# 1-Ethyl-3-methylimidazolium halogenoaluminate melts as reaction media for the Friedel–Crafts acylation of ferrocene

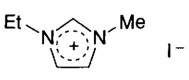
**Jacqueline K. D. Surette, Laine Green and Robert D. Singer***

*Department of Chemistry, Saint Mary's University, Nova Scotia, Canada B3H 3C3*

**Ionic liquid mediated Friedel–Crafts acylation of the organometallic complex ferrocene can be performed in 1-ethyl-3-methylimidazolium halogenoaluminate melts, EtMeimI–$AlCl_3$, as well as in the liquid clathrate formed upon addition of an excess of toluene to EtMeimI–$AlCl_3$ affording solely the monoacylated product acetylcyclopentadienyl (cyclo- pentadienyl)iron(II) in good to excellent yields under the appropriate conditions.**

Use of low-melting ionic liquids composed of an organic chloride and aluminium chloride as solvent and catalyst for Friedel–Crafts reactions at ambient temperatures was first reported in 1976.[1] Other electrophilic substitution reactions have been performed in chloroaluminate salts such as $AlCl_3$–NaCl and $AlCl_3$–$NH_4Cl$, but these reactions were generally performed at substantially elevated temperatures (*i.e.* > 100 °C).[2] The Friedel–Crafts alkylation and acylation of benzene has also been studied in room-temperature ionic liquids.[3] A particularly easily prepared ionic liquid, similar to those reported, is that prepared from the mixture of 1 to 2 equiv. of aluminium trichloride to 1-ethyl-3-methylimidazolium iodide, ('EtMeimI–$AlCl_3$'). This, and other binary mixtures of 1,3-dialkylimidazolium halide and aluminium chloride, possess desirable physical properties that we endeavoured to exploit.[4] For example, these molten salts are liquid at room temperature and some mixtures (*i.e.* those containing excess $AlCl_3$) are liquid far below room temperature. This is an advantage when performing reactions that involve thermally labile organometallic reactants and/or intermediates. The EtMeimI–$AlCl_3$ melts are also electrochemically and chemically inert[5] and possess a wide range of Lewis acidity depending on the proportion of aluminium trichloride added to the melts.[6] Furthermore, ease of preparation of 1-ethyl-3-methylimidazolium iodide *vs.* 1-ethyl-3-methylimidazolium chloride, which involves the use of iodoethane instead of the volatile chloroethane, renders our method attractive to the preparative synthetic chemist.

Ionic reaction media undoubtedly impart unique solvent effects on any reaction involving charged intermediates along their reaction pathways. Since many organometallic reactions involve such charged intermediates leading to isomeric product mixtures, differential solvation of the intermediates in ionic liquids may lead to single products. Although organochloroaluminate molten salts have been used as reaction media for catalytic dimerizations of alkenes in the presence of nickel complexes[7] and Ziegler–Natta homogeneous catalysis,[8] to our knowledge, no reactions in which new carbon–carbon bonds are formed within an isolable organometallic complex have been performed in ionic media. We report herein our preliminary results involving the Friedel–Crafts acylation of ferrocene in EtMeimI–$AlCl_3$ melts and in the liquid clathrate[9] formed from the addition of toluene to the EtMeimI–$AlCl_3$ melts (Scheme 1).



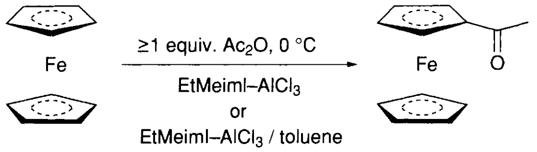
EtMeimI

Solid EtMeimI, prepared from the reaction of 1-methylimidazole and ethyl iodide under reflux in dry thf, was mixed with a twofold excess of aluminium trichloride† in a dry-box to afford the molten salts used as a reaction medium in these experiments.[4] Addition of an excess of $AlCl_3$ ensured the Lewis acidity of the reaction medium, according to eqn. (1),

$$2\,AlCl_4^- \rightleftharpoons Al_2Cl_7^- + Cl^- \qquad (1)$$

(where $Al_2Cl_7^-$ is the Lewis acid and $Cl^-$ is the Lewis base), that was found to be necessary for reaction to proceed (Table 1, entry 6).[6]‡ A transparent, light red liquid clathrate was observed when an excess of toluene was added to this acidic melt.[10]§ Any excess toluene layered above the clathrate was removed prior to reaction to avoid side-reactions with toluene when the clathrate was used as the reaction medium. After dissolving the requisite amount of ferrocene in the reaction media, the reaction vessels were removed from the dry-box and cooled to 0 °C under a positive $N_2$ atmosphere. Acetic anhydride was added to the reaction mixture *via* syringe and allowed to react for the indicated times (Table 1).

Table 1 shows that synthetically useful yields of the monoacetylated product, acetylferrocene, are obtained in the molten salt either when an excess of acetic anhydride is used (Table 1, entries 1–3) or when extended reaction times are used (Table 1, entries 3 and 5). No diacylated product, bis(acetylcyclopentadienyl)iron(II), was observed under the conditions used in any of these reactions.¶ Excellent yields of acetylferrocene are obtained when the liquid clathrate, EtMeimI–$AlCl_3$–toluene, is used as the reaction medium at all ratios



**Scheme 1** EtMeimI–$AlCl_3$ or EtMeimI–$AlCl_3$/toluene mediated Friedel–Crafts acylation of ferrocene

**Table 1** Friedel–Crafts acylation of ferrocene in EtMeimI–$AlCl_3$ or EtMeimI–$AlCl_3$/toluene

| Entry | Reaction medium | Mole ratio $Ac_2O : Fe(\eta\text{-}C_5H_5)_2$ | Reaction time/h | Yield (%) |
|---|---|---|---|---|
| 1 | EtMeimI –$AlCl_3$ | 3 : 1 | 2 | 72 |
| 2 | | 2 : 1 | 2 | 62 |
| 3 | | | 4 | 84 |
| 4 | | 1 : 1 | 2 | 31 |
| 5 | | | 4 | 71 |
| 6 | | 2 : 1 | 2 | 0[a] |
| 7 | EtMeimI –$AlCl_3$/toluene | 6.6 : 1 | 2 | 90 |
| 8 | | 3 : 1 | 2 | 96 |
| 9 | | 2 : 1 | 2 | 90 |
| 10 | | 1 : 1 | 2 | 80 |

[a] Reaction performed in neutral melt containing 1 : 1 ratio of EtMeimI–$AlCl_3$.

$\geqslant 1:1$ of acetic anhydride : ferrocene (Table 1, entries 7–10). It is significant that no acetylated toluene is observed in these reactions even when acetic anhydride is in excess. It is likely that this observation is related to the enhanced reactivity of ferrocene with respect to toluene ($k_{\text{ferrocene}}/k_{\text{toluene}} \approx 10^6$).[11] The improved yields obtained when performing the acylation reaction in the liquid clathrate have been attributed to better solubility of the ferrocene in the clathrate. An identical amount of ferrocene was observed to dissolve instantly in an equal volume of the clathrate when compared to EtMeimI–AlCl$_3$ alone in which it took several minutes for the ferrocene to dissolve into a homogeneous solution.

The work-up employed in these reactions involved quenching the reaction using deionized water followed by extraction of products with toluene, concentration of the combined extracts *in vacuo*, and purification by silica column chromatography using a 10 : 1 hexanes–ethyl acetate as eluent. Consequently, the reaction medium was destroyed in the presence of a proton source and could not be recycled. Experiments are under way that will enable isolation of reaction products without exposing the reaction medium to a protic source; hence, the Lewis acidity and ionic integrity of the media will be maintained. This will enable the ionic liquid or liquid chathrate to be recycled and re-used in two or more subsequent acylation reactions. $^{1}$H and $^{13}$C NMR spectral data obtained for acetylcyclopentadienyl(cyclopentadienyl)iron(II) agreed with literature values.[12]

In conclusion, it has been shown that Friedel–Crafts acylation of an organometallic compound, namely ferrocene, can be conducted in the molten salt EtMeimI–AlCl$_3$ or in the liquid clathrate formed when excess toluene is added to EtMeimI–AlCl$_3$. Several physical properties of these uncommon reaction media have contributed to the facility at which these reactions can take place. These properties include high solubility of the organometallic reactants and other organic compounds,[5] a 'built-in' Lewis catalyst, and potential to recycle the solvent. Investigations of the addition reactions of other metallocenes as well as other organometallic reactions (*i.e.* nucleophilic additions of alkyllithiums to carbonyl compounds) in ionic liquid reaction media are currently under way.

We thank the Natural Sciences and Engineering Research Council of Canada, the Petroleum Research Fund administered by the American Chemical Society and Saint Mary's University for support of this research.

## Footnotes

† Aluminium trichloride utilized in these experiments was used directly from the bottle obtained from commercial sources (Aldrich Chemical Company) and was not purified prior to use. Hence, the possibility that some impurity in the aluminium trichloride is responsible for catalysing these reactions cannot be omitted. However, use of commercially available aluminium trichloride renders our procedure more synthetically useful.

‡ Addition of < 1 equiv. of AlCl$_3$ results in a basic melt, 1 equiv. of AlCl$_3$ a neutral melt, and > 1 equiv. of AlCl$_3$ an acidic melt.[6]

§ The light red colour of the clathrate may be due to the presence of aluminium oxide complexes and proton impurities arising through degradation of the ionic liquid by adventitious moisture. Any adventitious oxygen may also result in the formation of oxide impurities or triiodide, affording a light red colour. The exact cause of the colour and the potential implications in these reactions is under investigation; ref. 10.

¶ Some diacylated product, bis(acetylcyclopentadienyl)iron(II), was isolated when the reactions were allowed to run for > 18 h. For example, reaction of a 2 : 1 ratio of $Ac_2O : Fe(\eta\text{-}C_5H_5)_2$ at 0 °C for 18 h resulted in the isolation of 34% bis(acetylcyclopentadienyl)iron(II) and 25% of acetylcyclopentadienyl(cyclopentadienyl)iron(II), and unreacted starting material.

## References

1 V. R. Koch, L. L. Miller and R. A. Osteryoung, *J. Am. Chem. Soc.*, 1976, **98**, 5277.
2 R. M. Pagni, *Advances in Molten Salt Chemistry*, ed. G. Mamantov, C. B. Mamantov and J. Braunstein, Elsevier, Netherlands, 1987, vol. 6, p. 211 and references therein.
3 J. A. Boon, J. A. Levisky, J. L. Pflug and J. S. Wilkes, *J. Org. Chem.*, 1986, **51**, 480.
4 A. A. Fannin, A. F. Danilo, A. K. Lowell, J. S. Landers, B. J. Piersma, D. J. Stech, R. L. Vaughn, J. S. Wilkes and J. L. Williams, *J. Phys. Chem.*, 1984, **88**, 2614.
5 J. S. Wilkes, J. A. Levisky, R. A. Wilson and C. L. Hussey, *Inorg. Chem.*, 1982, **21**, 1263.
6 T. Matsumoto and K. J. Ichikawa, *J. Am. Chem. Soc.*, 1984, **106**, 4316; J. S. Wilkes, J. S. Frye and G. F. Reynolds, *Inorg. Chem.*, 1983, **23**, 3870; S. Takahashi, N. Koura, M. Murase and H. Ohno, *J. Chem. Soc., Faraday Trans. 2*, 1986, **82**, 49.
7 Y. Chauvin, B. Gilbert and I. Guibard, *J. Chem. Soc., Chem. Commun.*, 1990, 1715.
8 R. T. Carlin and J. S. Wilkes, *J. Mol. Catal.*, 1990, **63**, 125.
9 J. L. Atwood, *Recent Developments in Separation Science—Liquid Clathrates*, ed. N. N. Li, CRC Press, Ohio, 1977, vol. 3, part B, p. 195.
10 C. L. Hussey, *Pure Appl. Chem.*, 1988, **60**, 1763 and references therein.
11 F. A. Cotton and G. Wilkinson, *Advanced Inorganic Chemistry*, 5th edn., Wiley-Interscience, New York, 1988, p. 1176.
12 B. S. Furniss, A. J. Hannaford, P. W. G. Smith, A. R. Tatchell, *Vogel's Textbook of Practical Organic Chemistry*, 5th edn., Longman Scientific and Technical, Essex, England, 1989, p. 1014.

*Received, 27th June 1996; Com. 6/04502B*