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Efficient Dehydration of Aldoximes to Nitriles Catalyzed by a Lewis Acid Ionic Liquid

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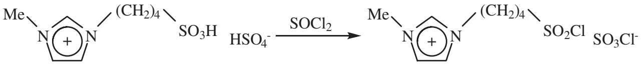
A Lewis acid ionic liquid, 1-[4-(chlorosulfonyl)butyl]-3-methylimidazolium chlorosulfate ([CBMIm]SO$_3$Cl), with Lewis acid sites in both the anion and cation was synthesized. This was demonstrated to be an efficient catalyst for dehydration of aldoximes to nitriles. An unexpected self-induced phase separation of the reaction mixture was observed when the reaction was carried out in acetonitrile. This could be attributed to the hydrolysis of [CBMIm]SO$_3$Cl to regenerate 1-(4-sulfobutyl)-3-methylimidazolium hydrogensulfate ([SBMIm]HSO$_4$), which was the Brønsted precursor of [CBMIm]SO$_3$Cl.

Acidic ionic liquids are an important subset of functional ionic liquids that have many important applications in synthetic chemistry.[1] In comparison with conventional catalysts such as AlCl$_3$, H$_2$SO$_4$, HNO$_3$, or HCl, acidic ionic liquids usually improve catalytic performance, including enhancing the reaction rate, increasing the yield, and simplifying product separation/catalyst recycling.[2]

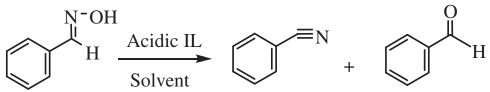
Sulfonyl chlorides are usually known as Lobe-LUMO Lewis acids. Recently, we reported the synthesis of some sulfonyl chloride-based Lewis acid ionic liquids and their use as catalysts in synthetic chemistry.[3] These Lewis acid ionic liquids had only one Lewis acid site, which was located in either the cation or the anion. As a continuation of this study, we herein report synthesis of a novel sulfonyl chloride-based ionic liquid, 1-[4-(chlorosulfonyl)butyl]-3-methylimidazolium chlorosulfate ([CBMIm]SO$_3$Cl), which features Lewis acid sites in both the cation and anion. Our primary results showed that [CBMIm]SO$_3$Cl was a very efficient catalyst for dehydration of aldoximes to nitriles. Moreover, an unexpected self-induced phase separation was observed when the dehydration reaction was carried out in acetonitrile.

[CBMIm]SO$_3$Cl was easily synthesized by reaction of the common Brønsted acid ionic liquid 1-(4-sulfobutyl)-3-methylimidazolium hydrogensulfate ([SBMIm]HSO$_4$), with SOCl$_2$ (Scheme 1). To prepare [CBMIm]SO$_3$Cl, 6 g of SOCl$_2$ was added dropwise to 10 g of [SBMIm]HSO$_4$ in a 50 mL flask in an ice water bath. Then the reaction mixture was stirred for 12 h at room temperature. After another 2 h of reaction at 80 °C, excess SOCl$_2$ was removed from the reaction mixture via vacuum distillation. The remaining yellow liquid was washed with diethyl ether three times, and dried under vacuum at room temperature. The structure of [CBMIm]SO$_3$Cl was confirmed by high-resolution mass spectrometry (HRMS), ^{1}H NMR, FT-IR, and element analysis (see Supporting Information; SI[8]).



Scheme 1. Synthesis of [CBMIm]SO$_3$Cl from [SBMIm]HSO$_4$.

Table 1. Catalytic conversion of benzaldehyde oxime in the presence of acidic ionic liquids[a]



Run	Solvent	Temp /°C	[SBMIm]HSO$_4$		[CBMIm]SO$_3$Cl	
			Conv. /%	Sel.[b] /%	Conv. /%	Sel.[b] /%
1	Toulene	80	7	51	91	81
2	THF	80	10	77	42	95
3	Acetonitrile	80	26	82	79	94
4	Acetonitrile	100	48	90	99	97

[a]Reaction conditions: ionic liquid, 0.57 mmol; solvent, 3 g; oxime, 2.85 mmol; reaction time, 1 h. [b]Selectivity of benzonitrile.

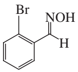
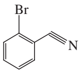
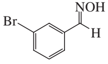
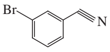
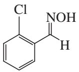
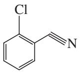
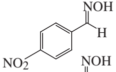
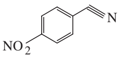
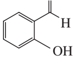
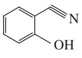
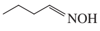
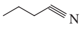
Dehydration of aldoximes to nitriles is an important reaction in synthetic chemistry. A variety of catalysts, such as diethyl chlorophosphate, palladium, chlorosulfonic acid, and chloral, have been applied to this reaction.[4] However, only a few examples of ionic liquid-based catalysts have been reported.[5] Therefore, we investigated the catalytic activity of [CBMIm]SO$_3$Cl in dehydration of aldoximes. Benzaldehyde oxime was used as the probe substrate in these experiments. For comparison, the catalytic activity of [SBMIm]HSO$_4$ was also examined, and the results are summarized in Table 1.[6]

Benzaldehyde oxime in an acidic medium commonly reacts via three different pathways, including dehydration to benzonitrile, hydrolysis to benzaldehyde, or the Beckmann rearrangement to benzamide.[7] Only benzonitrile and benzaldehyde were detected as products when benzaldehyde oxime was treated with the acidic ionic liquids [CBMIm]SO$_3$Cl and [SBMIm]HSO$_4$ in different solvents, including toluene, THF, and acetonitrile. Benzamide, the product of the Beckmann rearrangement of benzaldehyde oxime, was not detected in our experiments.

The results showed dehydration of benzaldehyde oxime to benzonitrile depended largely on the catalyst, solvent, and reaction temperature. The Lewis acid [CBMIm]SO$_3$Cl provided better catalysis of the reaction than the Brønsted acid [SBMIm]HSO$_4$ in terms of both conversion and selectivity when the reaction was carried out under the same reaction conditions. This enhanced catalytic activity was apparent in all the different solvents tested (Runs 1–4). Increasing the reaction temperature from 80 (Run 3) to 100 °C (Run 4) also enhanced the catalytic activity.

The solvent, especially acetonitrile, played an important role in this reaction. [SBMIm]HSO$_4$ was immiscible with all of the three solvents, and when it was used as the catalyst the dehydration reaction proceeded in a biphasic manner with a very

Table 2. Dehydration of aldoximes to nitriles in acetonitrile catalyzed by $[CBMIm]SO_3Cl$[a]

Run	Aldoxime	Product	Time/h	Conv./%	Sel./%
1			1.5	93	96
2			1	96	97
3			3	99	98
4			1	97	96
5			1	97	96
6			2	93	99

[a] Reaction conditions: ionic liquid, 0.57 mmol; acetonitrile, 3 g; aldoxime, 2.85 mmol; reaction temp, 100 °C.

low reaction efficiency. Although $[CBMIm]SO_3Cl$ was also immiscible with toluene and THF, it can show better catalytic performance than $[SBMIm]HSO_4$, which suggests that the Lewis acid ionic liquid is more favorable for the reaction.

In contrast to $[SBMIm]HSO_4$, $[CBMIm]SO_3Cl$ was miscible with acetonitrile, and acetonitrile/$[CBMIm]SO_3Cl$ was the most efficient catalytic system for dehydration of benzaldehyde oxime to benzonitrile (Run 4). Interestingly, an unexpected self-induced phase separation was observed when the acetonitrile/$[CBMIm]SO_3Cl$ system was used for dehydration of benzaldehyde oxime to benzonitrile (see SI[8]). The homogeneous solution of acetonitrile/$[CBMIm]SO_3Cl$/benzaldehyde oxime became biphasic after the reaction finished.

Because $[SBMIm]HSO_4$ is immiscible with acetonitrile, the biphasic reaction mixture suggested that $[CBMIm]SO_3Cl$ might be converted to $[SBMIm]HSO_4$ via hydrolysis with water, which is a by-product of the dehydration reaction. To confirm this, the lower phase of the reaction solution was separated and analyzed by HRMS. The results showed that the lower phase was a mixture of $[SBMIm]HSO_4$ (33%) and $[CBMIm]SO_3Cl$ (67%) (see SI[8]). These results indicate that $[CBMIm]SO_3Cl$ is converted to $[SBMIm]HSO_4$, and that the acetonitrile/$[CBMIm]SO_3Cl$ system can provide a simple way to separate the product and catalyst.

The acetonitrile/$[CBMIm]SO_3Cl$ system was then applied to dehydration of other aldoximes with high conversion and selectivity (Table 2). The reaction resulted in self-induced phase separation of $[CBMIm]SO_3Cl$ from acetonitrile in all the experiments.

Because $[SBMIm]HSO_4$ was used as the precursor of $[CBMIm]SO_3Cl$, the lower phase could be converted into pure $[CBMIm]SO_3Cl$ again by reacting the lower phase with $SOCl_2$. Our primary results showed that about 96% $[CBMIm]SO_3Cl$ can be recovered (see SI[8]). Then the regenerated $[CBMIm]SO_3Cl$ was reused for dehydration of benzaldehyde oxime to benzonitrile. The catalytic activity for the regenerated $[CBMIm]SO_3Cl$ was almost the same as that for the original catalyst, offering 97% conversion of benzaldehyde and 97% selectivity for benzonitrile. The self-induced phase separation was also observed. These results suggest that the acetonitrile/$[CBMIm]SO_3Cl$ system can be used as a recyclable catalytic system for dehydration of aldoximes to nitriles with high catalytic performance and simple product separation.

In conclusion, we synthesized a novel ionic liquid, $[CBMIm]SO_3Cl$, that had Lewis acid sites in both its cation and anion. This ionic liquid was an efficient catalyst for dehydration of aldoximes to nitriles, and had higher catalytic activity than its Brønsted acid precursor. Moreover, the acetonitrile/$[CBMIm]SO_3Cl$ system resulted in self-induced phase separation of the reaction mixture after dehydration of aldoximes to nitriles. We believe this will lead to further applications in acid-catalyzed dehydration reactions, and additional studies are underway.

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References and Notes

1 For the latest review on ionic liquids, see: H. Olivier-Bourbigou, L. Magna, D. Morvan, *Appl. Catal., A* **2010**, *373*, 1, and references cited therein.

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6 The typical experimental procedure for dehydration of aldoximes to nitriles in the presence of acidic ionic liquid was as follows: aldoxime (2.85 mmol), solvent (3.0 g), and ionic liquid (20% equiv) were placed in a 10 mL glass test tube. Then the reaction was allowed to proceed at 100 °C for the desired time. After the reaction was finished, the upper phase was analyzed by a gas chromatograph (Shimadzu GC-2014) equipped with a flame ionization detector and an ULBON HR-52 capillary column (25 m × 0.32 mm i.d., Shinwa Chemical Industries Ltd., Japan). Toluene was used as an internal standard.

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8 Supporting Information is available electronically on the CSJ-Journal Web site, http://www.csj.jp/journals/chem-lett/index.html.