

“Ionic Liquid – Environmental Benign Solvent For Organic Reaction, Prospect And Challenges”

Bedanta Kr. Bora

Dep't Of Chemistry D. R. College Golaghat, Assam Pin: 785621

Abstract: - Till date, most chemical reactions have been carried out in molecular solvents. For two millennia, most of our understanding of chemistry has been based upon the behavior of molecules in the solution. However, a new class of liquid has emerged—**ionic liquids**. These liquids look like classical liquid but do not contain any molecules. Ionic liquids consist entirely of ionic species but has low melting point and remain in liquid state at low temperature, below 100°C. Important feature of ionic liquid is its ability to dissolve polar and non polar substances, low vapor pressure, Chemical and thermal stability, nonflammability, high electrical conductivity etc. Due to low vapor pressure, ionic liquid are considered substitute of volatile organic solvent and attracted enormous attraction as GREEN SOLVENT.

Keywords: - Solvent, Ionic liquid, ion, Green solvent, vapor pressure.

I. INTRODUCTION

Aristotle's famous philosophy, “No **Coopora nisi Fluida**” which means “No reaction occurs in the absence of solvent” had a big influence in the development of modern chemistry. It provides one historical reason; most organic reactions have been studied in solution. Common solvent which are generally used in the synthesis of organic molecules are toxic. Few of them like benzene, chlorinated hydrocarbons are carcinogens. Most of them are potential threat to respiratory disease, throat disease etc. Toxicity of few organic solvent:

1. Benzene : Highly carcinogenic
2. CHCl₃ : Cancer suspect agent
3. CH₂Cl₂ : Cancer suspect agent
4. DMF : Teratogen Irritant
5. THF : Irritant
6. Ethyl acetate: Irritant
7. Acetonitrile : Very toxic
8. Ether : Irritant

The organic solvents are inflammable and require extra care in handling. **These solvents are also expensive and due to their high vapour pressure they are difficult to get recycled.** The types and amounts of organic solvents used in the organic laboratory varies, but the following process map is applicable to all of them. The spent solvents and other material are disposed as hazardous waste which is polluting the whole environment and creating a **well designed health hazard. Their high cost leads to the drainage of funds.**

However, a new class of solvent has emerged—**ionic liquids**. These solvents are often fluid at room temperature, and consist entirely of ionic species. Today, the term “ionic liquid” is used for the salt whose melting point is relatively low(below 100°C)[1]. The first room-temperature ionic liquid [EtNH₃][NO₃] (m.pt. 12 °C) was discovered in 1914[2] but interest did not develop until the discovery of binary ionic liquids made from mixtures of aluminum(III) chloride and N-alkylpyridinium[3] or 1,3-dialkylimidazolium chloride[4]. Ionic liquids come in two main categories, namely simple salts (made of a single anion and cation) and binary ionic liquids (salts where equilibrium is involved). For example, [EtNH₃][NO₃] is a simple salt whereas mixtures of aluminum(III) chloride and 1,3-dialkylimidazolium chlorides (a binary ionic liquid system) contain several different ionic species, and their melting point and properties depend upon the mole fractions of the aluminum(III) chloride and 1,3-dialkylimidazolium chloride present. In general, ionic liquids consist of a salt where one or both the ions are large, and the cation has a low degree of symmetry. These factors tend to reduce the lattice energy of the crystalline form of the salt, and hence lower the melting point[5].

They have many fascinating properties which make them of fundamental interest to all chemists, since both the thermodynamics and kinetics of reactions carried out in ionic liquids are different to those in conventional molecular solvents.

A number of simple physical properties of ionic liquids suggest that they have great promise:

- By combining different anions and cations, it is possible to generate a huge number of different ionic liquids, each with their own specific solvation properties.
- Ionic liquids are non-volatile, hence they may be used in high vacuum systems and they eliminate many containment problems.
- They are good solvents for a wide range of both inorganic and organic materials and unusual combinations of reagents can be brought into the same phase.
- They are immiscible with a number of organic solvents and provide a non-aqueous, polar alternative for two phase systems, this has been used to effect total catalyst recovery in a number of transition metal catalysed reactions. Hydrophobic ionic liquids can also be used as immiscible polar phases with water.
- They are often composed of poorly coordinating ions, so they have the potential to be highly polar non coordinating solvents, this is particularly important when using transition-metal based catalysts.

II. WHAT FEATURES MAKE IONIC LIQUIDS SO ATTRACTIVE?

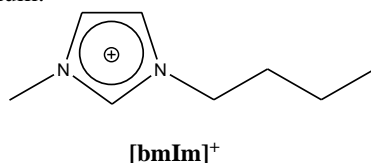
Beside their very low vapor pressure which makes ionic liquids good alternative solvents to volatile organic solvents, they display a large operating range (typically from -40°C to 200°C), a good thermal stability high ionic conductivity and large electrochemical window.

Ionic liquids have no measurable vapor pressure, and hence cannot emit any volatile organic compounds (VOCs) and finds enormous attention as **media for green synthesis**. As they are made up of at least two components which can be varied (the anion and cation), the solvents can be designed with a particular use in mind, or to possess a particular set of properties. Hence, the term “**designer solvents**” has come into common use.

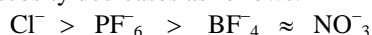
Some typical physical characteristics of ionic liquids consisting of a simple salt of 1-Butyl– 3-methylimidazolium are given below :

Anion	m.p $^{\circ}\text{C}$	Density (gcm^{-3})	Viscosity(cp)	Conductivity(Sm^{-1})
BF_4^-	-82	1.17(30°C)	233(30°C)	0.173(25°C)
PF_6^-	-61	1.37(30°C)	312(30°C)	0.146(25°C)
CF_3CO_2^-	-50	1.209(21°C)	73(20°C)	0.32 (20°C)

1-Butyl– 3- methylimidazolium:



It has been demonstrated that the viscosity of 1-butyl-3-methylimidazolium salts can be decreased by using highly branched and compact alkyl chain but more importantly by changing the nature of the anion. For a same cation the viscosity decreases as follows:



An illustration of their versatility is given by their exceptional solubility characteristics which make them good candidates for multiphase catalysis. For example, their solubility with water depends on the nature of the anions, on the temperature and on the length of the alkyl chain on the dialkylimidazolium cation. Salts based on 1,3-dialkylimidazolium cation remain preferred as they generally interact weakly with the anions and are more thermally stable than other quaternary ammonium cations. Huddleston *et al.* have examined physical properties (rarely systematically explored in the literature) of different hydrophobic and hydrophilic 1-alkyl-3-methylimidazolium room temperature ionic liquids. It is demonstrated that water content, density, viscosity, surface tension, melting point, and thermal stability were affected by changes in alkyl chain length of the imidazolium cations and by the nature of the anion. The solubility of 1-hexene in different N,N-dialkylimidazolium and N-methyl-N-ethylpyrrolidinium salts has been measured. Interestingly increasing the length of the alkyl chain on the cation but also by tuning the nature of the anion can increase the solubility of 1-hexene in the melt.

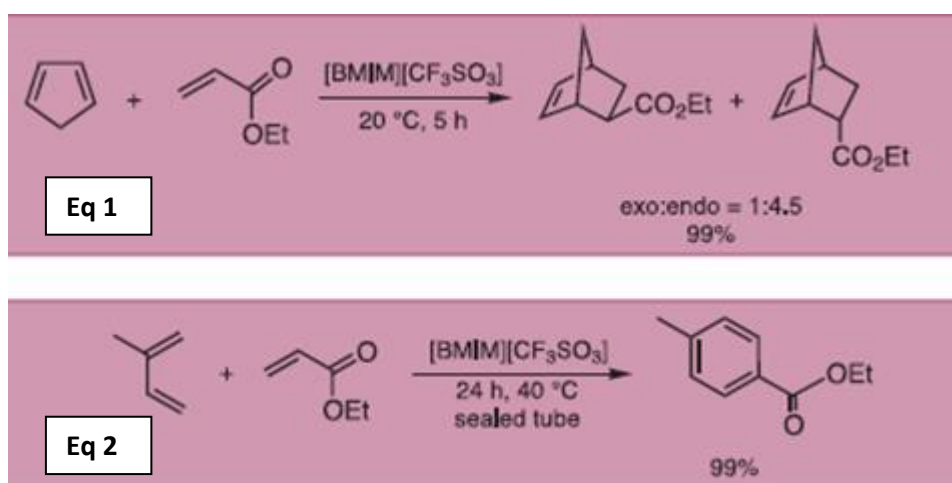
Often, the organic products can be removed from the ionic liquid by extraction with, e.g., ether, without resorting to an aqueous workup. This can be particularly useful when a precious metal catalyst is used in the

reaction. The catalyst often remains in the ionic liquid, so that the catalyst solution can be directly reused.

III. RESULT & DISCUSSION

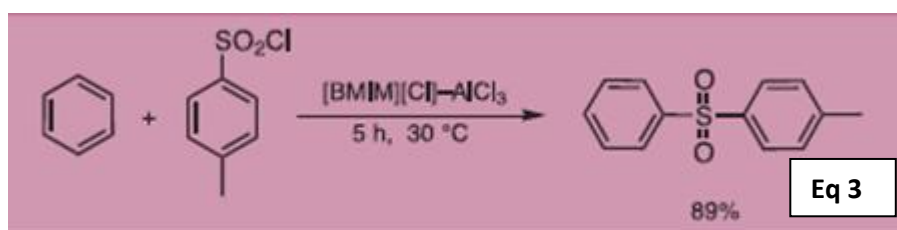
At first, the prospect of carrying out chemical reactions in ionic liquids may seem daunting to a chemist who has not worked with them before, but it turns out that carrying reactions out in ionic liquids can be exceptionally easy. Few common reaction carried in ionic liquid are presented below.

Diels–Alder Reaction: An early study of the Diels–Alder reaction of cyclopentadiene with methyl acrylate or methyl vinyl ketone in $[\text{EtNH}_3][\text{NO}_3]$ was reported in 1989[5]. Although the reaction rate and selectivity were lower than those in water, the study showed that ionic liquids could be employed in this type of reaction. Encouraged by these findings, Diels–Alder reactions were conducted in several other ionic liquids such as $[\text{EMIM}][\text{PF}_6]$, [6][7], $[\text{EMIM}][\text{BF}_4]$ [7] $[\text{EMIM}][\text{CF}_3\text{SO}_3]$, [7] $[\text{BMIM}][\text{ClO}_4]$, [6] $[\text{EMIM}][\text{Cl}]-\text{AlCl}_3$, [8] and $[\text{BMIM}][\text{CF}_3\text{SO}_3]$. [9]. Two examples of these reactions are illustrated in **eq 1** and **2[9]**. The use of LiClO_4 in diethyl ether has become one of the biggest developments in Diels–Alder chemistry. The LiClO_4 – Et_2O system can accelerate the Diels–Alder reaction due to the high concentration of electrolyte. By using ionic liquids instead of LiClO_4 – Et_2O , reactivities can be improved and the need for potentially explosive perchlorate-based reaction media is eliminated.¹⁰



Friedel–Crafts Reaction: Friedel–Crafts acylations are of industrial importance and are associated with a massive consumption of aluminum(III) chloride. It has been demonstrated that acylation reactions can be carried out in acidic chloroaluminate(III) ionic liquids [10][11]. The regioselectivities and rates observed in these reactions are comparable to the best values known for the traditional acylations. The Friedel–Crafts acylation of benzene has been conducted in acidic chloroaluminate(III) ionic liquid. [11]. The monoacylated products were obtained as a result of the deactivation of the aromatic ring by the acyl substituent.

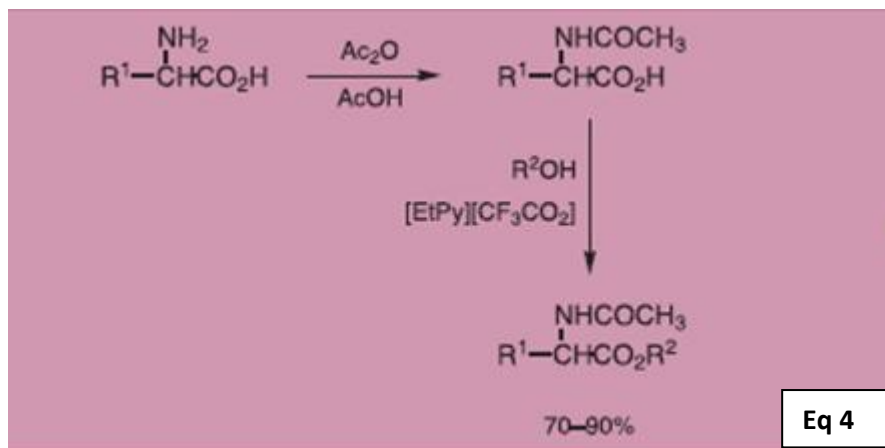
An in situ IR spectroscopic study was performed on the Friedel–Crafts acetylation of benzene in ionic liquids using AlCl_3 and FeCl_3 [12]. The results revealed that the mechanism of the Friedel–Crafts acetylation of benzene in ionic liquids was exactly the same as that in 1,2-dichloroethane. Another interesting development is the use of $[\text{BMIM}][\text{chloroaluminate}]$ as Lewis acid catalyst for the Friedel–Crafts sulfonylation of benzene and substituted benzenes with TsCl (**eq 3**). [13]. The substrates exhibited enhanced reactivity, and furnished the corresponding unsymmetrical diaryl sulfones in 83–91% yields under ambient conditions.



Esterification:

Esterifications of alcohols and acetic acids in the room-temperature ionic liquid 1-butylpyridinium chloride–aluminum(III) chloride as a “green” catalyst have been reported by Deng et al [14]. Satisfactory conversions and selectivities were obtained, and most of the ester products were easily recovered due to their

immiscibility with the ionic liquid. Amino acid esters are very important intermediates in the chemical and pharmaceutical industry. They are usually difficult to prepare because amino acids exist as zwitterions (dipolar ions), in which the carboxyl group is not in the free form. Our group has recently developed a successful method for synthesizing amino acid esters using [EtPy][CF₃CO₂] (EtPy = *N*-ethylpyridinium) as a “green” catalyst.[15]. Excellent conversions have generally been achieved for the ethyl and isopropyl esters of many amino acids (eq 4).



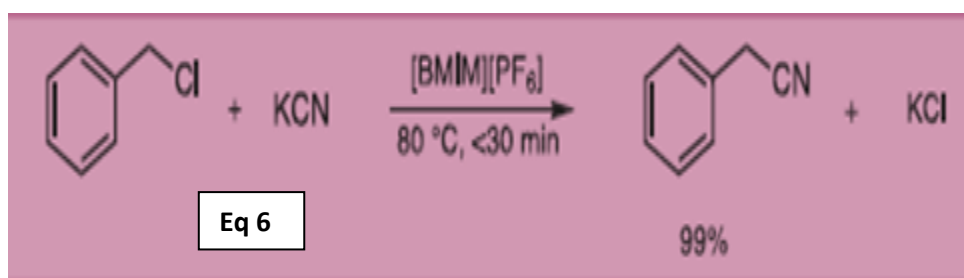
Regioselective Alkylation:

Alkylation of indole or 2-naphthol is usually achieved by preformation of the ambident indolate⁸² or 2-naphtholate⁸³ anion and subsequent treatment with alkyl halide. Regioselective alkylation at the heteroatom of these anions is solvent-dependent, and can be achieved by using a dipolar aprotic solvent such as DMF.[16][17]. As an environmentally friendly alternative, [BMIM][PF₆] has been utilized for the regioselective alkylation at the heteroatom of indole and 2-naphthol (eq 5).[18]. Advantages of this process include simple operation, easy product isolation, no measurable solvent vapor pressure, high regioselectivity, and the potential for recycling the solvent.



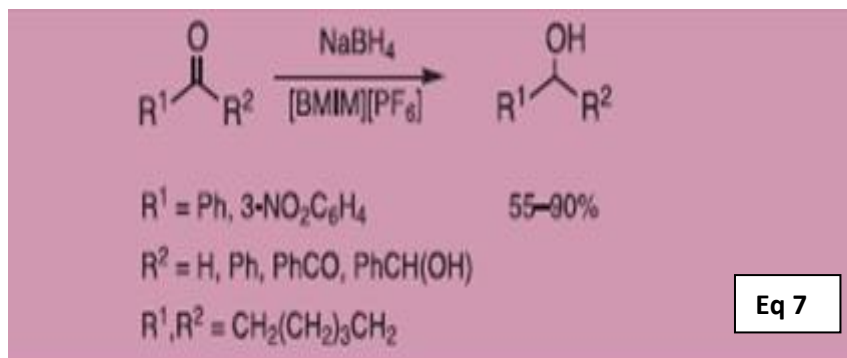
Displacement Reaction with Cyanide:

Nucleophilic displacement reactions are often achieved using phase-transfer catalysis (PTC) to facilitate reaction between the organic reactants and the inorganic ionic salts that provide the nucleophiles[19]. In conventional PTC, the typical organic solvents used, such as dichloroethane or *o*-dichlorobenzene, are environmentally undesirable. In addition, catalyst separation and recovery are very difficult. It has been demonstrated that the use of roomtemperature ionic liquids as catalytic, environmentally benign solvents for the displacement of benzylic chloride with cyanide can replace phase-transfer-catalyzed biphasic systems (eq 6)[20]. This eliminates the need for a volatile organic solvent and hazardous catalyst disposal.



Reduction of Aldehydes and Ketones:

Howarth et al. have investigated the reduction of aldehydes and ketones with NaBH_4 in $[\text{BMIM}][\text{PF}_6]$. [21]. In this study, six common aldehydes and ketones were converted into the corresponding alcohols in moderate-to-high yields (eq 7). The ionic liquid was recycled, and, in some cases, the product alcohol was distilled directly from the ionic liquid.



Beckmann Rearrangement:

The Beckmann rearrangement is typically carried out in strong Brønsted or Lewis acids, such as concentrated sulfuric acid, phosphorus pentachloride in ether, or hydrogen chloride in a mixture of acetic acid and acetic anhydride. These conditions give rise to significant amounts of by-products and serious corrosion problems [22]. In a recent study by Peng and Deng, [23] the catalytic Beckmann rearrangement of several ketoximes was achieved with satisfactory conversion and selectivity in 1,3-dialkylimidazolium or alkylpyridinium salts and phosphorylated compounds (PCl_5 , POCl_3 , or P_2O_5) (eq 8).



IV. CONCLUSION

From the discussion it can be concluded that ionic liquid due to low volatility, non flammability, low melting point, high thermal stability, controlled miscibility with organic compound, recyclability, no apparent toxicity make it economically and eco friendly green solvent. The use of ionic liquids as solvents or catalysts has a profound effect on the observed activities and selectivities. As a result, there is growing interest in developing applications for them in a wide range of synthetic reactions. The present review was not designed to be comprehensive, but rather to summarize some of the recent advances in the application of ionic liquids in organic synthesis. We hope that readers will find it helpful in their day-to-day work. Ionic liquids have all potential to replace conventional solvent in both laboratories and industry.

V. REFERENCE

- [1] Hagiwara, R.; Ito, Y. *J. Fluorine Chem.* 2000, 105, 221-227.
- [2] P. Walden. *Bull. Acad. Imper. Sci. (St. Petersburg)* 1800 (1914).
- [3] H. L. Chum, V. R. Koch, L. L. Miller, R. A. Osteryoung. *J. Am. Chem. Soc.* **97**, 3264– 3267 (1975).
- [4] J. S. Wilkes, J. A. Levisky, R. A. Wilson, C. L. Hussey. *Inorg. Chem.* **21**, 1236–1264 (1982).
- [5] Jaeger, D. A.; Tucker, C. E. *Tetrahedron Lett.* **1989**, 30, 1785.

- [6] Fischer, T.; Sethi, A.; Welton, T.; Woolf, J. *Tetrahedron Lett.* **1999**, 40, 793.a
- [7] Earle, M. J.; McCormac, P. B.; Seddon, K. R. *Green Chem.* **1999**, 1, 23; *Chem. Abstr.* **1999**, 131, 87674
- [8] Lee, C. W. *Tetrahedron Lett.* **1999**, 40, 2461.
- [9] Holbrey, J. D.; Seddon, K. R. *Clean Prod.Proc.* **1999**, 1, 223.
- [10] Adams, C. J.; Earle, M. J.; Roberts, G.; Seddon, K. R. *Chem. Commun.* **1998**, 2097.
- [11] Boon, J. A.; Levisky, J. A.; Pflug, J. L.; Wilkes, J. S. *J. Org. Chem.* **1986**, 51, 480.
- [12] A. J. P.; Zigras, T. *J. Chem. Soc., Dalton Trans.* **1997**, 3465.
- [13] Csihony, S.; Mehdi, H.; Horvath, I. T. *Green Chem.* **2001**, 3, 307.
- [14] Deng, Y.; Shi, F.; Beng, J.; Qiao, K. *J. Mol.Catal. A: Chem.* **2001**, 165, 33.
- [15] Zhao, H.; Malhotra, S. V. *Esterification of Amino Acids by Using Ionic Liquid as a Green Catalyst. In Catalysis of OrganicReactions; Morrell, D., Ed.; Marcel Dekker:New York, 2002; Volume 83; pp 667-672.*
- [16] Kornblum, N.; Seltzer, R.; Haberfield, P. *J. Am. Chem. Soc.* **1963**, 85, 1148.
- [17] Cardillo, B.; Casnati, G.; Pochini, A.; Ricca, A. *Tetrahedron* **1967**, 23, 3771.
- [18] Earle, M. J.; McCormac, P. B.; Seddon, K. R. *Chem. Commun.* **1998**, 2245.
- [19] Starks, C. M.; Liotta, C. L.; Halpern, M. *Phase-Transfer Catalysis; Chapman and Hall: New York, 1994.*
- [20] Wheeler, C.; West, K. N.; Liotta, C. L.; Eckert, C. A. *Chem. Commun.* **2001**, 887.
- [21] Howarth, J.; James, P.; Ryan, R. *Synth. Commun.* **2001**, 31, 2935.
- [22] Izumi, Y.; Sato, S.; Urabe, K. *Chem. Lett.* **1983**, 1649.
- [23] Peng, J.; Deng, Y. *Tetrahedron Lett.* **2001**, 42, 403.