Ionic Liquids – A Key Technology?

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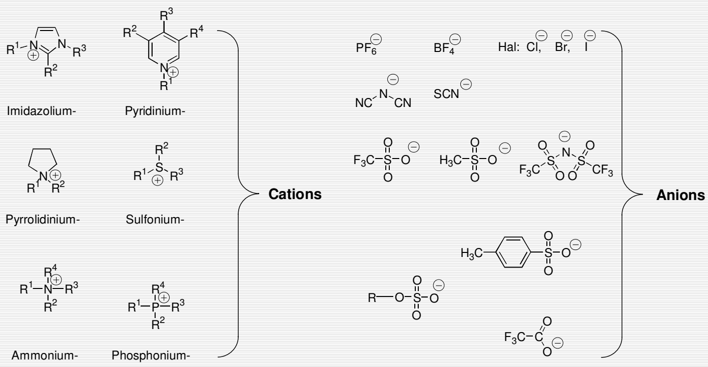
io·li·tec
Ionic Liquids Technologies

What are Ionic Liquids?

Ionic Liquids are a new class of salt-like materials, consisting entirely of ions, which are liquid at unusual low temperatures. For the most common definition of Ionic Liquids (probably for emotional reasons) the boiling point of water was chosen as reference value:

„Ionic Liquids is the generic term for materials consisting entirely of ions, which are in the liquid state below 100°C."

Ionic Liquids build large, but still mobile molecular clusters. As a consequence, they exist in the liquid phase over a large temperature-range, in some cases even up to 300°C. Furthermore, the strong ionic (Coulomb-) interactions causing a negligible low, in some cases not measurable vapour-pressure.



Typical structural motifs combine organic cations with inorganic, or, still more rarely, organic anions.

If ionic liquids are compared with pure inorganic salts, e.g. with kitchen salt (NaCl, m.p. 801°C), a lower symmetry and a distribution of the charge over larger parts of the molecule by resonance are mainly responsible for the low melting points of ionic liquids.

The combination of a broad variety of already known and theoretically possible cations and anions leads to the number of 10^{18} theoretically possible ionic liquids. The actual number of compounds to fall under the above definition, is presumably some magnitudes smaller, but still amazingly high. Today about 1500 materials are described in literature, about 300 are commercially available. The physical and chemical properties are only characterized for a few ionic liquids in a sufficient way. So one of the major challenges in ionic liquids research will surely be the determination of physical data. Since most physical properties of ionic liquids show a strong dependency on impurities, it's obvious that the purity has to be determined in a precise way to obtain reliable data.

SEPARATION TECHNOLOGY
- deep desulfurination
- gas-separation
- extractive distillation
- liquid-liquid-extraction

COOLING-TECHNOLOGY
- sorption-cooling-media

ANALYTICS
- electrophoresis
- solvents for GC-head-space
- matrix-materials for MALDI-TOF-MS
- solvents for Karl-Fischer titration
- solvents for protein-crystallisation

IONIC LIQUIDS
- thermal stability
- electrochemical stability
- low vapor pressure
- non volatility
- non-flammability
- electric conducting
- tuneable miscibility
- liquid over a wide range of temperatures

ELECTROLYTES
- fuel cells
- metal deposition & metal finishing
- batteries
- dye sensitized solar cells (DSCs)
- sensors
- supercapacitors

FUNCTIONAL FLUIDS
- lubricants
- hydraulic oils
- surfactants
- storage media for gases

SYNTHESIS & CATALYSIS
- Enzymatic reactions
- Immobilisation of catalysts
- Nano-Particle-Synthesis
- Solvents for organic reactions

HEAT TRANSPORT & STORAGE
- thermal fluids
- phase changing materials (PCM)

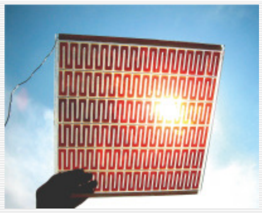
STATUS:
- R&D
- Pilot
- Commercialized

Selected Applications:

Derived from their often unique combination of physical and chemical properties a number of applications from totally different fields of technology are possible.

Dye Sensitized Solar Cells (DSSCs) [1,2]

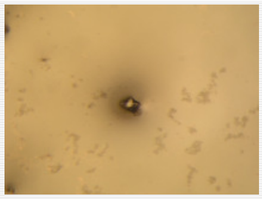
DSSCs (or "Grätzel-Cells") are an interesting alternative to the more common photovoltaic cells. Their biomimetic working-principle is derived from the photosynthesis: the irradiation of light activates a photosensitive dye. After a complex redox-cascade the redox-couples are transported in a conductive electrolyte to the counter-electrode, where they are reduced. Since Ionic Liquids are thermally stable, are conducting and have no detectable vapour pressure, they are the ideal electrolytes for this application. The commercialisation of this technology is financially supported by the German BMBF in the project named "COLORSOL".


A module of a dye-sensitized solar cell. © FhG ISE, 2004.

[1] B. O'Regan, M. Grätzel, *Nature* **1991**, *353*, 737-740.
[2] M. Grätzel, *J. Photochem. Photobiol. C: Photochem. Rev.* **2003**, *4*, 145.

Crystallization of Proteins [3]

In modern biotechnology it is a challenge to learn more about the working-principles of enzymes and other proteins. In this context, the structural analysis by using x-ray, e.g. for the determination of enzymes actives sites, is one of the most powerful tools.
To analyse proteins by x-ray, they first have to be crystallized. The crystallization itself, is often a very difficult and time-consuming process. Ionic liquids have surface-active properties similar to tensides stabilising most enzymes. In IOLITEC's approach, a water-miscible, non-hygroscopic and ultra-pure ionic liquid is saturated with a protein. Subsequent to that, an amount of water is added. As shown by some examples, e.g. in the crystallisation of lysozyme, after the slow evaporation of the water, the enzyme crystallizes in way that can be analysed by x-ray.


Crystallized Lysozyme. © IOLITEC, 2004.

[3] A. Bösmann, T. J.S. Schubert, 2004, DE 102004027196.8, Patent Pending.

Electrodeposition of metals [4]

Ionic liquids are electrochemically stable electrolytes. The electrochemical window of some materials reaches up to 6.0 V. As a consequence, a lot of electrochemistry can be conducted using ionic liquids as electrolytes.
The electrodeposition of metals like Al, Mg or Ti is not possible from aqueous solution, since if a voltage that is necessary to deposit those metals is impressed on the set-up, the water will be cleaved into oxygen and hydrogen. Unlike that, ionic liquids are much more stable against electrochemical oxidation and reduction processes, so a deposition of commercially interesting metals like the cited above becomes possible.


An Iron-screw, coated with Aluminium. © IOLITEC, 2005.

[4] S.Z. El Abedin, F. Endres, *Chemphyschem* **2006**, *7*, 58-61.

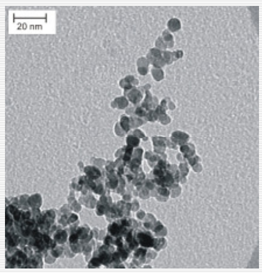
Sorption-Cooling-Media [5]

By far the most air-conditioning-systems use the compression-decompression-principle to produce coldness. Another approach is to generate coldness by using a medium that absorbs a volatile medium like water or ammonia. The evaporating water (or ammonia) generates the coldness. If saturation of absorbing medium is achieved, it has to be pumped off in a vessel, where it is regenerated by heating. Typical absorbing media are aqueous solutions of Lithium bromide, which has sufficient thermodynamic properties. The main disadvantages of LiBr are 1. the corrosiveness and 2. the tendency to crystallize, resulting in a shutdown of the system.
As shown in a project funded by the German "Deutsche Bundesstiftung Umwelt e.V.", certain halogen-free ionic liquids have three main advantages: 1. they have comparable thermodynamic properties like LiBr, 2. they are not corrosive and 3. they are liquid over the whole range of temperature, so it is not possible to crystallize.

[6] A. Bösmann, T.J.S. Schubert, 2004, DE 10 2004 024967.9, Patent Pending.

Synthesis and Dispersion of Nano-Materials [6,7]

Over the past years, the number of publications concerning "nano-technology" increased dramatically. Just as one aspect, the production of nano-materials, e.g. nano-metal-powders or nano-metal-oxides has become a real market. In this context, ionic liquids are very good solvents for the synthesis of such materials that can not be derived from common solvents. In a number of examples, it was possible to control size and shape of the corresponding materials just by using different Ionic Liquids. Furthermore, it is possible to use them to disperse nano-particles, e.g. single-walled nano-tubes.



TEM of NiO-nano-particles. © IOLITEC, 2005.

[7] Y. Zhou, *Current Nanosci.* **2006**, *1*, 35.
[8] H.B. Kim, J.S. Choi. S.T. Lim, H.S. Kim, *Synthetic Metals*, **2005**, *54*, 145.

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