The synthesis of quaternary ammonium salts from ammonium salts and dialkyl carbonate†

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Quaternary ammonium salts were synthesized from ammonium salts and dialkyl carbonates over an ionic liquid catalyst 1-ethyl-3-methylimidazolium bromide.

Quaternary ammonium salts are widely used as surfactants,[1] phase-transfer catalysts,[2] templates,[3,4] molecular probes, and ionic channel blockers.[5] Considerable efforts have already been devoted to studies in the synthesis, structure, and thermal stability of these compounds. Quaternary ammonium salts were conventionally synthesized by reacting amines or amides with alkyl halides. Wang *et al.*[6,7] reported a facile method to synthesize quaternary ammonium salts by the direct reaction of tertiary amines with alcohols over acidic zeolites, such as H–Y and H-ZSM-5. In most of the circumstances, quaternary ammonium salts, such as quaternary ammonium fluoride, nitrate, and carbonate, cannot be directly synthesized *via* the methods mentioned. In these cases, an anion-exchange procedure is necessary.[8] It would be desirable to have a method, by which, a variety of quaternary ammonium salts with different anions could be directly synthesized *via* a one-step reaction.

Ionic liquids or room temperature molten salts have attracted the increasing attention of chemists because of their potential applications in chemical reactions as solvents and/or catalysts.[9,10] 1-Ethyl-3-methylimidazolium bromide (EMImBr), which can be readily prepared from 1-methylimidazole and ethyl bromide, has found applications as alternative reaction media and/or catalysts for organic reactions. Hence, in the current study, we explored the possibility of using EMImBr as a catalyst in quaternary ammonium salt synthesis from ammonium salts and dialkyl carbonates.

EMImBr was prepared according to the procedures described in the literature.[11,12] In a typical reaction, the ammonium salt (2.0 mmol), dimethyl carbonate (8.0 mmol), and EMImBr (0.8 mmol) were tranferred into a stainless steel autoclave (inside volume 3.0 mL), and then the reactor was heated to 443 K and kept at this temperature for 8 h to carry out the reaction. After finishing the reaction, the reactor was cooled to room temperature and opened for analysis of the sample on an NMR spectrometer (Brucker Avance 400 MHz). The calculation of the quaternary ammonium salt yield was based on the ^{1}H-NMR peak areas (see supporting information†).

Results obtained when not using a catalyst are listed in Table 1. After carrying out the reactions at 443 K for 8 h, except with NH_4NO_3 in entry 5, the ammonium salts reacted with dimethyl carbonate to yield corresponding quaternary ammonium salts. However, their yields were low (below 20%). Relatively high quaternary ammonium salt yields were obtained when ammonium fluoride or ammonium acetate reacted with ammonium carbonate.

Table 2 shows the results of reactions between ammonium salts and dialkyl carbonates over the EMImBr catalyst. Except for the reactions of ammonium carbonate with dimethyl carbonate, ammonium oxalate with dimethyl carbonate, and ammonium salts with diethyl carbonate, quaternary ammonium salt yields above 80.0% were obtained. Compared to the cases without the EMImBr catalyst (Table 1), we have obtained higher quaternary ammonium salt yields. In the reactions, carbamates were also formed as by products, which were the target products reported by Deng *et al.* in their reaction.[13] There might also be quaternary ammonium salts formed in their reaction (since they started with amines not ammonium salts, the quaternary ammonium yield might be low), which were not detected in their GC analysis (GC-MS is not the right tool for quaternary ammonium salts analysis). Our investigation has also demonstrated that EMImCl, EMImI, $EMImCH_3CO_2$, and $EMImNO_3$ are also efficient catalysts. Because of the space limit of a communication, that research work will be reported later.

Our study shows that the quaternary ammonium salt yield depends on both the ammonium salt and the alkyl group on dialkyl carbonates. When dimethyl carbonate reacted with different ammonium salts, the quaternary ammonium salt yield decreases according to the order of $Br^- \sim NO_3^- \sim Cl^- > F^- > SO_4^{2-} > C_2O_4^{2-} \sim CO_3^{2-} \sim OAc^-$. For the same ammonium

Table 1 Results obtained by directly reacting the dialkyl carbonate with ammonium salts[a]

Entry	Ammonium salt	Dialkyl carbonate	*Y* (%)
1	NH_4F	Dimethylcarbonate	21.6
2	NH_4Cl	Dimethylcarbonate	3.6
3	NH_4Br	Dimethylcarbonate	0.4
4	NH_4OAc	Dimethylcarbonate	15.4
5	NH_4NO_3	Dimethylcarbonate	0
6	$(NH_4)_2CO_3$	Dimethylcarbonate	17.4
7	$(NH_4)_2SO_4$	Dimethylcarbonate	0.4
8	$(NH_4)_2C_2O_4$	Dimethylcarbonate	1.5

[a] *Y* is the yield of product. The molar ratio of ammonium ion to dialkyl carbonate is 1 : 4.

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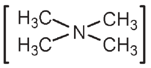
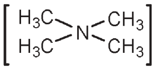
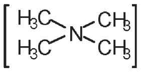
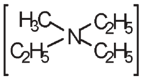
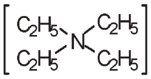
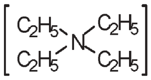
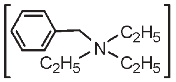
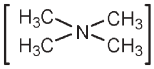
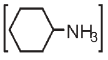
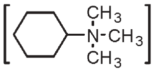
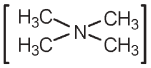
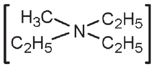
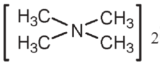
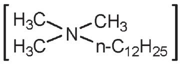
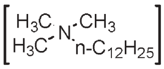
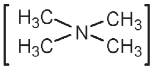
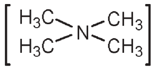
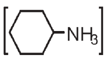
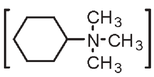
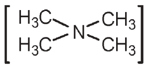
Table 2 Quaternary ammonium salts synthesized over the EMImBr catalyst[a]

Entry	AM	DAC	Product	*Y* (%)
1	NH_4F	DMC	 F	82.3
2	NH_4Cl	DMC	 Cl	96.0
3	$[(CH_3)_3HN]Cl$	DMC	 Cl	99.0
4	$[(CH_2CH_3)_3HN]Cl$	DMC	 Cl	>99.0
5	NH_4Cl	DEC	 Cl	0
6	$(CH_2CH_3)_3HNCl$	DEC	 Cl	54.0
7	$(CH_2CH_3)_3HNCl$	DBC	 Cl	>99.0
8	NH_4Br	DMC	 Br	96.5
9	 Br	DMC	 Br	>99.0
10	NH_4NO_3	DMC	 NO_3	96.4
11	$[(CH_2CH_3)_3HN]NO_3$	DMC	 NO_3	98.2
12	$(NH_4)_2SO_4$	DMC	 $_2SO_4$	70.4
13	$(NH_4)_2SO_4$	DEC	$[N(C_2H_5)_4]_2SO_4$	2.9
14	$[NH_3(n\text{-}C_{12}H_{25})]_2SO_4$	DMC	 $_2SO_4$	97.3
15	$[NH_3(n\text{-}C_{12}H_{25})]_3PO_4$	DMC	 $_3PO_4$	88.7
16	$(NH_4)_2C_2O_4$	DMC	 $_2C_2O_4$	47.6
17	$NH_4CH_3CO_2$	DMC	 CH_3CO_2	44.3
18	 CH_3CO_2	DMC	 CH_3CO_2	95.7
19	$NH_4CH_3CO_2$	DEC	$[N(C_2H_5)_4]_2CH_3CO_2$	6.8
20	$(NH_4)_2CO_3$	DMC	 $_2CO_3$	44.8
21	$(NH_4)_2CO_3$	DEC	$[N(C_2H_5)_4]_2CO_3$	2.3

[a] AM-Ammonium salt, DAC-Dialkyl carbonate, *Y*-yield of product, DMC-dimethylcarbonate, DEC-diethylcarbonate, DBC-dibenzyl carbonate. In each reaction, 2.0 mmole of AM was employed. The molar ratio of hydrogen on nitrogen of ammonium ion to dialkyl carbonate is 1 : 1, and the amount of EMImBr is 10.0 mol% based on that of dialkyl carbonate.

salt anion, dimethyl carbonate is a much better alkylation reagent than diethyl carbonate. Only trace or small amounts of quaternary ammonium salts could be obtained in diethyl carbonate cases. However, dibenzyl carbonates are a good alkylation reagent, which is as good as dimethyl carbonates. Our investigations have also shown that if there is(are) electron donor group(s) on the nitrogen atom of the reactant ammonium salt, the quaternary ammonium salt yields were higher than those when the NH_4^+ salt was used (Table 2 Entries: 2, 3, and 4; 5 and 6; 8 and 9; 12 and 14; 17 and 18).

Apparently, the reaction occured through the electrophilic attack of the alkyl group from the dialkyl carbonate on the nitrogen of the reactant ammonium. In such a reaction mechanism, electron donor group(s) on the nitrogen atom and electron withdrawing group(s), such as benzyl carbonate, on the methylene carbon of the dialkyl carbonate will favour the alkylation reaction, which is what can be found in Table 2. The detailed role of the catalyst EMImBr in the reaction is still not known yet. Work on this aspect is still in progress.

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