CHEMCOMM
Communication
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Catalytic C–O bond cleavage of ethers using group 5 or 6 metal halide/acid chloride systems

Qiaoxia Guo, Taichi Miyaji, Guohua Gao, Ryuichiro Hara and Tamotsu Takahashi*

Catalysis Research Center and Graduate School of Pharmaceutical Science, Hokkaido University and CREST, Science and Technology Corporation (JST), Kita-Ku, Sapporo 060-0811, Japan.
E-mail: tamotsu@cat.hokudai.ac.jp

Received (in Cambridge, UK) 24th January 2001, Accepted 19th April 2001
First published as an Advance Article on the web 15th May 2001

Ethers reacted with acid chlorides in the presence of a catalytic amount of $MCl_{5/6}$ (M = Mo, W, Nb or Ta) to give esters in 75–98% yield; a stoichiometric reaction of dioctyl ether with $MoCl_5$ afforded 1-chlorooctane in 93% yield and addition of benzoyl chloride to the resulting mixture gave octyl benzoate in 49% yield.

C–O bond cleavage is a versatile reaction in organic synthesis; in particular, the catalytic cleavage of the C–O bond of ethers is very attractive.[1] There are several examples of catalytic C–O bond cleavage of ethers in the presence of acid chlorides and Lewis acids such as $ZnCl_2$,[2] $FeCl_3$,[3] $SnBr_2$,[4] $CoCl_2$,[5] $AlCl_3$,[6] YCl_3,[7] $LnCl_3$,[8] Al[9] and Zn.[10] As for group 6 metal compounds, low-valent molybdenum compounds such as $Mo(CO)_6$[11] and $ArMo(CO)_3$[12] have been used as catalysts for acylative cleavage of ethers. It is generally believed that these catalytic reactions proceed *via* a cationic mechanism in which the acid chloride reacts with the catalyst first to generate a RCO^+ ion. Addition of an ether gives an oxonium salt ($RCO_2{}^+R'_2$) followed by cleavage of the C–O bond to give an ester. Here, we report a novel catalytic system for acylative cleavage of ethers [eqn. (1)] using group 5 or 6 metal halides and propose a novel catalytic reaction mechanism.

$$R^1OR^2 + R^3COCl \xrightarrow{\text{cat. } MCl_{5/6}} R^3CO_2R^1 \qquad (1)$$

M = Mo, W, Nb or Ta

A representative procedure for the catalytic C–O bond cleavage is as follows: All reactions were carried out under nitrogen and metal chlorides were handled under nitrogen. Solvents were dried and distilled. To a mixture of molybdenum(v)chloride (0.1 mmol, 27 mg) and dichloroethane (DCE) (5 ml) was added dibutyl ether (1 mmol, 130 mg) and benzoyl chloride (1 mmol, 141 mg). The reaction mixture was stirred at 80 °C for 3 h. GC analysis of the resulting mixture after hydrolysis showed the formation of butyl benzoate in 95% yield. Purification by column chromatography on silica gel afforded butyl benzoate in 75% isolated yield. The results are summarized in Table 1.

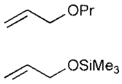
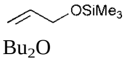
The C–O bond of dibutyl ether was cleaved in the presence of 10 mol% of $MoCl_5$ and *n*-caproyl chlorides at 80 °C for 24 h and the caproic acid *n*-butyl ester was obtained in 96% yield (Run 2). The lower reactivity of aliphatic acid chlorides than that of aromatic acid chlorides has been reported in the case of graphite.[13] In the reaction reported here, there is no significant reactivity difference between the aromatic acid chloride and the aliphatic acid chloride. Dioctyl ether also reacted with benzoyl chloride and *n*-caproyl chloride to give octyl benzoate and *n*-caproyl acid *n*-octyl ester, respectively, in high yield (Runs 3 and 4). It is interesting to note that some unsymmetric ethers showed selective cleavage of the C–O bond. For example, methyl *tert*-butyl ether reacted with benzoyl chloride to give methyl benzoate in 99% yield (Run 5) *i.e.* the Bu^t–O bond in methyl *tert*-butyl ether was selectively cleaved. Allyl propyl ether was also selectively cleaved under the same conditions. The allyl–O bond was cleaved to give caproyl acid propyl ester (Run 6). In contrast, for allyl trimethylsilyl ether, selective cleavage of the Si–O bond was observed (Run 7) and the allyl–O bond was not cleaved. Other group 5 and 6 metal chlorides were also quite active for acylative cleavage of ethers. Dibutyl ether reacted with benzoyl chloride in the presence of 10 mol% of WCl_6 for 24 h to give butyl benzoate in 96% yield (Run 8). When $NbCl_5$ and $TaCl_5$ were used as catalysts, catalytic C–O bond cleavage was also successful and butyl benzoate was obtained in 98 and 96% yield, respectively (Runs 9 and 10).

In order to investigate the reaction mechanism, a stoichiometric reaction of dioctyl ether with molybdenum(v) chloride was carried out at 80 °C. After 3 h, 1-chlorooctane was obtained in 93% yield [eqn. (2)]. To the resulting mixture, benzoyl chloride was added and octyl benzoate was obtained in 49% yield [eqn. (3)].

$$C_8H_{17}OC_8H_{17} + MoCl_5 \xrightarrow[80\ ^\circ C,\ 3\ h]{DCE,} \underset{93\%}{C_8H_{17}Cl} + \underset{\text{reaction mixture}}{[C_8H_{17}OMoCl_n]} \qquad (2)$$

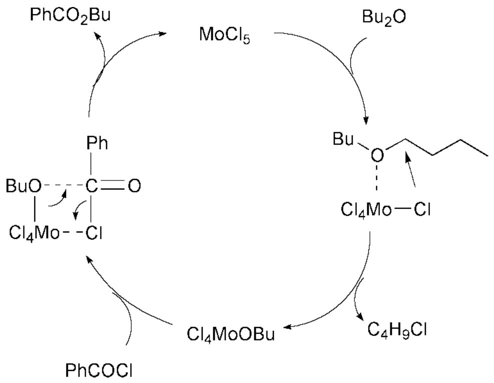
$$\underset{\text{reaction mixture}}{[C_8H_{17}OMoCl_n]} \xrightarrow[80\ ^\circ C,\ 3\ h]{PhCOCl} \underset{49\%}{PhCO_2C_8H_{17}} \qquad (3)$$

Table 1 Acylative cleavage of ethers with acid chlorides in the presence of $MCl_{5/6}$[a]

Run	Ether	RCOCl	$MCl_{5/6}$	Time/h	Product	Yield[b] (%)
1	Bu_2O	PhCOCl	$MoCl_5$	3	$PhCO_2Bu$	95(75)
2	Bu_2O	$C_5H_{11}COCl$	$MoCl_5$	24	$C_5H_{11}CO_2Bu$	96(78)
3	$C_8H_{17}OC_8H_{17}$	PhCOCl	$MoCl_5$	1	$PhCO_2C_8H_{17}$	88(78)
4	$C_8H_{17}OC_8H_{17}$	$C_5H_{11}COCl$	$MoCl_5$	3	$C_5H_{11}CO_2C_8H_{17}$	94(82)
5	$CH_3OC(CH_3)_3$	PhCOCl	$MoCl_5$	1[c]	$PhCO_2CH_3$	99(76)
6	 OPr	$C_5H_{11}COCl$	$MoCl_5$	1	$C_5H_{11}CO_2C_3H_7$	98(81)
7	 OSiMe3	$C_5H_{11}COCl$	$MoCl_5$	3	$C_5H_{11}CO_2CH_2CH{=}CH_2$	75(58)
8	Bu_2O	PhCOCl	WCl_6	3	$PhCO_2Bu$	96
9	Bu_2O	PhCOCl	$NbCl_5$	24	$PhCO_2Bu$	98
10	Bu_2O	PhCOCl	$TaCl_5$	6	$PhCO_2Bu$	96

[a] *Conditions*: $MCl_{5/6}$, 0.1 mmol; ether, 1 mmol; acid chloride, 1 mmol, 80 °C. [b] GC yields: isolated yields in parentheses. [c] 50 °C.

The results obtained here showed that the ether reacted with MoCl$_5$ first, to form 1-chlorooctane and the [C$_8$H$_{17}$OMoCl$_n$] complex, although this complex was not characterized.[†] Benzoyl chloride then reacted with the molybdenum complex to give octyl benzoate. A proposed mechanism is shown in Scheme 1. The mechanism proposed here is quite different from the cationic mechanism which has been generally proposed for the catalytic acylative cleavage of the C–O bond of ethers. For example, Alper and Huang[11] and Tsonis[12] used group 6 metal carbonyl or substituted group 6 metal carbonyl complexes to catalyze the acylative cleavage of ethers. In both studies a mechanism was proposed whereby acid chloride reacts with the metal carbonyl to form a RCO$^+$ ion, followed by the reaction with an ether to produce an oxonium salt which is then cleaved to give the ester.



Scheme 1 Proposed reaction mechanism for catalytic acylative cleavage of ethers using MoCl$_5$.

The C–O bond of ethers can be cleaved only by MoCl$_5$ in our system which is similar to stoichiometric C–O bond cleavage of ethers with Lewis acids. The role of the acid chlorides in the reactions reported here does not lead to formation of the oxonium salt but rather provides Cl$^-$ to Cl$_4$MoOR to regenerate MoCl$_5$ and esters.

Notes and references

[†] The ^{13}C NMR spectrum of the reaction mixture of Bu$_2$O and MoCl$_5$ showed the following signals, δ_C(CDCl$_3$, Me$_4$Si): 13.66, 19.56, 29.26, 60.30.

1 M. V. Bhatt and S. U. Kulkarni, *Synthesis,* 1983, 249; R. C. Larock, *Ether cleavage*, in *Comprehensive Organic Transformations*, Wiley-VCH, 2nd edn., 1999.
2 P. Mimero, C. Saluzzo and R. Amouroux, *Tetrahedron Lett.*, 1994, **35**, 1553.
3 B. Ganem and V. R. Small, Jr., *J. Org. Chem.*, 1974, **39**, 3728.
4 T. Oriyama, M. Kimura, M. Oda and G. Koga, *Synlett*, 1993, 437.
5 S. Ahmad and J. Iqbal, *Chem. Lett.*, 1987, 953; J. Iqbal, M. A. Khan and R. R. Srivastava, *Tetrahedron Lett.*, 1988, **29**, 4985; J. Iqbal and R. R. Srivastava, *Tetrahedron*, 1991, **47**, 3155.
6 L. Green, I. Hemeon and R. D. Singer, *Tetrahedron Lett.*, 2000, **41**, 1343.
7 C. Qian, A. Qiu, Y. Huang and W. Chen, *J. Organomet. Chem.*, 1991, **412**, 53.
8 C. Qian, A. Qiu, D. Zhu and X. Yang, *J. Mol. Catal.*, 1994, **87**, 357.
9 F. A. Luzzio and R. A. Bobb, *Tetrahedron*, 1999, **55**, 1851.
10 S. Bhar and B. C. Ranu, *J. Org. Chem.*, 1995, **60**, 745.
11 H. Alper and C.-C. Huang, *J. Org, Chem.*, 1973, **38**, 64.
12 C. P. Tsonis, *J. Mol. Catal.*, 1988, **45**, 145.
13 Y. Suzuki, M. Matsushima and M. Kodomari, *Chem. Lett.*, 1998, 319.