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## Revisiting Characteristics of Ionic Liquids: A Review for Further Application Development

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### ABSTRACT

In literature concerning ionic liquid (IL) applications, the commonly accepted properties of ionic liquids are frequently mentioned. For example, ionic liquids are described as possessing immeasurably low vapor pressure, being "green material", non-coordinating, physically and chemically stable, and non-toxic, to name a few. However, all these descriptions are deemed "not exact" [1] as intensive research on ionic liquid properties continues. This review highlights the most recent developments in IL chemistry where the "well-known" description of IL properties sometimes proves to be inaccurate. However, in the authors' opinion, all these new research developments concerning ionic liquid properties serve to update knowledge on the typical physical and chemical properties of ILs, which is significant to both theoretical research and industrial applications. This review presents an opportunity to understand IL through a more complete and accurate view. It seeks to pave the way for further studies on IL application in various fields.

### KEYWORDS

Ionic Liquids, Functionalized Ionic Liquids, Volatility, Polarity, Green Chemistry

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### References

- [1] M. Deetlefs and K. R. Seddon, "Ionic Liquids: Fact and Fiction," *Chimica oggi*, Vol. 24, No. 2, 2006, pp.16-23.
- [2] H. Olivier-Bourbigou and F. Hughes, "Green Industrial Applications of Ionic Liquids," Kluwer Academic Publishers, Dordrecht, 2003, pp.67.
- [3] J. H. Davis Jr., "Task-Specific Ionic Liquids," *Chemistry Letters*, Vol. 33, No. 9, 2004, pp. 1072-1077.
- [4] Z. Fei, T. J. Geldbach, D. Zhao, et al., "From Dysfunction to Bis-function: On the Design and Applications of Functionalised Ionic Liquids," *Chemistry a European Journal*, Vol. 12, No. 8, 2006, pp. 2122-2130.
- [5] S.-G. Lee, "Functionalized Imidazolium Salts for Task-Specific Ionic Liquids and their Applications," *Chemical Communications*, 2006, pp. 1049-1063.
- [6] K. R. Seddon, "Ionic Liquids for Clean Technology," *Journal of Chemical Technology and Biotechnology*, Vol. 68, No. 4, 1997, pp. 351-356.
- [7] T. Welton, "Room-Temperature Ionic Liquids. Solvents for Synthesis and Catalysis," *Chemical Reviews*, Vol. 99, No. 8, 1999, pp. 2071-2083.
- [8] R. Sheldon, "Catalytic Reactions in Ionic Liquids," *Chemical Communications*, 2001, pp. 2399-2407.
- [9] C. M. Gordon, "New Developments in Catalysis Using Ionic Liquids," *Applied Catalysis A: General*, Vol. 222, No. 1-2, 2001, pp. 101-117.

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- [10] M. J. Earle and K. R. Seddon, " Ionic Liquids. Green Solvents for the Future," *Pure and Applied Chemistry*, Vol. 72, No. 7, 2000, pp. 1391-1398.
- [11] J. Dupont, R. F. D. Souza and P. A. Z. Suarez, " Ionic Liquid (Molten Salt) Phase Organometallic Catalysis," *Chemical Reviews*, Vol. 102, No. 10, 2002, pp. 3667- 3691.
- [12] H. Olivier-Bourbigou and L. Magna, " Ionic Liquids: Perspectives for Organic and Catalytic Reactions," *Journal of Molecular Catalysis A-Chemical*, Vol. 182, No. 1, 2002, pp. 419-437.
- [13] D. Zhao, M. Wu, Y. Kou, et al., " Ionic Liquids: Applications in Catalysis," *Catalysis Today*, Vol. 74, 2002, pp. 157.
- [14] V. A. Cocalia, K. E. Gutowski and R. D. Rogers, " The Coordination Chemistry of Actinides in Ionic Liquids: A Review of Experiment and Simulation," *Coordination Chemistry Reviews*, Vol. 250, No. 7-8, 2006, pp. 755-764.
- [15] H. Weingärtner, " Understanding Ionic Liquids at the Molecular Level: Facts, Problems, and Controversies," *Angewandte Chemie International Edition*, Vol. 47, No. 4, 2008, pp. 654-670.
- [16] M. Koel, " Ionic Liquids in Chemical Analysis," *Critical Reviews in Analytical Chemistry*, Vol. 35, No. 3, 2005, pp. 177-192.
- [17] P. Kubisa, " Ionic Liquids in the Synthesis and Modification of Polymers," *Journal of Polymer Science Part A: Polymer Chemistry*, Vol. 43, No. 20, 2005, pp. 4675- 4683.
- [18] H. Xue, R. Verma and J. M. Shreeve, " Review of Ionic Liquids with Fluorine-Containing Anions," *Journal of Fluorine Chemistry*, Vol. 127, No. 2, 2006, pp. 159-176.
- [19] M. Antonietti, D. Kuang, B. Smarsly, et al., " Ionic Liquids for the Convenient Synthesis of Functional Nanoparticles and Other Inorganic Nanostructures," *Angewandte Chemie International Edition*, Vol. 43, No. 38, 2004, pp. 4988-4992.
- [20] K. R. Seddon, " Room-Temperature Ionic Liquids: Neoteric Solvents for Clean Catalysis," *Kinetics and Catalysis*, Vol. 37, No. 5, 1996, pp. 693-697.
- [21] H. L. Ngo, K. LeCompte, L. Hargens, et al., " Thermal Properties of Imidazolium Ionic Liquids," *Thermochimica Acta*, Vol. 97, 2000, p. 357.
- [22] H. Zhao, " Review: Current Studies on Some Physical Properties of Ionic Liquids," *Physics and Chemistry of Liquids*, Vol. 41, 2003, p. 545.
- [23] S. P. Verevkin, T. V. Vasil'tsova, E. Bich, et al., " Thermodynamic Properties of Mixtures Containing Ionic Liquids: Activity Coefficients of Aldehydes and Ketones in 1-methyl-3-ethyl-imidazolium bis (Trifluoromethyl-Sulfonyl) imide Using the Transpiration Method," *Fluid Phase Equilibria*, Vol. 218, No. 2, 2004, pp. 165-175.
- [24] K.-S. Kim, B.-K. Shi, H. Lee, et al., " Refractive Index and Heat Capacity of 1-butyl-3-methylimidazolium bromide and 1-butyl-3-methylimidazolium tetrafluoroborate, and Vapor Pressure of Binary Systems for 1-butyl-3-methylimidazolium Bromide + Trifluoroethanol and 1-butyl-3-methylimidazolium Tetrafluoroborate + Trifluoroethanol," *Fluid Phase Equilibria*, Vol. 218, No. 2, 2004, pp. 215- 220.
- [25] A. Shariati and C. J. Peters, " High-Pressure Phase Behavior of Systems with Ionic Liquids: Part III. The Binary System Carbon Dioxide + 1-hexyl-3-methylimidazolium hexafluorophosphate," *Journal of Supercritical Fluids*, Vol. 30, No. 2, 2004, pp. 139-144.
- [26] L. P. N. Rebelo, V. Najdanovic-Visak, Z. P. Visak, et al., " A Detailed Thermodynamic Analysis of [C4mim][BF4]+ Water as a Case Study to Model Ionic Liquid Aqueous Solutions," *Green Chemistry*, Vol. 6, No. 8, 2004, pp. 369-381.
- [27] K.-S. Kim, S. Y. Park, S. Choi, et al., " Vapor Pressures of the 1-Butyl-3-methylimidazolium Bromide + Water, 1- Butyl-3-methylimidazolium Tetrafluoroborate + Water, and 1-(2-Hydroxyethyl)-3-methylimidazolium Tetrafluoroborate + Water Systems," *Journal of Chemical and Engineering Data*, Vol. 49, No. 6, 2004, pp. 1550-1553.
- [28] J. Zhao, C.-C. Dong, C.-X. Li, et al., " Isobaric Vapor- Liquid Equilibria for Ethanol-Water System Containing Different Ionic Liquids at Atmospheric Pressure," *Fluid Phase Equilibria*, Vol. 242, No. 2, 2006, pp. 147-153.

- [29] J. Sararov, S. P. Verevkin, E. Bich, et al., " Vapor Coefficients of n-Alcohols and Benzene in Binary Mixtures with 1-Methyl- 3-butylimidazolium Octyl Sulfate and 1-Methyl-3-octylimidazolium Tetrafluoroborate," *Journal of Chemical and Engineering Data*, Vol. 51, No. 2, 2006, pp. 518-525.
- [30] K. Swiderski, A. McLean, C. M. Gordon, et al., " Esti-mates of Internal Energies of Vaporisation of Some Room Temperature Ionic Liquids," *Chemical Communications*, 2004, pp. 2178-2179.
- [31] Y. U. Paulechka, G. J. Kabo, A. V. Blokhin, et al., " Thermodynamic Properties of 1-Butyl-3-methylimidazolium Hexafluorophosphate in the Ideal Gas State," *Journal of Chemical and Engineering Data*, Vol. 48, No. 3, 2003, pp. 457-462.
- [32] M. Yoshizawa, W. Xu and C. A. Angell, " Ionic Liquids by Proton Transfer: Vapor Pressure, Conductivity, and the Relevance of  $\Delta pK_a$  from Aqueous Solutions," *Journal of the American Chemical Society*, Vol. 125, No. 50, 2003, pp. 15411-15419.
- [33] U. P. Kreher, A. E. Rosamilia, C. L. Raston, et al., " Self-Associated, " Distillable" Ionic Media," *Molecules*, Vol. 9, No. 6, 2004, pp. 387-393.
- [34] H. Luo, G. A. Baker, J. S. Lee, et al., " Ultrastable Super-base-Derived Protic Ionic Liquids," *Journal of Physical Chemistry B*, Vol. 113, No. 13, 2009, pp. 4181-4183.
- [35] L. P. N. Rebelo, J. N. C. Lopes, J. M. S. S. Esperança, et al., " On the Critical Temperature, Normal Boiling Point, and Vapor Pressure of Ionic Liquids," *Journal of Physical Chemistry B*, Vol. 109, No. 13, 2005, pp. 6040-6043.
- [36] Y. U. Paulechka, D. H. Zaitsau, G. J. Kabo, et al., " Vapor Pressure and Thermal Stability of Ionic Liquid 1-butyl- 3-methylimidazolium Bis(trifluoromethylsulfonyl)amide," *Thermochimica Acta*, Vol. 439, No. 1-2, 2005, pp. 158- 160.
- [37] D. H. Zaitsau, G. J. Kabo, A. A. Strechan, et al., " Ex-perimental Vapor Pressures of 1-Alkyl-3-methylimidazolium Bis(trifluoromethylsulfonyl)imides and a Correlation Scheme for Estimation of Vaporization Enthalpies of Ionic Liquids," *Journal of Physical Chemistry A*, Vol. 110, No. 22, 2006, pp. 7303-7306.
- [38] M. J. Earle, J. M. S. S. Esperança, M. A. Gilea, et al., " The Distillation and Volatility of Ionic Liquids," *Nature*, Vol. 439, No. 7078, 2006, pp. 831-834.
- [39] D. R. MacFarlane, J. M. Pringle, K. M. Johnsson, et al., " Lewis Base Ionic Liquids," *Chemical Communications*, 2006, pp. 1905-1917.
- [40] P. Anastas and J. Warner, " *Green Chemistry-Theory and Practice*," Oxford University Press, US, 2002.
- [41] B. Jastorff, R. St?rmann, J. Ranke, et al., " How Hazardous are Ionic Liquids? Structure– Activity Relationships and Biological Testing as Important Elements for Sustainability Evaluation," *Green Chemistry*, Vol. 5, No. 2, 2003, pp. 136-142.
- [42] J. Ranke, K. M?lter, F. Stock, et al., " Biological Effects of Imidazolium Ionic Liquids with Varying Chain Lengths in Acute *Vibrio Fischeri* and WST-1 Cell Viability Assays," *Ecotoxicology and Environmental Safety*, Vol. 58, No. 3, 2004, pp. 396-404.
- [43] K. M. Docherty and C. F. Kulpa Jr., " Toxicity and An-timicrobial Activity of Imidazolium and Pyridinium Ionic Liquids," *Green Chemistry*, Vol. 7, No. 4, 2005, pp. 185- 189.
- [44] P. Stepnowski, A. C. Skladanowski, A. Ludwiczak, et al., " Evaluating the Cytotoxicity of Ionic Liquids Using Hu-man Cell Line Hela," *Human & Experimental Toxicology*, Vol. 23, No. 11, 2004, pp. 513-517.
- [45] M. Matsumoto, K. Mochiduki, K. Fukunishi, et al., " Ex-traction of Organic Acids Using Imidazolium-Based Ionic Liquids and their Toxicity to *Lactobacillus Rhamnosus*," *Separation and Purification Technology*, Vol. 40, No. 1, 2004, pp. 97-101.
- [46] M. Matsumoto, K. Mochiduki and K. Kondo, " Toxicity of Ionic Liquids and Organic Solvents to Lactic Acid- Producing Bacteria," *Journal of Bioscience and Bioengi-neering*, Vol. 98, No. 5, 2004, pp. 344-347.
- [47] F. Ganske and U. Bornscheuer, " Growth of *Escherichia coli*, *Pichia pastoris* and *Bacillus cereus* in the Presence of the Ionic Liquids [BMIM][BF4] and [BMIM][PF6] and Organic Solvents," *Biotechnology Letters*, Vol. 28, No. 7, 2006, pp. 465-469.

- [48] R. P. Swatloski, J. D. Holbrey, S. B. Memon, et al., " Using Caenorhabditis Elegans to Probe Toxicity of 1-alkyl- 3-methylimidazolium Chloride Based Ionic Liquids," Chemical Communications, 2004, pp. 668-669.
- [49] F. Stock, J. Hoffmann, J. Ranke, et al., " Effects of Ionic Liquids on the Acetylcholinesterase—A Structure-Activity Relationship Consideration," Green Chemistry, Vol. 6, No. 6, 2004, pp. 286-290.
- [50] A. Latała, P. Stepnowski, M. Nędzi, et al., " Marine Toxicity Assessment of Imidazolium Ionic Liquids: Acute Effects on the Baltic Algae *Oocystis Submarina* and *Cyclotella meneghiniana*," Aquatic Toxicology, Vol. 73, No. 1, 2005, pp. 91-98.
- [51] R. J. Bernot, M. A. Brueseke, M. A. Evans-White, et al., " Acute and Chronic Toxicity of Imidazolium-Based Ionic Liquids on *Daphnia magna*," Environmental Toxicology and Chemistry, Vol. 24, No. 1, 2005, pp. 87-92.
- [52] C. Pretti, C. Chiappe, D. Pieraccini, et al., " Acute Toxicity of Ionic Liquids to the zebrafish (*Danio rerio*)," Green Chemistry, Vol. 8, No. 3, 2006, pp. 238-240.
- [53] T. D. Landry, K. Brooks, D. Poche, et al., " Acute Toxicity Profile of 1-Butyl-3-Methylimidazolium Chloride," Bulletin of Environmental Contamination and Toxicology, Vol. 74, 2005, pp. 559.
- [54] R. J. Bernot, E. E. Kennedy and G. A. Lamberti, " Effects of Ionic Liquids on the Survival, Movement, and Feeding Behavior of the freshwater snail, *Physa acuta*," Environmental Toxicology & Chemistry, Vol. 24, 2005, pp. 1759.
- [55] D. M. Costello, L. M. Brown and G. A. Lamberti, " Acute Toxic Effects of Ionic Liquids on Zebra Mussel (*Dreissena polymorpha*) Survival and Feeding," Green Chemistry, Vol. 11, No. 4, 2009, pp. 548-553.
- [56] D. J. Couling, R. J. Bernot, K. M. Docherty, et al., " Assessing the Factors Responsible for Ionic Liquid Toxicity to Aquatic Organisms via Quantitative Structure-Property Relationship Modeling," Green Chemistry, Vol. 8, No. 1, 2006, pp. 82-90.
- [57] P. Stepnowski and P. Storonik, " Lipophilicity and Metabolic Route Prediction of Imidazolium Ionic Liquids," Environmental Science and Pollution Research, Vol. 12, No. 4, 2005, pp. 199-204.
- [58] N. Gathergood, M. T. Garcia and P. J. Scammells, " Bio-degradable Ionic Liquids: Part I. Concept, Preliminary Targets and Evaluation," Green Chemistry, Vol. 6, No. 3, 2004, pp. 166-175.
- [59] S. Kumar, W. Ruth, B. Sprenger, et al., " On the Biodegradation of Ionic Liquid 1-Butyl-3-methylimidazolium tetrafluoroborate," Chimica Oggi, Vol. 24, No. 2, 2006, pp. 24-26.
- [60] G.-H. Tao, L. He, N. Sun, et al., " New Generation Ionic Liquids: Cations Derived from Amino Acids," Chemical Communications, 2005, pp. 3562-3564.
- [61] B. Ni, A. D. Headley and G. Li, " Design and Synthesis of C-2 Substituted Chiral Imidazolium Ionic Liquids from Amino Acid Derivatives," Journal of Organic Chemistry, Vol. 70, No. 25, 2005, pp. 10600-10602.
- [62] P. Wasserscheid, A. Bösmann and C. Bolm, " Synthesis and Properties of Ionic Liquids Derived from the Chiral Pool," Chemical Communications, 2002, pp. 200-201.
- [63] W. Bao, Z. Wang and Y. Li, " Synthesis of Chiral Ionic Liquids from Natural Amino Acids," Journal of Organic Chemistry, Vol. 68, No. 2, 2003, pp. 591-593.
- [64] E. B. Carter, S. L. Culver, P. A. Fox, et al., " Sweet Success: Ionic Liquids Derived from Non-Nutritive Sweeteners," Chemical Communications, 2004, pp. 630-631.
- [65] N. Gathergood and P. J. Scammells, " Design and Preparation of Room-Temperature Ionic Liquids Containing Biodegradable Side Chains," Australian Journal of Chemistry, Vol. 55, No. 9, 2002, pp. 557-560.
- [66] P. J. Scammells, J. L. Scott and R. D. Singer, " Ionic Liquids: The Neglected Issues," Australian Journal of Chemistry, Vol. 58, No. 3, 2005, pp. 155-169.
- [67] N. Gathergood, P. J. Scammells and M. T. Garcia, " Bio-degradable Ionic Liquids: Part III. The First Readily Bio-degradable Ionic Liquids," Green Chemistry, Vol. 8, No. 2, 2006, pp. 156-160.
- [68] M. T. Garcia, N. Gathergood and P. J. Scammells, " Bio-degradable Ionic Liquids: Part II. Effect of the Anion and Toxicology," Green Chemistry, Vol. 7, No. 1, 2005, pp. 9-14.
- [69] J. R. Harjani, R. D. Singer, M. T. Garcia, et al., " Biodegradable Pyridinium Ionic Liquids: Design,

- [70] Y. Fan, M. Chen, C. Shentu, et al., " Ionic liquids Extrac-tion of Para Red and Sudan Dyes from Chilli Powder, Chilli Oil and Food Additive Combined with High Per-formance Liquid Chromatography," *Analytica Chimica Acta*, Vol. 650, 2009, pp. 66.
- [71] A. Martin-Calero, V. Pino, J. H. Ayala, et al., " Ionic Liq-uids as Mobile Phase Additives in High-Performance Liquid Chromatography with Electrochemical Detection: Application to the Determination of Heterocyclic Aromatic Amines in Meat-Based Infant Foods," *Talanta*, Vol. 79, No. 3, 2009, pp. 590-597.
- [72] J. L. Manzoori, M. Amjad and J. Abulhassani, " Ultra- Trace Determination of Lead in Water and Food Samples by Using Ionic Liquid-Based Single Drop Microextrac-tion-Electrothermal Atomic Absorption Spectrometry," *Analytica Chimica Acta*, Vol. 644, No. 1-2, 2009, pp. 48-52.
- [73] M. Matzke, S. Stolte, J. Arning, et al., " Ionic Liquids in Soils: Effects of Different Anion Species of Imidazolium Based Ionic Liquids on wheat ( *Triticum Aestivum* ) as Affected by Different Clay Minerals and Clay Concentra-tions," *Ecotoxicology*, Vol. 18, No. 2, 2009, pp. 197-203.
- [74] A. Latała, M. Nędzi and P. Stepnowski, " Toxicity of Imidazolium and Pyridinium Based Ionic Liquids towards Algae. *Chlorella vulgaris*, *Oocystis submarina* (green algae) and *Cyclotella meneghiniana*, *Skeletonema marinoi* (diatoms)," *Green Chemistry*, Vol. 11, No. 4, 2009, pp. 580-588.
- [75] M. Matzke, K. Thiele, A. Mueller, et al., " Sorption and Desorption of Imidazolium Based Ionic Liquids in Dif-ferent Soil Types," *Chemosphere*, Vol. 74, No. 4, 2009, pp. 568-574.
- [76] M. Rebros, H. Q. N. Gunaratne, J. Ferguson, et al., " A High throughput Screen to Test the Biocompatibility of Water-Miscible Ionic Liquids," *Green Chemistry*, Vol. 11, No. 3, 2009, pp. 402-408.
- [77] G. Turian, " Polarity: From Electromagnetic Origins to Biological Take-Over," Hamburg Kovač, 1994.
- [78] A. J. Carmichael and K. R. Seddon, " Polarity Study of Some 1-Alkyl-3-Methylimidazolium Ambient-Temperature Ionic Liquids with the Solvatochromic Dye, Nile Red," *Journal of Physical Organic Chemistry*, Vol. 13, 2000, pp. 591.
- [79] S. N. V. K. Aki, J. F. Brennecke and A. Samanta, " How Polar are Room-Temperature Ionic Liquids?" *Chemical Communications*, 2001, pp. 413-414.
- [80] P. K. Mandal and A. Samnta, " Fluorescence Studies in a Pyrrolidinium Ionic Liquid: Polarity of the Medium and Solvation Dynamics," *Journal of Physical Chemistry B*, Vol. 109, No. 31, 2005, pp. 15172-15177.
- [81] A. Kawai, T. Hidemori and K. Shibuya, " Polarity of Room-Temperature Ionic Liquid as Examined by EPR Spectroscopy," *Chemistry Letters*, Vol. 33, No. 11, 2004, pp. 1464-1465.
- [82] G. Angelini, C. Chiappe, P. D. Maria, et al., " Determina-tion of the Polarities of Some Ionic Liquids Using 2-Nitrocyclohexanone as the Probe" . *Journal of Organic Chemistry*, Vol. 70, No. 20, 2005, pp. 8193-8196.
- [83] C. Wakai, A. Oleinikova, M. Ott, et al., " How Polar are Ionic Liquids? Determination of the Static Dielectric Constant of an Imidazolium-Based Ionic Liquid by Mi-crowave Dielectric Spectroscopy," *Journal of Physical Chemistry B*, Vol. 109, No. 36, 2005, pp. 17028-17030.
- [84] G.-H. Tao, M. Zou, X.-H. Wang, et al., " Comparison of Polarities of Room-Temperature Ionic Liquids Using FT-IR Spectroscopic Probes," *Australian Journal of Chemistry*, Vol. 58, No. 5, 2005, pp. 327-331.
- [85] T. K?ddermann, C. Wertz, A. Heintz, et al., " The Association of Water in Ionic Liquids: A Reliable Measure of Polarity," *Angewandte Chemie International Edition*, Vol. 45, No. 22, 2006, pp. 3697-3702.
- [86] C. Reichardt, " Polarity of Ionic Liquids Determined Em-pirically by Means of Solvatochromic Pyridinium N- Phenolate Betaine Dyes," *Green Chemistry*, Vol. 7, No. 5, 2005, pp. 339-351.
- [87] P. J. Dyson, G. Laurency, C. A. Ohlin, et al., " Determination of Hydrogen Concentration in Ionic Liquids and the Effect (or Lack of) on Rates of Hydrogenation," *Chemical Communications*, 2003, pp.2418-2419.
- [88] C. A. Ohlin, P. J. Dyson and G. Laurency, " Carbon Monoxide Solubility in Ionic Liquids: Determination, Prediction and Relevance to Hydroformylation," *Chemical Communications*, 2004, pp.

- [89] H. Liu, G.-H. Tao, D. G. Evans, et al., "Solubility of C<sub>60</sub> in Ionic Liquids," *Carbon*, Vol. 43, No. 8, 2005, pp. 1782-1785.
- [90] Y. Kou, W. Xiong, G. Tao, et al., "Absorption and Capture of Methane into Ionic Liquid," *Journal of Natural Gas Chemistry*, Vol. 15, No. 4, 2006, pp. 282-286.
- [91] P. Wasserscheid, C. M. Dordon, C. Hilgers, et al., "Ionic Liquids: Polar, but Weakly Coordinating Solvents for the First Biphasic Oligomerisation of Ethene to Higher -olefins with Cationic Ni Complexes," *Chemical Communications*, 2001, pp. 1186.
- [92] A.-V. Muderling, A. Babai, S. Arenz, et al., "The "Non-coordinating" Anion Tf<sub>2</sub>N<sup>-</sup> Coordinates to Yb<sup>2+</sup>: A Structurally Characterized Tf<sub>2</sub>N<sup>-</sup> Complex from the Ionic Liquid [mppy<sub>r</sub>][Tf<sub>2</sub>N]," *Angewandte Chemie International Edition*, Vol. 44, No. 34, 2005, pp. 5485-5488.
- [93] D. B. Williams, M. E. Stoll, B. L. Scott, et al., "Coordination Chemistry of the bis(trifluoromethylsulfonyl)imide Anion: Molecular Interactions in Room Temperature Ionic Liquids," *Jr. Chemical Communications*, 2005, pp. 1438-1440.
- [94] A. Babai and A.-V. Muderling, "Crystal Engineering in Ionic Liquids. The Crystal Structures of [Mppy<sub>r</sub>]<sub>3</sub>[Ndl<sub>6</sub>] and [Bmpy<sub>r</sub>]<sub>4</sub>[Ndl<sub>6</sub>][Tf<sub>2</sub>N]," *Inorganic Chemistry*, Vol. 45, No. 13, 2006, pp. 4874-4876.
- [95] R. J. P. Williams and R. D. Gillard, "Coordination Chemistry and Analysis," Pergamon Press, Oxford, 1987.
- [96] P. Wasserscheid and E. T. Welton, "Ionic Liquids in Synthesis," Wiley-VCH verlag GmbH & Co. KGaA, 2002.
- [97] A. G. Avent, P. A. Chaloner, M. P. Day, et al., "Evidence for Hydrogen Bonding in Solutions of 1-ethyl-3-methylimidazolium Halides, and its Implications for Room-Temperature Halogenoaluminate(III) Ionic Liquids," *Journal of the Chemical Society Dalton Transactions*, 1994, pp. 3405-3413.
- [98] A. Elaiwi, P. B. Hitchcock, K. R. Seddon, et al., "Hydrogen Bonding in Imidazolium Salts and its Implications for Ambient-Temperature Halogenoaluminate(III) Ionic Liquids," *Journal of the Chemical Society Dalton Transactions*, 1995, pp. 3467-3472.
- [99] A. R. Choudhury, N. Winterton, A. Steiner, et al., "In Situ Crystallization of Low-Melting Ionic Liquids," *Journal of the American Chemical Society*, Vol. 127, 2005, pp. 16792-16793.
- [100] A. R. Katritzky, H. Yang, D. Zhang, et al., "Strategies toward the Design of Energetic Ionic Liquids: Nitro- and Nitrile-Substituted N,N-dialkylimidazolium Salts," *New Journal of Chemistry*, Vol. 30, No. 3, 2006, pp. 349-358.
- [101] D. J. Tempel, P. B. Henderson, J. R. Brzozowski, et al., "Liquid Media Containing Lewis Acidic Reactive Compounds for Storage and Delivery of Lewis Basic Gases," *U.S. Pat. Appl. Publ.*, 2005.US 2005276733.
- [102] D. R. Graham, D. J. Tempel, B. A. Toseland, et al., "Storage and Delivery Systems for Gases Held in Liquid Medium," *Eur. Pat. Appl.*, 2006.EP 1614955.
- [103] Z. Fei, D. Zhao, T. J. Geldbach, et al., "Structure of Ni-trile-Functionalized Alkyltrifluoroborate Salts," *European Journal of Organic Chemistry*, Vol. 2005, No. 5, 2005, pp. 860-865.
- [104] Z. Fei, D. Zhao, R. Scopelliti, et al., "Organometallic Complexes Derived from Alkyne-Functionalized Imidazolium Salts," *Organometallics*, Vol. 23, No. 7, 2004, pp. 1622-1628.
- [105] D. Zhao, Z. Fei, R. Scopelliti, et al., "Synthesis and Characterization of Ionic Liquids Incorporating