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Synthesis of isocyanates from carbamate esters employing boron trichloride

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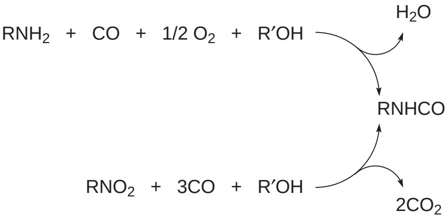
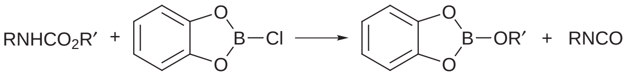
The conversion of carbamate esters to isocyanates and diisocyanates of industrial importance is possible using BCl_3 in the presence of Et_3N; the reaction is simple in execution and work-up, occurring under mild conditions and affording isocyanates in excellent yields.

Presently, isocyanates are manufactured on a commercial scale by reaction of phosgene with amine or amine salt precursors.[1] As restrictions upon the use of very toxic materials such as phosgene and other chlorine-containing compounds within the chemical industry have become more rigorously enforced, there has been increasing interest in developing alternative methods for isocyanate production.[2] One such method (Scheme 1) involves the catalytic production of carbamate esters (by reductive carbonylation of nitro derived compounds,[3] or oxidative carbonylation of amines[4,3b]), dealcoholysis of which gives isocyanates. One of us showed recently that elimination of alcohol from carbamate esters to yield isocyanates can be facilitated using chlorocatecholborane in toluene, in the presence of Et_3N (Scheme 2).[5] This paper demonstrated that the way in which the alcohol product is irreversibly removed from the reaction solution, in the form of an alkyl catecholborate, is pertinent to the significance of this method compared with those which employ the thermal decomposition of carbamate esters, in which recombination of the resulting isocyanate with alcohol is possible.



Scheme 1



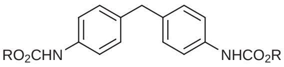
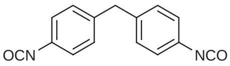
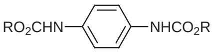
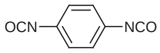
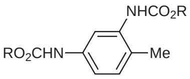
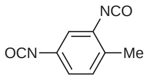
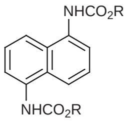
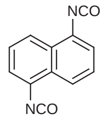
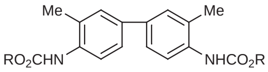
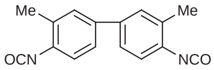
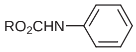
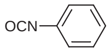
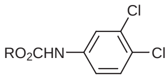
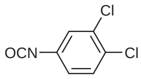
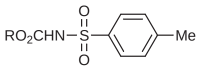
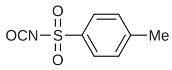
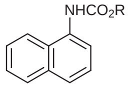
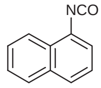
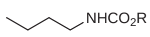
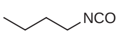
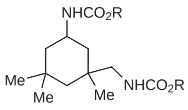
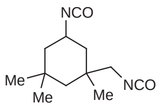
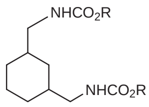
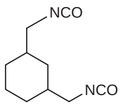
Scheme 2

Having demonstrated the use of chlorocatecholborane in this type of reaction, we reasoned that simple boron halides, BX_3 (X = Cl, Br), may also be active as cheap alternatives. Additionally, it has previously been shown that BX_3 can be generated in the production of benzyl esters by reaction of trialkyl borates with benzylic halides and CO in the presence of catalytic quantities of Pd^0 or Rh^I.[6] This offers the rather attractive option of two concomitant processes achieving commercially valuable ends together with constant recycling of boron.

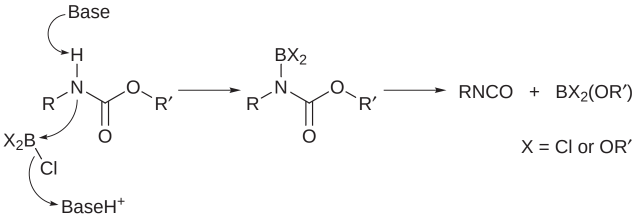
Boron trihalides are known for their strong Lewis acid character, and for their ability to cleave a wide variety of ethers, acetals and esters under relatively mild conditions.[7] In pursuit of alternative methods of isocyanate production, we now report the results of our work with BBr_3 and BCl_3 in facilitating the conversion of carbamate esters to isocyanates of industrial importance.

Treatment of a carbamate ester with 0.37 equiv. of BCl_3 and 1.1 equiv. of Et_3N, for 30 min in refluxing benzene, afforded the

Table 1 Conversions of carbamate esters to the corresponding isocyanates using BCl_3

Substrate[a]	Product[b]	R	Yield (%)[c]
		Me Et Pr	87 (72)[d] 93 88
		Me Et Pr	90 (79)[d] 100 100
		Me Et Pr	92 (70)[d] 90 94
		Me Et	98 100
		Me Et	91 100
		Me Et	93 (57)[d] 94
		Me Et	87 97
		Me Et	92 100
		Et	100
		Me Et	71 86
		Me[e] Et[e]	73 68
		Me[e] Et[e]	68 79

[a] Purities of the carbamate esters were assessed by ^1H NMR analysis and melting points. Reaction conditions: isocyanates: BCl_3 (0.37 equiv.), NEt_3 (1.1 equiv.), refluxing benzene, 0.5 h; diisocyanates: BCl_3 (0.74 equiv.), NEt_3 (2.2 equiv.), refluxing benzene, 0.5 h. [b] Product isocyanates were identified by GC–MS and GC analysis compared with authentic materials. [c] Yields by GC analysis with tetradecane as the internal calibrant. [d] Mixture of *cis* and *trans* isomers. [e] Yields of pure products isolated by vacuum distillation, characterized by ^1H NMR, ^{13}C NMR, IR and MS analysis and by comparison with authentic materials.



Scheme 3

isocyanate in good yield. In most cases, quantitative or near-quantitative conversion to the product isocyanates was obtained under these relatively mild reaction conditions for a series of aryl, alkyl, alicyclic and tosyl carbamate esters. The reactions were found to be highly selective with only the product isocyanates, partially cleaved carbamate esters (where dicarbamate esters were employed as starting materials), or starting materials being observed in the final solutions. The product isocyanates can usually be easily isolated by evaporation of the solvent and trialkyl borate under reduced pressure followed by vacuum distillation at elevated temperature. For example, toluene-2,4-diyl diisocyanate (TDI), *para*-phenylene diisocyanate (PDI) and 4,4′-methylenebis(phenyl isocyanate) (MDI), which are large-scale raw materials for the manufacture of polyurethane foams,[8] can be isolated as spectroscopically pure materials from their corresponding methyl carbamate esters in 70–79% yield. Toluene-2,4-diyl diisocyanate can also be isolated in good yield from its methyl carbamate ester when the reaction is performed in toluene (65% isolated yield) or hexanes (41% isolated yield). Chlorinated solvents, however, are not suitable media for this reaction. As expected, BCl_3 is converted to trialkyl borate (identifiable by GC–MS), observed after the reaction, consistent with the reaction shown in Scheme 3.

BBr_3, a stronger Lewis acid than BCl_3, was also effective in this reaction, with isocyanate yields being similar to those quoted for BCl_3 in Table 1. However, appreciable amounts of amine were also produced in some cases bringing the selectivity of this reagent into question.

It has previously been shown that PCl_3, and other Lewis acids, can effect the removal of OH from carbamate anions to yield isocyanates by electrophilic, *oxophilic* dehydration.[9] However, we found that PCl_3, when used instead of BCl_3, is capable of less than *ca*. 5% conversion of carbamate esters to isocyanates. Similar yields were attained with $AlCl_3$, and $TiCl_4$ was found to be totally inactive. It is conceivable that PCl_3 can react as an electrophile at nitrogen in this case, and a possible reason for its overall inactivity is the inability to promote cleavage of an alkoxy group from the resulting intermediate.

In conclusion, BCl_3 is an excellent, efficient and economical reagent for the synthesis of mono- and di-isocyantes in high yield.

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Notes and references

1 P. Braunstein, *Chem. Rev.*, 1989, **89**, 1927; G. Ortel, *Polyurethane Handbook*, Hanser, Munich, 1985; H. Twichett, *Chem. Rev.*, 1974, **74**, 209.

2 Kirk-Othmer, *Encyclopaedia of Chemical Technology*, 4th edn., Wiley, New York, 1995, vol. 14, p. 902.

3 (*a*) S. J. Skoog and W. L. Gladfelter, *J. Am. Chem. Soc.*, 1997, **119**, 11 049; (*b*) A. M. Tafesh and J. Weiguny, *Chem. Rev.*, 1996, **96**, 2035; (*c*) P. Wehman, P. C. J. Kamer and P. W. N. M. van Leeuwen, *Chem. Commun.*, 1996, 217; (*d*) I. Pri-Bar and J. Schwartz, *J. Org. Chem.*, 1995, **60**, 8124; (*e*) V. L. K. Valli and H. Alper, *J. Am. Chem. Soc.*, 1993, **115**, 3778 and references cited therein.

4 V. L. K. Valli and H. Alper, *Organometallics*, 1995, **14**. 80; T. W. Leung and B. D. Dombek, *J. Chem. Soc.*, *Chem. Commun.*, 1992, 205; S. Cenini, M. Pizzotti and C. Crotti, in *Aspects of Homogeneous Catalysis*, ed. R. Ugo, Reidel, Dordrecht, The Netherlands, 1988, vol. 6, p. 97 and references cited therein.

5 V. L. K. Valli and H. Alper,. *J. Org. Chem.*, 1995, **60**, 257.

6 H. Alper, H. Hamel, D. J. H. Smith and J. B. Woell, *Tetrahedron Lett.*, 1985, **26**, 2273; K. E. Hashem, J. B. Woell and H. Alper, *Tetrahedron Lett.*, 1984, **25**, 4879; J. B. Woell and H. Alper, *Tetrahedron Lett.*, 1984, **25**, 3791.

7 L. A. Paquette, *Encyclopaedia of Reactants for Organic Synthesis*, Wiley, Chichester, 1995, p 645.

8 Kirk-Othmer, *Encyclopaedia of Chemical Technology*, 4th edn., Wiley, New York, 1997, vol. 24, p. 695.

9 D. Riley, W. D. McGhee and T. Waldman, *ACS Symp. Ser.*, 1994, **577**, 122.

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