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Thermal stability of ionic liquid $BMI(BF_4)$ in the presence of nucleophiles

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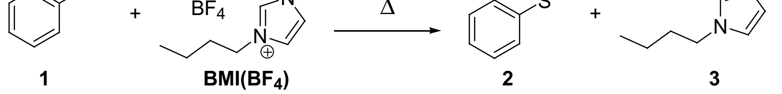
Abstract—We have found that a common ionic liquid—one containing a *N*-*N*′-dialkylimidazolium cation—decomposes in the presence of nucleophiles at much lower temperatures than previously believed. The decomposition occurs through S_N2 attack of the nucleophile on the electrophilic alkyl groups attached to the imidazolium ring.

Room temperature ionic liquids (RTILs) have been increasingly studied as environmentally benign, or 'green', solvents.[1] Due to their very low vapor pressures and limited miscibility with water and organic solvents, these liquids are, conceivably, completely recyclable. The most common RTILs are made up of a dialkylimidazolium cation and a bulky, hydrophobic anion. These solvents are relatively inert and tolerate a variety of chemistries, as demonstrated by the large number of reactions that have been carried out in ionic solution.[2] Ionic liquids are generally very good solvents for nucleophilic substitution reactions.[3] Additionally, because the salts have a strongly polar nature, they are effective as solvents and co-solvents for reactions carried out under microwave heating.[4] Microwaves have been used to great effect in a variety of reactions in ionic liquids, including nucleophilic substitution reactions.[5]

The decomposition at high temperature of *N*,*N*′-dialkylimidazolium halides by nucleophilic attack of the halide on the electrophilic alkyl groups has been documented.[6] A recent report suggested ionic liquids composed of imide anions may undergo alkyl transfer from the cation to the anion via nucleophilic displacement as one of several thermal decomposition pathways.[7]

While studying another process using thiophenol (**1**) in $BMI(BF_4)$ (1-butyl-3-methylimidazolium tetrafluoroborate) solvent at high temperature (>200 °C), we observed the formation of thioanisole (**2**) and *n*-butyl phenyl sulfide with both microwave and conventional heating (Scheme 1). The only possible source of these products was nucleophilic attack by the thiophenol on the methyl or butyl groups of the BMI cation. Because this result could have a significant impact on use of ionic liquids in microwave and/or high temperature applications or as reaction media for nucleophilic substitution (or addition) reactions, we studied the reaction of $BMI(BF_4)$ with various nucleophiles. We found that in some cases,



Scheme 1.

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Table 1. Reaction of nucleophiles with BMI(BF_4) under microwave heating[a]

Entry	Temp (°C)/power (W)	Nuc	Nuc–Me	Nuc–Bu	Total substitution yield
1	225/20	PhSH	5%	1%	6%
2	225/20	NaSPh	39%	7%	46%
3	200/20		29%	4%	33%
4	175/20		30%	4%	34%
5	150/20		21%	2%	23%
6	125/20		16%	1%	17%
7	225/20	$PhCO_2Na$	27%	13%	40% (32%)
8	225/15		17%	6%	23%
9	200/15		15%	4%	19%
10	175/20		2%	Trace	2%
11	225/20	$PhNH_2$	4%	1%	6%[b]
12	225/20	PhONa	2%	Trace	2%

Yields were determined by GC and an internal standard (isolated yield in parentheses).

[a] $BMIBF_4$ (1 mL) and the desired nucleophile (0.7–1.0 mmol) were placed in a microwave reaction tube and sealed under Ar. The reaction was heated in a CEM Discover® Labmate™ microwave (with stirring) at 15–20 W for 10 min. The reaction was diluted with 3 mL DI H_2O, extracted with 3 × 2 mL Et_2O and the Et_2O extracts washed with DI H_2O and dried ($MgSO_4$). Mesitylene was added as an internal standard and the reaction analyzed by GC–MS. Products were identified in most cases by comparison of the MS of authentic samples.

[b] In addition to methylation and butylation of aniline, some dimethylaniline was observed.

significant quantities of substitution products were observed, even at temperatures as low as 125 °C. Our results are described below and tabulated in Table 1.

Reaction yields were determined by GC versus an internal standard (and by isolated yield in certain cases). Using this technique, the yield of thioanisole when thiophenol was heated to 225 °C in neat BMI(BF_4) for 10 min in a microwave was 6%. Butyl phenyl sulfide (1%) was also detected. The reaction darkened considerably, which did not occur in the absence of thiophenol. When the more reactive sodium thiophenolate was used as the nucleophile, combined yields of substitution products (thioanisole and butyl phenyl sulfide) increased to nearly 50%. In fact, some nucleophilic substitution occurred on the butyl chain with each nucleophile studied.

As expected, yields of substitution products decreased with decreasing temperature. Sodium thiophenolate gave significant product at temperatures as low as 125 °C. Sodium benzoate gave both methyl and butyl benzoates in 40% combined yield (32% isolated yield) at 225 °C and 17% combined yield at 200 °C. Aniline and sodium phenoxide were significantly less reactive. Aniline gave a combination of nucleophilic substitution products in 6% combined yields at 225 °C. Under the same conditions, sodium phenoxide only gave 2–3% yields of the substitution products. All of the results in Table 1 were obtained using microwave heating. Reactions carried out using conventional heating techniques gave similar results, but required much longer reaction times (3 h vs 10 min).

N-Butylimidazole was detected in each reaction in which significant substitution occurred. It proved difficult to accurately measure yields of this compound as it tended to remain in the ionic liquid layer upon extraction. Substitution also occurred in reactions run in 1-butyl-3-ethylimidazolium tetrafluoroborate, with attack on the electrophilic ethyl group accounting for most of the substitution product.

The relative reactivity of the BMI cation versus more conventional electrophiles was also examined (Table 2). Our results suggest that the reaction of BMI^+ as an electrophile is competitive with that of a typical alkyl halide. The reaction of sodium thiophenoxide with dodecyl bromide in BMI(BF_4) at 200 °C gave a 25% yield of the combined methyl and butyl substitution products and a 20% yield of dodecyl phenyl sulfide. Under the reaction conditions, the molar ratio of BMI(BF_4) to dodecyl bromide was 4:1. Therefore, the BMI(BF_4) reacted at approximately one third the rate of the bromide. When decyl chloride was included in the reaction at the same molar ratio, a 34% combined yield of methyl and butyl sulfides was obtained, along with a 19% yield of decyl phenyl sulfide. This result showed that BMI(BF_4) reacted with thiophenolate at about half the rate of decyl chloride.

The results obtained in our study indicated that *N*-*N*′-dialkylimidazolium cations, common in many ionic liquids, were reactive with nucleophiles. The substitution reaction of BMI(BF_4) is especially facile when microwave heating is used. While yields tended to be moderate

Table 2. Reaction of sodium thiophenoxide with alkyl halides in BMI(BF_4) at 200 °C

Entry	Alkyl halide	PhSMe	PhSBu	PhS–alkyl	BMI/electrophile[a]
1	n-$C_{12}H_{25}Br$	21%	4%	20%	1.25/1
2	n-$C_{10}H_{21}Cl$	30%	4%	19%	1.8/1

[a] This is the ratio of substitution products obtained from BMI^+ to those obtained from the alkyl halide.

to low, depending on the nucleophile, this reactivity could interfere with recycling of ionic liquids—a point that is repeatedly emphasized as these solvents are increasingly utilized. RTILs are very efficient absorbers of microwave energy, and as such have been suggested as excellent solvents for microwave reactions, as well as co-solvents to aid in the microwave heating of less microwave-absorbent solvents.[4,5] In addition, ionic liquids have been proposed for a variety of high temperature applications.[7,8] Our results suggest that the thermal stability of imidazolium based ionic liquids will be significantly reduced in the presence of nucleophiles. This data also implies that caution is advised when attempting nucleophilic substitution or addition reactions in ionic liquids, especially using microwave heating or for extended times at high temperature, due to the possibility of reaction of the nucleophile with the solvent.

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