CHAPTER-I

IONIC LIQUID CATALYZED ORGANIC REACTIONS
I.1 GENERAL INTRODUCTION

Organic chemicals are the important starting materials of major chemical industries. The production of organic chemicals as raw materials or reagents for other applications is a major sector of manufacturing polymers, pharmaceuticals, pesticides, paints, artificial fibers, food additives, etc. Organic synthesis on a large scale, compared to the laboratory scale, involves the use of energy, basic chemical ingredients from the petrochemical sector, catalysts and after the end of the reaction, separation, purification, storage, packaging, distribution etc. During these processes there are many problems of health and safety for workers in addition to the environmental problems caused by their use and disposition as waste.

Therefore, in modern synthetic organic chemistry, research effort is being made to design a chemical process which is eco-friendly and this is also the main objective of Green Chemistry.\(^1\)

Green Chemistry changes the conventional ways that were used for decades to make synthetic organic chemical substances by using less toxic starting materials. Green Chemistry would like to increases the efficiency of synthetic methods, to use less toxic solvents, reduce the stages of the synthetic routes and minimize waste as far as practically possible.

The term green chemistry was first used in 1991 by P. T. Anastas in a special program launched by the US Environmental Protection Agency (EPA) to implement sustainable development in chemistry and chemical technology by industry, academia and government which is defined as “To promote innovative chemical technologies that reduce or eliminate the use or generation of hazardous substances in the design, manufacture, and use of chemical products”. It can be also considered as an essential piece of comprehensive program to protect human health and the environment. This new approach is also known as:

- Environmentally benign chemistry
- Clean chemistry
- Atom economy
- Benign-by-design chemistry
Prof. Paul Anastas and Prof. John C. Warner define the green chemistry by these 12 principles for a chemical reaction and the summary of these are:

1. **Prevention:** It is better to prevent waste than to treat or clean up after it has been created.
2. **Atom Economy:** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. **Less Hazardous Chemical Syntheses:** Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing Safer Chemicals:** Chemical products should be designed to effect their desired function while minimizing toxicity.
5. **Safer Solvents and Auxiliaries:** The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. **Design for Energy Efficiency:** Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. **Use of Renewable Feedstocks:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce Derivatives:** Unnecessary derivatization (use of blocking groups, protection/deprotection, Temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation:** Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
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11. **Real-time analysis for Pollution Prevention**: Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. **Inherently Safer Chemistry for Accident Prevention**: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

From the standpoint of 12 principles of green chemistry, it can be concluded that green chemistry mainly involves a series of reductions. These reductions lead to the goal of triple bottom-line benefits of economic, environmental, and social improvements.

The replacement of hazardous volatile organic compounds as solvents is one of the most important targets of green chemistry because most of organic solvents used in performing reactions are very much toxic in nature. Toxicity of some common organic solvents is as below.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>Highly carcinogenic</td>
</tr>
<tr>
<td>CCl₄</td>
<td>Highly carcinogenic</td>
</tr>
<tr>
<td>CHCl₃</td>
<td>Cancer suspect Agent</td>
</tr>
<tr>
<td>CH₂Cl₂</td>
<td>Cancer suspect Agent</td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>Very Toxic</td>
</tr>
<tr>
<td>Dioxane</td>
<td>Cancer suspect Agent</td>
</tr>
<tr>
<td>DMF</td>
<td>Teratogen irritant</td>
</tr>
<tr>
<td>THF</td>
<td>Irritant</td>
</tr>
</tbody>
</table>

Therefore search for alternative green reaction medium and catalyst are of much interest. Common examples of green reaction medium and catalyst are water, supercritical fluids, ionic liquids and finally the no solvent is the best solvent means neat reaction conditions.
Additionally, ionic liquids (ILs) have attracted increasing interest recently in the context of green organic synthesis. Although ionic liquids were initially introduced as alternative green reaction media because of their distinctive chemical and physical properties of non volatility, non flammability, thermal stability, and controlled miscibility, today they have marched far away from this boundary, showing their significant role in controlling reactions as solvent or catalysts. \(^2\) Another important feature of ionic liquids is their reusability.

Generally ionic liquids are defined as liquid electrolytes composed entirely of ions. More recently, the melting criterion has been distinguished between molten salt and ionic liquid. The molten salt is a high melting, highly viscous and highly corrosive liquid, but an ionic liquid are salt of organic cation which has a melting point below 100 °C and has a relatively low viscosity. \(^3\) Table salt: NaCl contains small, single atom ions and has melting point 801 °C. NaCl is not an ionic liquid. But at 801 °C it behaves as a molten salt. However, both molten salts and ionic liquids are better described as liquid compounds that display ionic-covalent crystalline structures. \(^4\) The cations most commonly used in ionic liquids are alkylammonium, alkylphosphonium, \(N,N'\) dialkylimidazolium , and \(N\)- alkylpyridinium cations. The most commonly utilized alkyl chains are methyl, ethyl, butyl, hexyl, octyl, and decyl. (Fig 1)

![Commonly used cations in ionic liquids](image-url)
Typical inorganic anions are halides, tetrachloroaluminate, hexafluorophosphate, tetrafluoroborate, and bis(trifluoromethylsulfonyl)imide. Typical organic anions are alkylsulfate, alkylsulfonate, p-toluenesulfonate (tosylate) and trifluoroacetate (Fig 2).

Room-temperature ionic liquids (ILs) based on 1-alkyl-3-methylimidazolium salts were first reported in 1982 by Wilkes et al as tetrachloroaluminates (first generation). Replacement of this moisture-sensitive anion by the tetrafluoroborate ion and other anions led, in 1992, to air- and water-stable (second generation) ionic liquids, which have since found increasing applications as reaction media for various kinds of organic reactions. At the onset of the new millennium, the concept of task-specific ionic liquids (third generation) was introduced by Davis. These compounds are defined as ionic liquid in which the anion, cation, or both covalently incorporate a functional group (designed to give them with particular properties, either physical or chemical or in terms of reactivity) as a part of the ion structure.
1980s Chloroaluminates
Ionic Liquids

1990s Air and moisture-stable
Ionic Liquids

2000s Task-Specific
Ionic Liquids

1st generation

$\text{Me}^+\text{N}^+\text{N}^+\text{Et}$$\text{Cl}_4$

2nd generation

$\text{Me}^+\text{N}^+\text{N}^+\text{Et}$$\text{BF}_4$

3rd generation

$\text{Me}^+\text{N}^+\text{N}^+\text{Et}$$\text{BF}_4\text{Se}$

Fig 3 Three Ionic Liquids generations

The solubility of ionic liquid depends on cation and anion present in it. Generally ionic liquids are soluble in polar solvents but not in non-polar solvents. The solubility of ionic liquid largely depends on the anion present in the ionic liquid but the alkyl chains of the cation has some fine tuning on the solubility of ionic liquids. The ionic liquid has a wide range of application as shown in Fig 4.

Fig 4 Application of ionic liquids
We have synthesized zwitterionic type molten salt 4-(3-methylimidazolium) butane sulfonate and the corresponding task specific ionic liquid by using 1, 4 butane sultone and N-methyl imidazole. The synthetic strategy is as follows (Fig 5).

We have studied the role of both the molten salt and the corresponding task specific ionic liquid as catalyst for the synthesis of various types of important organic moieties.