N_4), and IL tetrabutylammonium chloride (TBACl) to obtain advanced electrochemical sensor for CBZ. Cyclic voltammetric experiments showed that TBACl-g-C_3N_4-CPE has an improved electrochemical response compared to unmodified CPE and g-C_3N_4-CPE due to the synergistic effect of electrode modifiers, as well as that the CBZ oxidation process is irreversible and diffusion-controlled. Using direct anodic square-wave voltammetry (SWV) under optimized conditions at pH 7.0, the CBZ sensor showed a linear dynamic range from 0.10 to 2.20 µg mL^{-1}, a limit of detection (LOD) of 0.030 µg mL^{-1} and relative standard deviation lower than 3%. No significant influence of inorganic ions or organic compounds on sensor response was verified. The practical applicability of TBACl-g-C_3N_4-CPE was tested for quality control of CBZ pharmaceutical formulation Karbapin® and for the determination of CBZ in spiked human urine sample. Based on the obtained results it can be concluded that TBACl-g-C_3N_4-CPE could be successfully applied as a very simple and perspective analytical tool for the determination of CBZ in different matrices with excellent recovery and reproducibility.

Acknowledgements: The authors gratefully acknowledge the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No. 451-03-66/2024-03/200125 & 451-03-65/2024-03/200125) and CEEPUSIII (CZ-0212-17-2324) network.

[1] S.K. Hassaninejad-Darzi,, F, Shajie, *Mater. Sci. Eng. C.,* 2018, **91**, 64.
[2] L. Daneshvar, *Talanta Open*, 2022, **6**, 100147.
[3] E.F. Fiorentini, M. Llaver, M.N. Oviedo, P.Y. Quintas, R.G. Wuilloud, *Green Anal. Chem.,* 2022, **1**, 100002.
[4] S. Šekuljica, V. Guzsvány, K. Kalcher, J. Anojčić, *J. Electrochem. Soc.,* 2020, **167**, 137504.

P7

Exploring protic ionic liquids-water interactions: Experimental and computational analysis of 2-hydroxypropylammonium formate

Milan Vraneš[1], Saša Laloš[2], Jovana Panić[1], Snežana Papović[1], Teona Teodora Borović[1], Nikolett Cakó Bagány[1], Sanja Belić[1], Andrija Vukov[1], Slobodan Gadžurić[1] and Siniša Bikić[3]

[1]Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 3, Novi Sad, 21000, Serbia
[2]University of Banja Luka, Faculty of Mechanical Engineering, Ulica Vojvode Stepe Stepanovića 71, Banja Luka, 78000, Bosnia and Herzegovina
[3]University of Novi Sad, Faculty of Agriculture, Trg Dositeja Obradovića 8, Novi Sad, 21000, Serbia

Presenting author email: milan.vranes@dh.uns.ac.rs

Ionic liquids (ILs) are a unique class of compounds that have garnered significant academic and industrial attention due to their distinct properties such as low volatility, high thermal stability, and a broad liquidus temperature range. These salts, which are liquid below 100°C, exhibit remarkable solvating abilities owing to their ionic nature. Among them, protic ionic liquids (PILs) are of particular interest for various industrial applications due to their economic feasibility and straightforward synthesis. The production of PILs involves the direct neutralization of a Brønsted acid with a Brønsted base, often in a solvent-free process, making it cost-effective and environmentally friendly [1,2].

The versatility of PILs is further enhanced by the wide variety of available Brønsted acids and bases, allowing for the creation of PILs with tailored properties. This customization is crucial for industrial processes where specific physicochemical properties, such as viscosity, conductivity, and thermal stability, can be fine-tuned. Adjusting the hydrophobic or hydrophilic nature of PILs by selecting appropriate acid-base combinations also improves their efficacy as solvents, catalysts, or electrolytes in various chemical reactions and processes.

PILs exhibit exceptional physicochemical properties, including low volatility, high thermal stability, high ionic conductivity, and wide electrochemical windows. These attributes make them suitable for applications in energy storage and conversion systems, such as batteries and fuel cells. Moreover, PILs are generally biodegradable and less toxic than traditional organic solvents and aprotic ionic liquids, making them more environmentally friendly [3,4].

In this study, the protic ionic liquid 2-hydroxypropylammonium formate [2-OHC_3NH_3][Fo] was synthesized through a solvent-free neutralization process using non-toxic, cost-effective formic acid and (±)-1-amino-2-propanol. The physicochemical properties of the synthesized ionic liquid and its mixtures with water were measured across the entire range of mole fractions and within the temperature interval of T = (278.15 - 333.15) K. These properties included density, viscosity, and electrical conductivity. Additionally, the thermal profile of the synthesized ionic liquid was presented.

The study provided an in-depth analysis of the interactions between the ionic liquid and water, focusing on how variations in temperature and composition affect the hydration properties and ionization degree of the ionic liquid. Computer simulations were also conducted to gain further insights into the structural organization of water molecules around the ions of the ionic liquid.

Acknowledgements: The authors would like to acknowledge the contribution of the Secretariat for Higher Education and Scientific Research of the Autonomous Province of Vojvodina, Serbia (Grant No. 142-451-2545/2021-01/2).

[1] T.L. Graves, C.J. Drumond, *Chem. Rev.*, 2008, **108(1)**, 206.
[2] J. Bailey, E.L. Byrne, P. Goodrich, P. Kavanagh, M. Swadźba-Kwaśny, *Green Chem.*, 2024, **26**, 1092.
[3] T. Stettner, A. Balducci, *En. Stor. Mat.*, 2021, **40**, 402.
[4] T.L. Greaves, A. Weerawardena, C. Fong, I. Krodkiewska , C.J. Drummond, *J. Phys. Chem. B.*, 2006, **110(45)**, 22479.

P8

Synthesis, characterization, and antimicrobial activity of an ionic liquid 1-butyl-3-methylimidazolium 2-hydroxy-2-phenylacetate

Sanja Belić, Nikolett Cakó Bagány, Milan Vraneš, Snežana Papović, Jovana Panić, Teona Teodora Borović, Andrija Vukov and Slobodan Gadžurić

Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Novi Sad, 21000, Republic of Serbia

Presenting author email: sanja.belic@dh.uns.ac.rs

Industrial processes often use organic solvents that are toxic and harmful to the environment and human health. To protect our environment, harmful solvents must be replaced with non-toxic and biodegradable solvents.

That is why green chemistry was developed, i.e., procedures for obtaining chemical products and processes that reduce or eliminate the use and creation of hazardous substances. It deals with the development of safe, non-flammable, and non-toxic compounds, and ionic liquids (ILs) fully meet these requirements. Ionic liquids are salts consisting of a large organic cation and a small organic or inorganic anion whose melting point is below 100°C. Most of them are already in a liquid aggregate state at room temperature (room temperature ionic liquids - RTIL). The main advantage of ionic liquids is the possibility of their design because by combining anions and cations, the desired properties are achieved, which makes it possible to overcome problems present in various fields. For example, in the last two years, disinfection has become commonplace in everyday life as a preventive measure against the spread of the new SARS-COV-2 virus. Ionic liquids can be designed so that they are non-volatile and, at the same time, exhibit antimicrobial and antiviral effects, thus ensuring long-term disinfection of the surfaces to which they are applied.

This work aims to synthesize and characterize aqueous solutions of the newly synthesized ionic liquid 1-butyl-3-methylimidazolium 2-hydroxy-2-phenylacetate. In the synthesis of the ionic liquid, mandelic acid, and 1-butyl-3-methylimidazolium chloride were used as starting components. One of the most important properties of mandelic acid is its bacteriostatic properties, while 1-butyl-3-methylimidazolium chloride shows good physicochemical properties derived from the aromatic imidazole ring. The density and viscosity of the ionic liquid at different temperatures were measured, and then the interactions that exist in aqueous solutions of this ionic liquid were considered. Then, the antimicrobial activity of the corresponding ionic liquid was tested, and it was determined whether it could serve as a disinfectant.

Acknowledgments: The authors are grateful for the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No. 451-03-66/2024-03/200125 and 451-03-65/2024-03)/200125).

P9

N-methylimidazolium-based ionic liquids as potential modulators of metabolic processes

Savina Stoyanova and Milen Bogdanov

Faculty of Chemistry and Pharmacy, Sofia University St. Kliment Ohridski, 1, Jammes Bourchier, blvd.,
Sofia, 1164, Bulgaria

Presenting author email: savinais@uni-sofia.bg

N-methylimidazolium-based ionic liquids were synthesized and characterized as potential modulators of beta-oxidation of fatty acids in the organism via inhibition of Carnitine Acetyltransferase (CrAT). The inhibitory effect of the synthesized compounds was tested *in vitro* and compared with controls: Meldonium (an approved drug for the treatment of coronary heart disease, under the trade name Mildronate®) and MeGBB (a compound in third-phase clinical trials).

All compounds demonstrate inhibitory effects in low millimolar concentrations, some being more active than the controls. The IC50 values of all compounds were determined. Structure-activity relationships (SAR) were elucidated – a) effect of the length of carbon chain – R (C2-C10), b) presence of different substituents attached to carbon chain – R (e.g. hydroxyl, nitrile, ester group), c) carbon chain branching and d) effect of the anion (e.g. Cl-, Br-, salicylate, caffeate) With the most active compounds of the group, kinetic studies were conducted to determine the mechanism of inhibition of Carnitine Acetyltransferase (CrAT).

The results showed that N-methylimidazolium-based ionic liquids are potential modulators of metabolic processes and drug for treatment of coronary heart decease, diabetes and even some types of cancer.

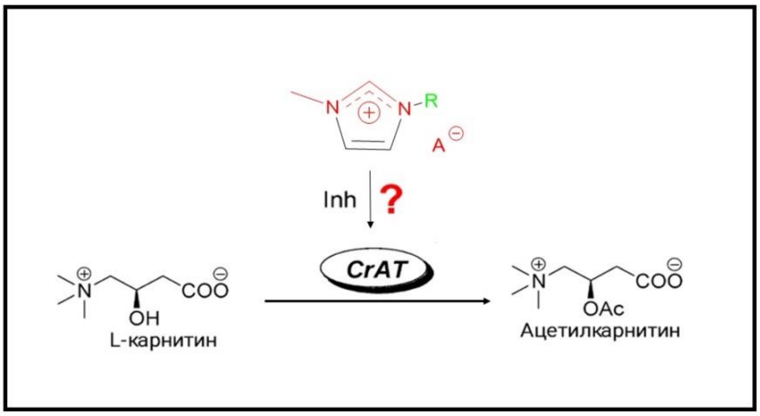


Figure 1. N-methylimidazolium-based ionic liquids are potential inhibitors of fatty acids oxidation as they supress conversion of L-carnitine to AcetylCarnitine.

P10
Sphalerite dissolution in deep eutectic solvents

Ehsan Bidari[1], Frank Agyemang[2] and Gero Frisch[1]

[1]Institut für Anorganische Chemie, Technische Universität Bergakademie Freiberg, Freiberg, 09599, Germany
[2]Department of Metallurgical and Materials Engineering, Montana Technological University, Butte, 59701, Montana, United States

Presenting author email: ehsan.bidari@chemie.tu-freiberg.de

Sphalerite (ZnS) is the main resource of zinc. The conventional method of zinc recovery from sphalerite involves roasting, leaching, and electrolysis. However, this process suffers from environmental issues, high energy demands, and the generation of impurities. Such drawbacks, along with the current drive for the minerals processing industries to develop low-energy, low-cost, and more environmentally sustainable processes, have led to the recent invention called ionometallurgy. Ionometallurgy aims to dissolve ores at low temperatures using non-aqueous solvents [1]. Promising results have been reported regarding the use of ionometallurgy for the treatment of sulfide minerals [2].

Here, we report our experimental results on the dissolution of sphalerite in **d**eep **e**utectic **s**olvents (DESs). DESs are binary or ternary mixtures with deep melting point depression. Three well-known DESs, namely Ethaline (1 mole choline chloride: 2 moles ethylene glycol), Reline (1 mole choline chloride: 2 moles urea), and Oxaline (1 mole choline chloride: 1 mole oxalic acid dihydrate), have been used for dissolution experiments. The results revealed that using DESs improves the dissolution of sphalerite under both non-oxidative and oxidative conditions compared to an equivalent acidic aqueous solution (Figure 1). The highest solubilities were found using Oxaline. Oxidants were found to influence the dissolution of sphalerite in both DESs and aqueous media, with cupric ions being most effective in DESs and ferric ions in aqueous media.

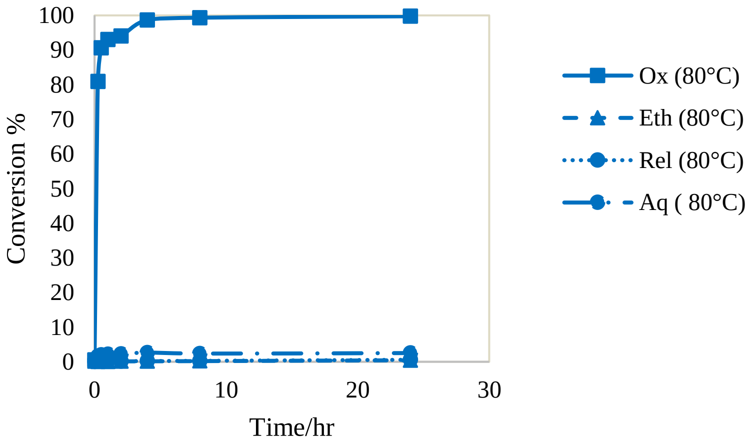


Figure 1. Conversion of sphalerite in Oxaline (Ox), Ethaline (Eth), Reline (Rel), and aqueous acidic (Aq) solutions, solid to liquid ratio = 1:100.

[1] A. Abbott, G. Frisch, *Royal Soc. Chem.*, 2013, **22**, 59.
[2] E. Bidari, C. Winardhi, G. Assuncao, G. Frisch, *ACS Omega*, 2024, **9**, 14592.

P11

Influence of the ionic liquids based electrolytes on the tomato (*Solanum lycopersicum* L.) and cucumber (*Cucumis sativus* L.) growth, development and oxidative stress

Snežana Papović[1], Ivana Maksimović[2], Marina Putkin Delić[2], Mingjiong Zhou[3], Zhu Lipeng[3] and Milan Vraneš[1]

[1]Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradivića 3, Novi Sad, 21000, Republic of Serbia
[2]Faculty of Agriculture, University of Novi Sad, Trg Dositeja Obradivića 8, Novi Sad, 21000, Republic of Serbia
[3]School of Materials Science and Chemical Engineering, Ningbo University, 315211, Zhejiang, People's Republic of China

Presenting author email: snezana.papovic@dh.uns.ac.rs

Ionic liquids have been identified as possible alternatives to traditional organic solvents in lithium-ion battery electrolytes due to their distinct properties, including high thermal stability, low volatility, and wide electrochemical windows. These features could make them safer and more efficient. Despite the benefits, there are concerns about the environmental consequences of using ionic liquids in lithium-ion battery electrolytes. One significant concern is the threat of soil and plant contamination. If these liquids spill or leak from used lithium-ion batteries [1,2], they could enter the soil through various pathways and contaminate crops such as cucumber and tomato plants, which have extensive root systems that may facilitate the absorption of ionic liquids. After absorption, some electrolyte components could accumulate inside the plants and have toxic effects, potentially harming plant growth and crop yields.

This study investigated how spilling electrolytes with varying combinations of ionic liquids, organic solvents, and lithium salts in different concentrations affects the growth and development of tomatoes and cucumbers. The focus is on ionic liquids in mixture with propylene-carbonate. Special attention was paid to examining the influence of electrolyte components on aerial parts and/or fruits of these plants and the levels of metabolites involved in antioxidant protection under stressful conditions, such as malonyldialdehyde and photosynthetic pigments like chlorophyll a, chlorophyll b, and carotenoids.

Acknowledgements: The authors are grateful for the financial support of Provincial Secretariat for Higher Education and Scientific Research, grant number: 142-451-2545/2021-01.

[1] M. Contestabile, S. Panero, B. Scrosati, *J. Power Sources*, 2001, **92**, 64.
[2] J. Schaff, C.C. Fink, B. Slepohenko, J.H. Carson, L.M. Loew, *Biophys. J.*, 1997, **73**, 1135.

P12

Quantitative precipitation of cobalt based oxide material from battery recycling solutions

Florian Gattnar, Daniela Freyer and Gero Frisch

Department of Inorganic Chemistry, TU Bergakademie Freiberg, Leipziger Str. 29, Freiberg, 09599, Germany

Presenting author email: florian.gattnar@chemie.tu-freiberg.de

Lithium-ion batteries are composed of a graphite anode and a mixed metal oxide cathode ($LiMO_2$; $M = x$ Ni, y Co, z Mn; $x + y + z = 1$), which are separated and recycled to reuse their valuable components when reaching their end of life [1].

In this study we investigate the reaction of cobalt(III) amines in lithium hydroxide solution to produce lithium cobalt oxide compounds by precipitation, as a possible step to produce the active material $LiCoO_2$ directly from black mass leachates.

It is well known that hexammine cobalt(III) ions form cobalt oxyhydroxide precipitates in alkaline media (Eq. 1). Due to similar crystal structures of CoO(OH) and $LiCoO_2$, an ion exchange of hydroxide protons and lithium ions takes place in solution (Eq. 2)[2,3].

$$[Co(NH_3)_6]^{3+} + 3\ OH^- \rightarrow CoO(OH) + 6\ NH_3 + H_2O \qquad \text{(Eq. 1)}$$

$$CoO(OH) + Li^+ + OH^- \rightarrow LiCoO_2 + H_2O \qquad \text{(Eq. 2)}$$

In our research, identification of phases via P-XRD, Raman spectroscopy as well as investigation of chemical composition by thermoanalytical methods and wet chemical analysis confirmed the presence of $Li_xCoO_{1+x}(OH)_{1-x}$ ($0.48 < x < 0.93$). The phase composition is adjustable by modifying the reaction temperature (70 - 200 °C), reaction time (2 - 48 h), and lithium concentration up to saturation of $LiOH \cdot H_2O$.

Analysis of the supernatant shows cobalt recovery of >99.9 %, which was confirmed by UV-Vis spectroscopy. Lithium and hydroxide concentrations decrease by precipitating hydroxidic lithium cobalt(III) oxide. Counterions, e.g. chloride and sulfate, do not take part in the precipitation process. In reactions under reflux only 20 % of the maximum amount of ammonia was detected. Contrarily, ammonia remains up to 90 % in hydrothermal reactions performed in autoclaves, which can be recovered as starting material to resynthesize cobalt(III) ammine compounds.

We aim to use these precipitates as potential cathode materials in lithium-ion batteries.

Acknowledgements: The authors would like to thank K-UTEC Salt Technologies for funding.

[1] O. Velázquez-Martínez, J. Valio et al., *Batteries*, 2019, **5**, 68.
[2] C. Barriga, A. Calero et al., *Reactivity of Solids*, 1989, **7**, 263.
[3] G. Amatucci, *Solid State Ionics*, 1996, **84**, 169.

P13

Studying the impact of converting creatine and guanidinoacetic acid from zwitterionic to cationic form on their water solubility

Jovana Panić, Snežana Papović, Teona Teodora Borović, Nikolett Cakó Bagány, Sanja Belić, Andrija Vukov, Slobodan Gadžurić and Milan Vraneš

[1]Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 3, Novi Sad, 21000, Serbia

Presenting author email: jovanap@dh.uns.ac.rs

Creatine (CR) is an endogenous amino acid naturally synthesized by the human body to provide energy to muscles. It facilitates the regeneration of adenosine triphosphate (ATP) utilized during muscular exertion, resulting in enhanced strength and endurance [1]. While creatine monohydrate is the most extensively researched and widely utilized form of creatine, it is associated with limitations such as poor water solubility, spontaneous conversion to creatinine, and the requirement for specific transporters for cellular uptake. Consequently, there is a need to explore novel formulations to mitigate these drawbacks [2].

Guanidinoacetic acid (GAA) serves as a natural metabolic precursor to creatine, undergoing biological conversion into creatine via hepatic methylation. Recent scientific literature suggests that the synergistic combination of creatine and GAA is more efficacious in elevating creatine levels in serum, muscle tissue, and the brain compared to the use of pure creatine [3]. However, both creatine and GAA exhibit relatively low water solubility, underscoring the desirability of converting them into more soluble hydrochloride salts. While several advanced formulations in the sports supplement market incorporate creatine hydrochloride salts, the solubility of creatine, creatinine, creatine hydrochloride, and GAA hydrochloride remains inadequately studied. In contrast, the solubility of GAA in water has been previously investigated [4].

Consequently, this study seeks to first convert creatine and GAA into hydrochloride salts and subsequently ascertain the solubility of creatine, creatinine, creatine hydrochloride, and GAA hydrochloride in water within the temperature range of T = (293.15-313.15) K at atmospheric pressure. The findings of this investigation will facilitate a comprehensive analysis of the thermodynamics governing the dissolution of the compounds.

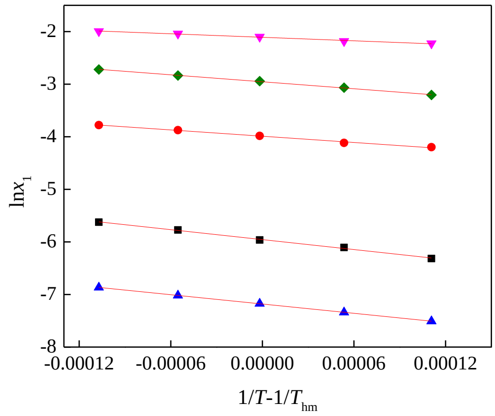


Figure 1. The plot of natural logarithm of the mole fraction of (■) creatine, (●) creatinine, (▲) GAA, (▼) creatine hydrochloride, (◆) GAA hydrochloride in a saturated aqueous solution, $\ln x_1$, against $1/T-1/T_{hm}$.

Acknowledgements: The authors are grateful for the financial support of Provincial Secretariat for Higher Education and Scientific Research, grant number: 142-451-2545/2021-01.

[1] R. Cooper, F. Naclerio, J. Allgrove, A. Jimenez, *J. Int. Soc. Sports Nutr*., 2012, **9**(1), 33.
[2] R. Jäger, M. Purpura, A. Shao, T. Inoue, R. B. Kreider, *Amino Acids*., 2011, **40**(5), 1369.
[3] S. Ostojić, B. Niess, M. Stojanović, M. Obrenović, *Int. J. Medical Sci.*, 2013, **10**(2), 141.
[4] M. Vraneš, S. Ostojić, A. Tot, S. Papović, S. Gadžurić, *Food Chem*., 2017, **237**, 53.

P14

Influence of differently structured aqueous solutions on organic reactions

Lena Schmauser, Evamaria Hofmann and Werner Kunz

Department of Physical and Theoretical Chemistry, University of Regensburg, Universtätsstraße 31,
Regensburg, 93053, Germany

Presenting author email: lena.schmauser@ur.de

To make organic reactions more environmentally friendly and to reduce waste caused by organic solvents, more and more reactions are tried to be carried out in aqueous systems. Water has the advantage of being non-toxic, environmentally friendly, and non-flammable. However, the challenges of using aqueous systems are the poor solubility of the reactants and the possible decomposition of these substances. In the literature, the yield of the reactions is often increased by the addition of surfactants, like TPGS-750-M. On the one hand, the formation of micelles can increase the solubility of the substances due to the more hydrophobic area of the micelles, and on the other hand, according to literature, the reactions are improved by the compartmentation of the solvent.

The physical background, such as solubility, structuring, and specific interactions with the solvent that influence different organic reactions has been investigated.

To investigate the influence of different aqueous systems, a cascade reaction consisting of a Heck reaction followed by an enzyme catalysis from the work of Cortes-Clergent *et al.* was carried out [1]. The reaction was performed in water, a surfactant-based and surfactant-free microemulsion, and in a non-structured binary mixture. The highest yield was obtained in the surfactant-free microemulsion. However, the higher yield compared to the reaction in pure water, cannot be attributed to the structuring of the system but to the solubility of the reaction components, as the reaction proceeds better in the non-structured binary system than in the micellar solution [2].

Furthermore, the synthesis of dihydroquinolinones with a rhodium catalyst from the work of Linsenmeier *et al.* was analysed [3]. The reaction was also performed in water, a surfactant-based and surfactant-free microemulsion, and in binary systems without structuring. In this reaction, the highest yields were obtained in the structured solvent systems. The increased yields can possibly be explained by the incorporation of the reactants into the interface. In the case of the surfactant-containing system, interactions occurring between the reactants and the surfactant were determined with NOESY NMR. The solubility of the reactants seems to play a subordinate role in this reaction, as the solubility in the binary non-structured mixtures is similar to the solubility in the surfactant-free microemulsion. However, it should be mentioned that the differences in the yields between the structured and unstructured systems is only about 12%.

Due to the mentioned small differences in the yields between structured and unstructured systems of the last reaction, the esterification by lipases in aqueous systems will be investigated in future work (from the work of Singhania *et al.*) [4]. Normally, lipases would catalyse the reverse reaction, i.e., the cleavage of the ester, at increased water content. This reaction was also carried out in various solvents. However, up to this point, only measurable yields were obtained in surfactant-containing systems. This allows the assumption that in this case the structuring and the interaction of the surfactants with the enzyme and the reaction partners play a decisive role.

The yields of the products are determined with NMR measurements.

In summary, it can be said that the influence of solvents, especially surfactant-based and surfactant-free microemulsions, can vary depending on the reaction. In some cases, it is sufficient to increase the solubility of substances, for which no surfactant is necessary, while in other reactions the micellar structuring actually has an influence on the reaction.

[1] M. Cortes-Clerget, N. Akporji, J. Zhou, F. Gao, P. Guo, M. Parmentier, F. Gallou, J. Berthon, B. Lipshutz, *Nat. Commun.*, 2019, **10**, 2169.

[2] E. Hofmann, L. Schmauser, J. Neugebauer, D. Touraud, F. Gallou, W. Kunz, *Chem. Eng. J.*, 2023, **472**, 144599.

[3] A. Linsenmeier, W. Braje, *Tetrahedron.*, 2015, **71**, 6913.

[4] V. Singhania, M. Cortes-Clerget, J. Dussart-Gautheret, B. Akkachairin, J. Yu, N. Akporji, F. Gallou, B. Lipshutz, *Chem. Sci.*, 2022, **13**, 1440.

P15

Critical evaluation of volume properties of the zirconium-based fluorides melts MF-K_2ZrF_6 (M = Li, Na, and K)

Jarmila Mlynáriková and Miroslav Boča

Department of Molten Systems, Institute of Inorganic Chemistry Slovak Academy of Sciences, Dúbravská cesta 9, SK-845 36 Bratislava, Slovakia

Presenting author email: miroslav.boca@savba.sk

MF-K_2ZrF_6 (M = Li, Na, and K) melts are important systems in metallurgy applications. Based on the experimentally measured data of density (determined by the Archimedean method) molar volumes, partial molar volumes and the excess molar volumes were calculated. Partial molar volumes of K_2ZrF_6 were obtained by using two different approaches - simple polynomial regression analysis and multicomponent polynomial regression in the form of the Redlich-Kister equation [1]. The excess molar volume possesses negative values throughout the entire concentration range for all three investigated systems. These negative values of the excess partial molar volumes of K_2ZrF_6 are similar in the case of the LiF and NaF and are slightly suppressed in the KF system. The excess partial molar volume of K_2ZF_6 in KF shows smaller overall volume contraction that adopts 60% of volume contraction in LiF or NaF systems.

Systems MF-K_2ZrF_6 (M = Li, Na and K) were converted to ZrF_4 coordinate and compared with the literature data. The partial molar volumes of ZrF_4 of the systems MF-ZrF_4 (M = Li, Na and K) are also significantly different in KF system in contrast to LiF and NaF systems.

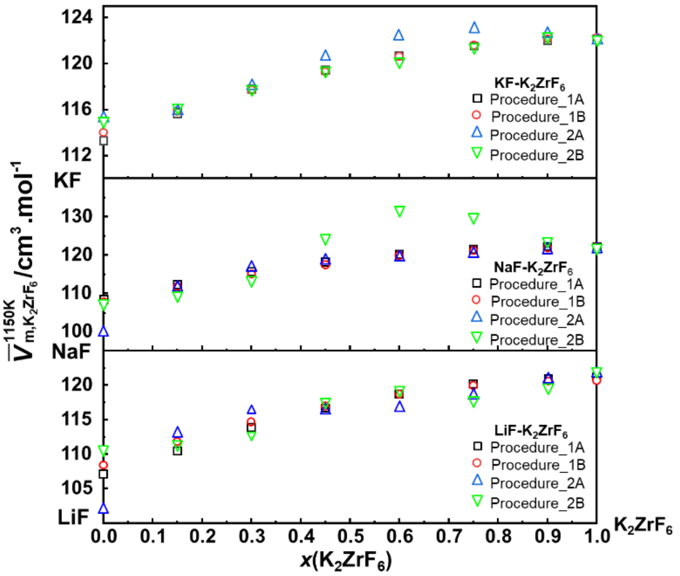


Figure 1. Concentration dependence of partial molar volumes of K_2ZrF_6 at 1150K.

Acknowledgements: This work was supported by the Slovak Research and Development Agency under contract No. APVV-19-0270 and by the Slovak Grant Agency, grant no. VEGA 2/0083/24.

[1] B. Kubikova, M. Boča, J. Mlynáriková, Z. Netriová, Z. Vasková *J. Therm. Anal. Cal.* 2016, **125**, 497.

P16

Solubility data of basic magnesium chloride hydrates (Sorel phases) and modelling with THEREDA in the oceanic salt system

Melanie Pannach, Iris Paschke, Daniela Freyer and Wolfgang Voigt

Department of Inorganic Chemistry, Laboratory of Salt and Mineral Chemistry, TU Bergakademie Freiberg, Leipziger Str. 29, 09599 Freiberg, Germany

Presenting author email: melanie.pannach@chemie.tu-freiberg.de

Basic magnesium chloride hydrates are the solid phases (Sorel phases) in the aqueous system Mg-Cl-OH-H_2O and the binder phases of magnesia building material (Sorel cement or concrete). They have special importance for the construction of geotechnical barriers (plug and sealing systems) in salt formations as well as for the adjustment of geotechnical environments to prevent transport processes of radionuclides.

The general composition of Sorel phases is $Mg_kCl(OH)_m \cdot nH_2O$, beyond that they can be described as x-y-z phases according to the double salt hydrate notation $xMg(OH)_2 \cdot yMgCl_2 \cdot zH_2O$, too. Various Sorel phases (x-y-z = 3-1-8, 5-1-8, 9-1-4, 2-1-4, 2-1-2, 3-1-0) are known and all of them have been well characterized.

To ensure the long-term stability against salt solutions containing Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^- and SO_4^{2-} the solubility diagrams with respect to crystallization branches of the basic magnesium chloride phases must be known at the temperature of interest. Solubility data in the ternary subsystem Mg-Cl-OH-H_2O have been published at 25°C to 120°C by [1]-[4]. In the quaternary subsystem Na-Mg-Cl-OH-H_2O solubility data are available only at 25°C ([3], [5], [6]).

Here we present our latest experimental solubility data of Sorel phases in terms of OH^- molalities and H^+ molalities in the ternary system and quaternary system at NaCl saturation depending on temperature [7]. In addition, our extended and adjusted data set, to include much higher temperatures of solubility constants of the Sorel phases (3-1-8, 9-1-4, 2-1-4) and Pitzer parameters, is implemented to the thermodynamic reference database THEREDA [8] and is discussed in the context of experimental data.

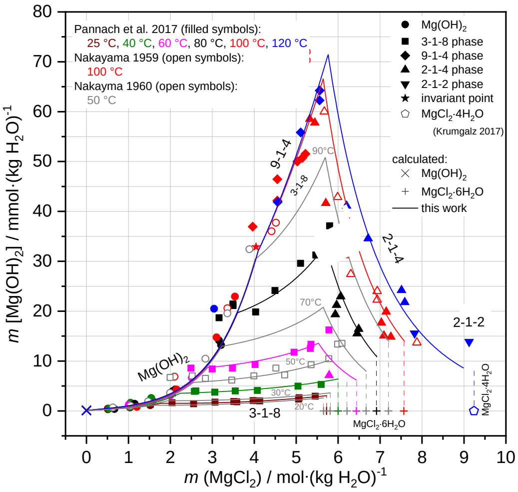


Figure 1. Calculated and experimental total $Mg(OH)_2$ molalities in the system Mg-Cl-OH-H_2O between 25°C and 120°C [9].

[1] M. Nakayama, *Bull. Agr. Soc. Japan*, 1959, **23**, 46.
[2] M. Nakayama, *Bull. Agr. Soc. Japan*, 1960, **24**, 362.
[3] M. Altmaier, V. Metz, V. Neck, R. Müller, T. Fanghänel, *Geochim. Cosmochim. Acta*, 2003, **67**, 3595.
[4] M. Pannach, S. Bette, D. Freyer, *J. Chem. Eng. Data*, 2017, **62**, 1384.
[5] J. D'Ans, W. Busse, H.E. Freund, *Kali Steinsalz*, 1955, 8, 3.
[6] Y. Xiong, H. Deng, M. Nemer, S. Johnsen, *Geochim. Cosmochim. Acta*, 2010, **74**, 4605.
[7] M. Pannach, I. Paschke, V. Metz, M. Altmaier, W. Voigt, D. Freyer, *Front. Nuc. Eng.*, 2023, **2**, 1.
[8] https://www.thereda.de
[9] D. Freyer, M. Pannach, W. Voigt, *Front. Nuc. Eng.*, 2023, **2**, 1.

P17

N-hydroxyamides' pK_a determination by NMR spectroscopy

Ricardo Santos[1], Andre Leesment[2], Clara Magalhães[3], Célia Amorim[4], Diana Pinto[1]
and Ivo Leito[2]

[1]LAQV-Requimte and Department of Chemistry, University of Aveiro, 3010-193 Aveiro,
Portugal
[2]Institute of Chemistry, University of Tartu, 50411, Tartu, Estonia
[3]School of Biological, Earth & Environmental Sciences, Faculty of Science, UNSW Sydney, Australia,
andLEAF Linking Landscape Environment Agriculture and Food Research Centre, Associate Laboratory
TERRA [4]LAQV-Requimte and Faculty of Pharmacy, University of Porto, 4050-313 Porto, Portugal

Presenting author email: ricardossantos@ua.pt

The *N*-hydroxyamides are siderophores present in nature with impact on agriculture and medicine[1-2]. They form metal complexes, mainly with iron(III), which modify the overall concentration of such cations in the aqueous systems. For the building of predictive models where *N*-hydroxyamides are present, their acid behaviour in water, expressed by the pK_a value, must be considered.

We have measured the aqueous pK_a values of five different *N*-hydroxyamides, two *N*-hydroxyimides, and three reference compounds (succinimide, benzotriazole and vanillic acid). Some of them were synthesized in the laboratory, others had been purchased. Due to the impurities or degradation products in some compounds, the ^1H and ^{19}F NMR spectroscopy were the chosen pK_a measurement techniques. Measurements were carried out at 298 K. The NMR enabled the identification of the peaks corresponding to the actual measured compounds, even in the presence of impurities. The observed changes in the chemical shifts ($\Delta\delta$) with p*H* were very close to theoretical relations between $\Delta\delta$ and p*H*, both for monoprotic and diprotic acids. Both absolute (pK_a) and relative (ΔpK_a between an acid and a reference acid) values were calculated. The ΔpK_a values between different acids were compiled into a ladder scale and, together with the absolute pK_a, used for achieving higher self-consistency and accuracy of the results. The activity coefficients were calculated using the Debye-Hückel theory.

Because of the multiple repetitions and the inclusion of relative measurements against reference pK_a values, we concluded that our pK_a values were more reliable than some literature data. New experimental data were also acquired, such as for vanillic acid, 2,2,2-trifluoro-*N*-hydroxyacetamide and the second acidity constant of 2-(hydroxyamino)-2-oxoethan-1-aminium.

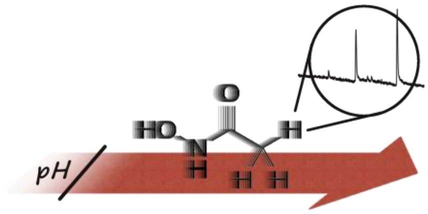


Figure 1. Graphical Abstract – The NMR heartbeat of *N*-hydroxyacetamide running on a p*H* scale.

Acknowledgements: Thanks are due to the University of Aveiro and Portuguese National Funds, through FCT (Fundação para a Ciência e Tecnologia), and as applicable co-financed by FEDER within the PT2020 Partnership agreement by funding the LAQV-REQUIMTE (UIDB/50006/2020+UIDP/50006/2020). RALS Santos thanks FCT for his PhD grant (UI/BD/151268/2021).
Funding: This work received financial support from PT national funds (FCT/MCTES, Fundação para a Ciência e Tecnologia and Ministério da Ciência, Tecnologia e Ensino Superior) through the projects UIDB/50006/2020 and UIDP/50006/2020 and from the Estonian Research Council (grant PRG690).

[1] P. Powell, P. Szaniszlo, G. Cline, C. Reid, *J. Plant Nutr.*, 1982, **5**, 653.
[2] A. Citarella, D. Moi, L. Pinzi, D. Bonanni, G. Rastelli, *ACS Omega*, 2021, **6**, 21843.

P18
Supersaturation of curcumin in plant protein-based carrier system

Lea Rohr and Werner Kunz

Department of Physical and Theoretical Chemistry, University of Regensburg, Universitätsstraße 31,
93053 Regensburg, Germany

Presenting author email: lea1.rohr@ur.de

Curcumin is a polyphenol extracted from the plant Curcuma Longa L. (C. Longa). Besides its bright yellow colour, the compound is an intensively studied phytochemical with a variety of highly praised health beneficial properties. Due to the low bioavailability and low chemical stability of curcumin in physiological conditions, it remains challenging to access these properties to such an extent that it has a proven positive effect on human health. [1]

The solubility in aqueous systems and thus in a broader sense, the bioavailability of curcumin, can be increased with protein-based carrier systems. [2] A non-equilibrium state of solubilised curcumin is achieved by binding the polyphenol to pea protein. To the best of our knowledge, this is not reported in the literature so far. Within 24 hours, precipitation occurs in the initially translucent sample. Considering the non-problematic nature of the pea protein and the magnitude of the supersaturation (factor of 5-10), a non-equilibrium-formulation of curcumin and pea protein is interesting for pharmaceutical applications.

For a deeper understanding of the solubilisation process and the supersaturation, the solutions of curcumin in aqueous pea protein (PPI-Cur) were analysed according to their (chemical) stability, the particle sizes, the role of the protein in the solution and variation in the parameters of the preparation process. These analyses are fundamental and important steps in evaluating the suitability of curcumin as a health-promoting component.

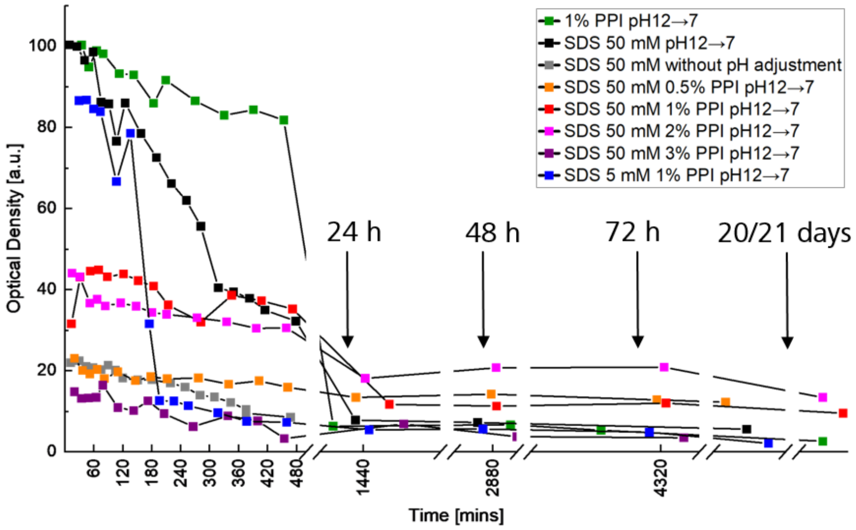


Figure 1. Evaluation of the stability of PPI-Cur (+surfactant) via optical density measurements.

[1] K.M. Nelson, J.L. Dahlin, J. Bisson, J. Graham, G.F. Pauli, M.A. Walters, *J. Med. Chem.*, 2017, **60**, 1620.
[2] A. Gomes, P.J. do Amaral Sobral, *Mol.*, 2022, **27**, 60.

P19

Green electrochemical sensor based on biochar for quantification of selected pesticides in aqueous solutions

Sanja Mutić, Jasmina Anojčić, Tajana Simetić, Tamara Apostolović, Nina Đukanović and Jelena Beljin

Department of Chemistry, Biochemistry and Environmental Protection, University of Novi Sad, Faculty of Sciences, Trg Dositeja Obradovića 3, Novi Sad, 21000, Serbia

Presenting author email: sanja.mutic@dh.uns.ac.rs

The sustainability of materials for developing the electrochemical sensor is crucial in the framework of a circular economy due to the need for environmentally friendly and greener analytical chemistry. The decrease in the impact of waste on the environment requires innovative approaches for biochar (BC) production and usage [1-2]. As a highly porous and carbon-rich material, BC has a desirable role as a catalytic material to enhance the analytical performance of BC-based sensors [3]. There has been a growing interest in the development of rapid and cost-effective techniques for detecting pesticides using electrochemical sensors with the possibility of their modification with sustainable materials [4]. Since the modification of carbon paste electrode (CPE) could improve the selectivity and sensitivity of trace level analysis of various electroactive analytes [5], the application of CPE modified with BC was investigated.

A sensitive and selective analytical method is developed regarding the voltammetric determination of fungicides maneb (MAN) and mancozeb (MCZ) using BC-CPE in an aqueous solution. The experimental conditions including pH of the supporting electrolyte, amount of BC in CPE, and differential pulse adsorptive stripping (DPAdSV) parameters were optimized. Under the optimal working conditions, the determination of MAN and MCZ was performed by applying the following DPAdSV parameters: E_{acc} = -0.2 V, t_{acc} = 90 s, and E_{acc} = -0.2 V, t_{acc} = 30 s, respectively. The linear increase of pesticides oxidation peak was recognized in a concentration range from 0.049–1.84 µg mL^{-1} MAN and 0.025–2.78 µg mL^{-1} MCZ in an aqueous Britton-Robinson buffer pH 7.0 using CPE modified with 10% BC. The relative standard deviation of six replicate measurements of MAN and MCZ was 3.2% and 2.9%, respectively, indicating a good repeatability of the developed DPAdSV method. The evaluated limit of detection of 0.015 µg mL^{-1} MAN and 0.0075 µg mL^{-1} MCZ indicated that the modification of CPE by BC provides a fast and sensitive determination of target analytes in an aqueous solution.

By exploring innovative solutions, electrochemical sensors based on BCs could provide monitoring of aquatic environmental samples to the control detrimental effects of pesticide residues.

Acknowledgements: This research was supported by the Science Fund of the Republic of Serbia, #10810, Sustainable solutions in environmental chemistry: exploring biochar potential–EnviroChar.

[1] P.S. Sfragano, S. Laschi, I. Palchetti, *Front. Chem.*, 2020, **8**, 644.
[2] R.A.A. Muñoz, *Microchim. Acta*, 2023, **190**, 486.
[3] J. Lee, K.-H. Kim, E.E. Kwon, *Renew. Sustain. Energy Rev.*, 2017, **77**, 70.
[4] H. Zhu, M. Li, C. Cheng, Y. Han, S. Fu, R. Li, G. Cao, M. Liu, C. Cui, J. Liu, X. Yang, *Foods*, 2023, **12**, 4274.
[5] H. Karimi-Maleh, F. Karimi, M. Rezapour, M. Bijad, M. Farsid, A. Beheshti, S.-A. Shahidi, *Curr. Anal. Chem.*, 2019, **15**, 410.

P20

Chromatographically Examination of thiocarbohydrazone's lipophilicity

Suzana Apostolov, Dragana Mekić, Gorana Mrđan, Borko Matijević and Đenđi Vaštag

Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Novi Sad, 21000, Serbia

Presenting author email: suzana.apostolov@dh.uns.ac.rs

Thiocarbohydrazone derivatives have become popular in contemporary scientific research due to their exceptionally antioxidant, antimicrobial and antitumor activity. Thanks to the presence of nitrogen and sulfur atoms, they easily form coordination bonds and build complexes with many metals, which have shown significant antiviral activity.

Knowledge of the new compound's lipophilicity is of crucial importance to assess the existence of its biological activity. In the first phase, a theoretical assessment of the thiocarbohydrazone derivatives' bioavailability and their ecotoxicity was performed. Also, their lipophilicity was determined *in silico*, as well as by using reversed phase thin-layer chromatography (RPTLC18F254s) in the presence of two organic modifiers (ethanol and dioxane). The effect of the substituent's nature and position, and the impact applied organic modifier on the chromatographic behavior of the analyzed derivatives were examined. The possibility of applying the chromatographic parameters (R_M^0 and m) of the tested thiocarbohydrazone derivatives as alternative measures of their lipophilicity and ecotoxicity was studied by their correlation with partition coefficient ($\log P$) and effective concentration (EC_{50}). As a result, satisfactory mathematical models were obtained.

Acknowledgements: The authors gratefully acknowledge the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No. 451-03-66/2024-03/ 200125 & 451-03-65/2024-03/200125.

P21

Examination of caffeine taste, hydration properties, and solubility in the presence of different additives

Teona Teodora Borović[1], Jovana Panić[1], Snežana Papović[1], Sanja Belić[1], Nikolett Cakó Bagány[1], Andrija Vukov[1], Marija Bešter-Rogač[2], Bojan Šarac[2], Slobodan Gadžurić[1] and Milan Vraneš[1]

[1]Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradivića 3, Novi Sad, 21000, Republic of Serbia
[2]Department of Physical Chemistry, Faculty of Chemistry and Chemical Technology, University of Ljubljana, Večna pot 113, 1000 Ljubljana, Slovenia

Presenting author email: teona@dh.uns.ac.rs

Caffeine, the most widely used psychoactive substance, is classified as a xanthine alkaloid. It is not only commonly found in coffee, black and green tea, soft drinks, and energy drinks, but also in medicinal products, making it a regular part of the daily routine for approximately 80% of the global population [1]. The prevalence of hydrophobic in water-poorly soluble drugs and supplements is a major problem in drug design, food science, delivery, drug effect, and bioavailability.

The solubility of caffeine in water is relatively low, approximately 16 mg/mL at room temperature. This limited solubility is attributed to the self-association and aggregation of caffeine molecules through hydrophobic interactions [2]. The low solubility of caffeine in water presents a significant challenge for products stored or consumed at low temperatures, such as certain beverages, supplements, pharmaceuticals, and cosmetics. The addition of some biocompatible molecules, excipients or hydrotropes can lead to better caffeine solubility in water. To this day, only the effects of several compound classes on enhancing solubility and preventing self-aggregation have been studied. However, a systematic and comprehensive investigation is required to derive definitive conclusions.

In addition to caffeine's low solubility in water, another concern is that caffeine can induce bitterness at high concentrations. Solving this problem is very important from the food and beverage industry aspect.

Our research aims to examine the solubility, structural organization and taste of caffeine molecules in the presence of seven different additives suitable for wide use in the pharmaceutical, food and cosmetic industries.

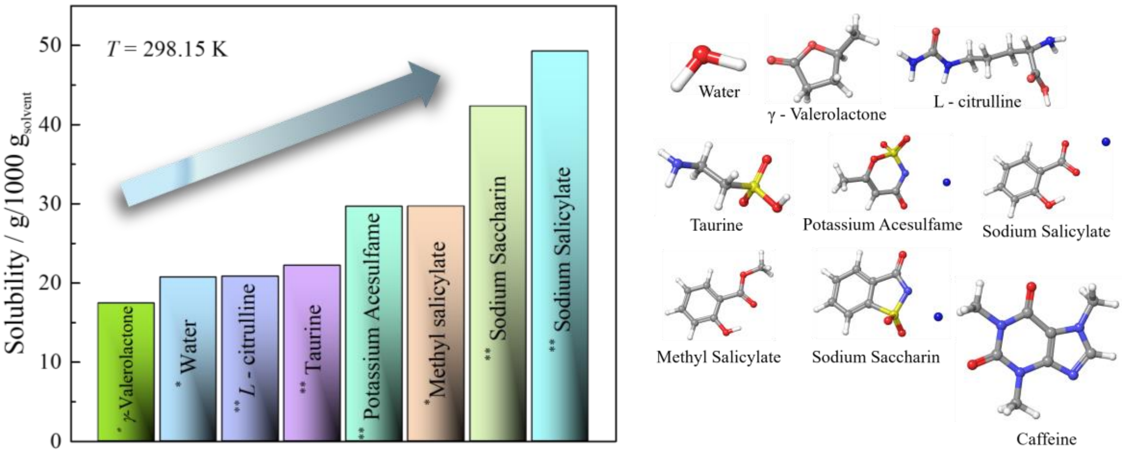


Figure 1. Compared the solubility of caffeine in the presence of different additives: * pure solvents, ** water solutions, at T = 298.15 K, along with their chemical structures.

Acknowledgements: The authors are grateful for the financial support of Provincial Secretariat for Higher Education and Scientific Research, grant number: 142-451-2545/2021-01.

[1] D.P. Evattand, R.R. Griffiths, *Encyclopedia of Human Nutrition*, 2013, Caffeine, 221- 227, Elsevier Inc.: Amsterdam, The Netherlands.
[2] A. Al-Maaieh, D.R. Flanagan, *J. Pharm. Sci.*, 2002, **91**, 1000-1008.

P22

$CsF-Al_2O_3$ system
The phase and structural analysis

František Šimko[1], Zuzana Netriová[1], Aydar Rakhmatullin[2], and Michal Korenko[1]

[1]Institute of Inorganic Chemistry, Slovak Academy of Sciences, 845 36 Bratislava, Slovakia
[2]Conditions Extrêmes ét Matériaux: Haute Température et Irradiation, CEMHTI, UPR 3079 -CNRS Univ. Orléans 450 71, Orléans, France

Presenting author email: zuzana.netriova@savba.sk

A critical evaluation of the chemistry and the thermal stability of cesium fluoro-, oxo- and oxo-fluoro-aluminates in the $CsF–AlF_3–Al_2O_3–Cs_2O$ system were carried out. Precise research of the binary $CsF–Al_2O_3$ sub-system was done by means of combining X-ray powder diffraction, high field solid state NMR spectroscopy, and thermal analysis methods. Cs_3AlF_6, $CsAlO_2$, $Cs_2Al_{22}O_{34}$ and new phase, $Cs_2Al_2O_3F_2$, were identified in the system. The structure of this new cesium oxo-fluoro-aluminate was determined. It is build up from single layers of oxygen connected (AlO_3F) tetrahedra, those layers being separated into by fluorine atoms. The thermal analysis of $CsF–Al_2O_3$ system revealed that it can be more defined as a pseudo-binary sub-system of the more general quaternary $CsF–AlF_3–Al_2O_3–Cs_2O$ system. From phase analysis of individual phase fields, the mutual metastable behavior of all founded phases can be considered. Fluoro- and oxo-aluminates are metastable precursors of thermodynamically more stable structure of cesium oxo-fluoro-aluminates.

Acknowledgements: This study was financially supported by the Slovak Grant Agencies (VEGA-2/0046/22; VEGA-2/0083/24). We acknowledge the facilities of “IR RMN” at the NMR 850MHz spectrometer.

P23

Optimizing the extraction of parthenolide from feverfew: an experimental design approach

Dajana Lazarević[1], Bojan Kopilović[2], Mara Freire[2], Slobodan Gadžurić[3] and Tatjana Trtić-Petrović[1]

[1]Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade, Mike Petrovića Alasa 12–14, 11001 Belgrade, Serbia
[2]CICECO – Aveiro Institute of Materials, Department of Chemistry, University of Aveiro, 3810–193 Aveiro, Portugal
[3]Faculty of Sciences, University of Novi Sad, Department of Chemistry, Biochemistry and Environmental Protection, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia

Presenting author email: dajana.lazarevic@vin.bg.ac.rs

Parthenolide (PAR), a sesquiterpene lactone isolated from the feverfew (*Tanacetum parthenium* (L.) Sch. Bip.), has gained significant attention due to its anticancer activity. Research has shown that PAR induces apoptosis in cancer cells and inhibits nuclear factor-kappa B (NF-κB) [1]. Feverfew contains a high amount of PAR, and its extraction from natural source is essential to preserving its full bioactivity.

The complex molecular structure of PAR poses significant challenges for synthesis, as it requires meticulous control over reaction conditions and stereochemistry. This often leads to numerous synthetic steps with low yields [2]. On the other hand, PAR extraction from natural sources is important, as it is generally more cost-effective, especially when improved extraction processes are applied through experimental design.

Experimental design is crucial in the green extraction process, optimizing procedures to maximize extraction efficiency while minimizing environmental impact. By carefully selecting and optimizing variables such as solvent type, temperature, and extraction time, green extractions aim to use environmentally friendly solvents, consume less energy, and generate less waste [3]. A promising category of solvents in this content is polymers, particularly Pluronics – block copolymers composed of ethylene oxide and propylene oxide. These amphiphilic molecules can self-assemble into micelles in aqueous solutions, effectively encapsulating hydrophobic compounds like PAR, thereby enhancing its solubility and stability in aqueous solutions. This feature is particularly beneficial for green extractions, as it reduces the need for hazardous organic solvents while maintaining high efficiency. Integrating Pluronics into extraction processes supports sustainable practices and development [4].

The current study's objectives were to ascertain the experimental variables that maximize extraction of PAR from feverfew by using the Box-Behnken experimental design and to assess the effect of temperature, time, and solid/liquid ratio. This study successfully optimized the extraction process of PAR from feverfew, demonstrating significant improvements in both efficiency and sustainability.

Acknowledgements: This work was supported by the Ministry of Science, Technological Development and Innovation, Republic of Serbia (contract number 451-03-66/2024-03/200017).

[1] L. Moujir, O. Callies, P.M.C. Sousa, F. Sharopov, A.M.L. Seca, *Appl. Sci.*, 2020, **10**, 3001.
[2] L. Li, X. Pan, B. Guan, Z. Liu, *Tetrahedron*, 2016, **72**, 4346.
[3] S.L.C. Ferreira, R.E. Bruns, H.S. Ferreira, G.D. Matos, J.M. David, G.C. Brandão, E.G.P. da Silva, L.A. Portugal, P.S. dos Reis, A.S. Souza, W.N.L. dos Santos, *Anal. Chim. Acta*, 2007, **600**, 152.
[4] A.K. Mahapatra, G.M. Cairns, R. McHale, D.J. Adams, *Polym. Chem.*, 2014, **5**, 2590.

P24
Hydration and deliquescence behavior of calcium chloride hydrates

Shaoheng Wang, Amelie Stahlbuhk and Michael Steiger

Department of Chemistry, University of Hamburg, Martin-Luther-King-Platz 6, 20146 Hamburg, Germany

Presenting author email: michael.steiger@uni-hamburg.de

Calcium chloride ($CaCl_2$) has gathered significant attention due to its presence in atmospheric aerosols [1], Martian soils [2], fluid inclusions [3] and applications in the storage and transformation of thermal energy [4]. Its various hydrates, their hygroscopic properties and the low eutectic temperature affect the water cycle on Earth and Mars and cloud condensation in the atmosphere [5,6]. Thermal engineering applications [4] include its use in sorption processes, e.g. for dehumidification, desiccant cooling, drying, refrigeration, water recovery from the atmosphere, the use as phase change material and for thermochemical heat storage.

A peculiarity of $CaCl_2{\cdot}6H_2O$ is that, depending on the experimental conditions, different deliquescence humidities (DRH) are observed if the salt is dehydrated and subsequently subjected to an increasing relative humidity [7]. Some measurements yield a higher value which is consistent with the commonly accepted DRH of 29.1 ± 0.4 % for $CaCl_2{\cdot}6H_2O$ based on the available water activities and solubilities [8,9]. In other measurements a lower DRH of about 19 % RH is observed. The lower value was assigned to the direct deliquescence of $CaCl_2{\cdot}2H_2O$ which did not undergo hydration to the hexahydrate state [7].

In this study, we used a consistent modeling approach to establish the phase diagram of the $CaCl_2$–H_2O system including metastable equilibria (Fig. 1a). As can be derived from its metastable solubility, the DRH of the dihydrate is significantly lower than the observed DRH of 19 %. Therefore, we carried out a series of water vapor sorption, XRD and *in situ* Raman microscopy experiments to investigate the hydration and deliquescence behavior of $CaCl_2{\cdot}xH_2O$. The results reveal two possible hydration sequences from lower hydrated states to deliquescence at 298.15 K (Fig. 1b): (1) Hydration of the monohydrate to the dihydrate, followed by the formation of metastable β-$CaCl_2{\cdot}4H_2O$, ending with its deliquescence at 18.5 % RH; (2) Hydration of the monohydrate to the dihydrate, followed by the formation of the stable polymorph α-$CaCl_2{\cdot}4H_2O$ and of the hexahydrate, ending with the deliquescence at 29 % RH. The two reaction pathways will be discussed in detail.

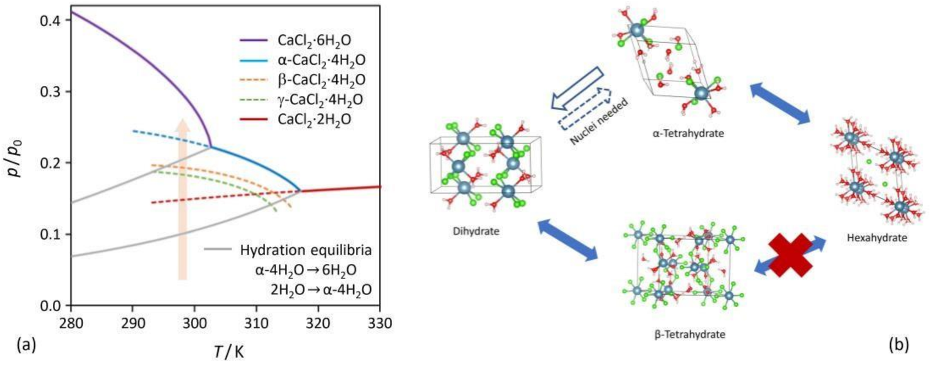


Figure 1. (a) Phase diagram, DRH (metastable dashed) and hydration equilibria (gray) (b) hydration–dehydration pathways

[1] R.C. Sullivan, M.J.K. Moore, M.D. Petters et al. *Atmos. Chem. Phys.* 2009, **9**, 3303.
[2] R.V. Gough, V.F. Chevrier, M.A. Tolbert, *Planet. Space Sci.* 2016, **131**, 79.
[3] M. Steele-MacInnis, R.J. Bodnar, J. Naden, *Geochim. Cosmochim. Acta* 2011, **75**, 21.
[4] K.E. N'Tsoukpoe, H.U. Rammelberg, A.F. Lele et al., *Appl. Therm. Eng.* 2015, **75**, 513.
[5] J.D. Toner, R.S. Sletten, *Geochim. Cosmochim. Acta* 2013, **110**, 84.
[6] D.D. Li, Y.Y.S. Zhao, P.Y. Meslin et al., *Commun. Earth Environ.* 2022, **3**, 15.
[7] L. Guo, W. Gu, C. Peng et al., *Atmos. Chem. Phys.* 2019, **19**, 2115.
[8] J.A. Rard, S.L. Clegg, *J. Chem. Eng. Data* 1997, **42**, 5, 819.
[9] B.S. Krumgalz, *J. Phys. Chem. Ref. Data* 2017, **46**, 043101.

P25

Optimizing solubility of spirulina pigments using natural deep eutectic solvent

Jelena Jovanović[1], Petar Ristivojević[2], Dajana Lazarević[1], Simeon Minić[2] and Tatjana Trtić- Petrović[1]

[1]Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade, Mike Petrovića Alasa 12–14, 11001 Belgrade, Serbia
[2]Department of Analytical Chemistry, Faculty of Chemistry, University of Belgrade, Studentski trg 12–16, Belgrade, 11158, Serbia

Presenting author email: jelena.jovanovic@vin.bg.ac.rs

This study focuses on isolating pigments from *Spirulina*, a blue-green microalga renowned for its rich nutritional profile and potent bioactive compounds. *Spirulina* is a source of phycocyanin, a vibrant blue pigment with strong antioxidant, anti-inflammatory, and potential anticancer properties, making it highly valuable in the food, pharmaceutical, and cosmetic industries. Traditional methods for extracting these pigments typically rely on organic solvents, which pose significant environmental concerns due to their toxicity and non-renewable nature [1,2].

The primary objective of this research is to extract *Spirulina* pigments using Natural Deep Eutectic Solvents (NADES) as eco-friendly alternatives to harmful organic solvents. NADES are a new generation of green solvents, composed of natural, biodegradable components such as choline chloride, betaine, glycerol, and sugars. These solvents are designed to meet the principles of green chemistry, offering low toxicity, biodegradability, and the ability to be tailored for specific extraction needs [3].

In this study, ten different NADESs were synthesized with a strong emphasis on optimizing solubility, a critical factor in maximizing the extraction efficiency of bioactive pigments. The antioxidant capacity of the extracted pigments was assessed using the DPPH test, a widely used method in chemistry for evaluating free radical scavenging activity. The DPPH test measures the ability of antioxidants to reduce the DPPH radical, a stable free radical with a deep violet colour, which fades upon reduction [4].

Among the NADESs tested, those based on betaine and glycerol demonstrated the highest solubility and antioxidant capacity in the extracted pigments from *Spirulina*. This research highlights the potential of NADES as a sustainable and effective solvent system for the extraction of valuable bioactive compounds from *Spirulina*, offering a greener alternative to conventional extraction methods [3].

Acknowledgements: This work was supported by the Ministry of Science, Technological Development and Innovation Republic of Serbia (contract number 451-03-66/2024-03/200017).

[1] Z.H. Zhang, B. Yu, Q. Xu, Z. Bai, K. Ji, X. Gao, B. Wang, R. M. Aadil, H. Ma, R. Xiao, *Foods*, 2022, **11**, 1809.
[2] A.P. Abreu, R. Martins, J. Nunes, *Bioengineering* 2023, **10**, 995.
[3] B. Socas-Rodríguez, M.V. Torres-Cornejo, G. Álvarez-Rivera, J.A. Mendiola, *Appl. Sci.*, 2021, **11**, 4897.
[4] A. Wawoczny, D. Gillner, *J. Agric. Food Chem.*, 2023, **71**, 10877.