Preliminary communication

BiCl₃-catalyzed Mukaiyama-aldol and carbonyl-ene reactions [1]

Laurence Peidro, Christophe Le Roux, André Laporterie, Jacques Dubac *

Hétérochimie Fondamentale et Appliquée (URA-CNRS 477), Université Paul Sabatier, 118 Route de Narbonne, 31062 Toulouse, France

Abstract

The H-ene pathway has not been detected for the bismuth(III) chloride-catalyzed Mukaiyama-aldol reaction involving silyl enol ethers and aldehydes. The silatropic ene-like process is the only mechanism observed, even with the weakly reactive 1-(trimethylsilyloxy) cyclohexene. However, trimerization of an aliphatic aldehyde can occur.

Keywords: Bi catalysis; Mukaiyama-aldol reaction

In previous studies, we have shown that allylsilanes or germanes can give ene reactions [1–8]. While thermal reactions with alkenes or activated hetero-enophiles imply a H-ene reaction mechanism, the catalyzed reactions involve migration of the silicon or germanium atom. In some cases, the two mechanisms have been observed [2–4]. In the condensation between an enoxysilane and a carbonyl compound (Mukaiyama-aldol reaction) [5], recent results have shown the possibilities of H-ene and silatropic-ene pathways [6].

It has been pointed out that catalytic amounts of Bi(III) chloride [7], especially when associated with metallic iodides [8], are very efficient in this reaction. We report here a possible H-ene reaction competitive with the Mukaiyama process using such catalysts.

At first, in order to know if BiCl₃ is suitable to catalyze classical H-ene reactions, its catalytic activity was tested for the cyclization of (+)-citronellal (1), and the reaction between (−)-β-pinene (2) and chloral. At room temperature, in benzene or dichloromethane solution, the cyclization of 1 was completed in a few hours using BiCl₃ in 2% mol, or in a few minutes with 5%.

On a 0.05 mol. scale, after distillation, a 65% yield of the pulegol diastereoisomers was obtained in which (−)-isopulegol (3) was identified by ¹H NMR [9] as the main one (70%). Thus, the catalytic power of BiCl₃ and the reaction stereoselectivity are similar to, or better than, those obtained with the usual catalyst present in 10% mol [10].

Concerning the ene-reaction between chloral and 2, the influence of a range of Lewis acids has been examined, showing that the polymerization of the terpene is an important problem [11].

At room temperature, with 2% mol. of BiCl₃, in CH₂Cl₂/Et₂O (9:1), an equimolar mixture of 2 and chloral gave the H-ene adduct 4, isolated by chromatography in 49% yield [12]. We observed that the formation of the (11R)-diastereoisomer of 4 (64%) is slightly favoured, whereas most Lewis acids lead to the preferential or exclusive (11S)-isomer [11]. In fact, from a stereochemical viewpoint, this BiCl₃-catalyzed reaction resembles – the thermal uncatalyzed process [11b,13].

Such a H-ene-like process has also been observed in the catalyzed condensation of an aldehyde with a vinyl ether [14] or a silyl enol ether [6], especially in alkylaluminium-catalyzed reactions involving long chain aliphatic aldehydes in nonpolar solvents. In the latter case, this mechanism competes with the Mukaiyama process, formally a sila-ene reaction, and the two mechanisms give the same aldol after aqueous workup.

---

* Corresponding author.

[1] Dedicated to Professor Robert Corriu in recognition of his outstanding contributions to organosilicon chemistry.

3   4

MeOH.HCl

(1)

8
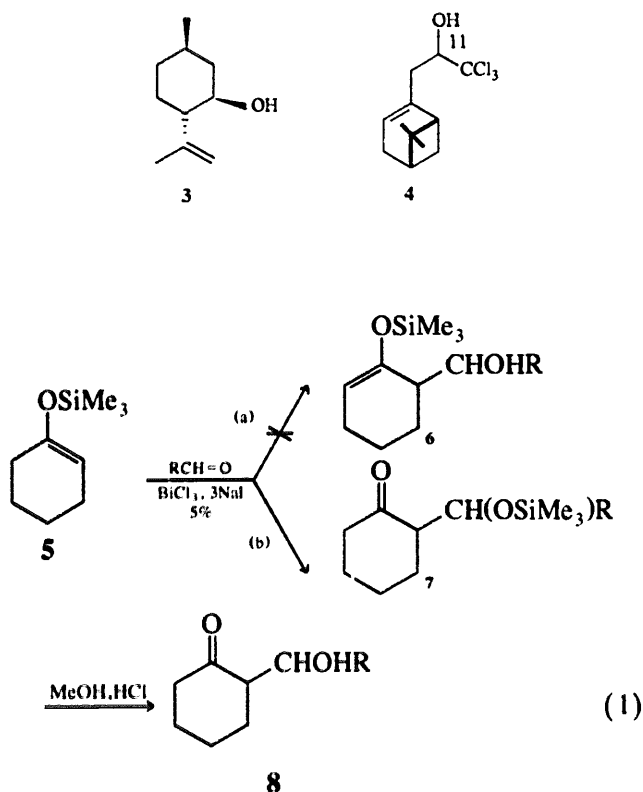
To see if the H-ene pathway is also observable in the bismuth chloride-catalyzed cross-aldol reaction, we studied the reaction between 1-(trimethylsilyloxy) cyclohexene 5 and butanal or heptanal (Eq. (1)). Due to the easy observation and separation of the silylated aldols before workup using this catalyst [8], the two paths (a) and (b) were easy to distinguish. BiCl₃, 3NaI (5% mol) was used as catalyst, BiCl₃ alone being inefficient for these reactions [7]. Moreover, there is a higher probability of observing an H-ene process with a substrate (such as 5) weakly reactive in the Mukaiyama condensation.

For the reaction with butanal in CH_2Cl_2 at room temperature, the Mukaiyama adduct (7, R = Pr) was obtained in 80% yield (Eq. (1), path b), while an H-ene adduct (6) (path a) was not detected. However, the formation of the aldehyde trimer 9 was observed (7/9 = 88/12) [15,16].

R = Pr (9), Hex (10)
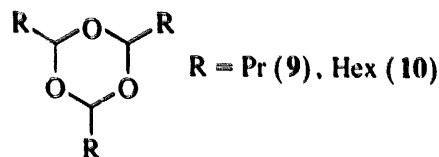
In hexane, no cross-condensation occurred and only the trimerization of butanal was detected. Aldehyde trimerization has also been described in a study of the complexation of butanal with $TiCl_4$ or $SnCl_4$ [17], but surprisingly, to our knowledge, was not reported for the $TiCl_4$ (or $SnCl_4$)-catalyzed Mukaiyama reaction. It is important to note that for the selected substrate 5, the ethylenic ^1H NMR signal (δ = 4.85 ppm) is superim-

posed on a similar pattern from the ^1H signal of the CHO group in 9 (δ = 4.81 ppm, triplet J = 4,5 Hz). The possible ene adduct 6 would also exhibit a similar signal as is also evident from the ene adduct between 5 and methanal [6c]. However, the absence of an OH infrared absorption band excludes its formation, and the aldehyde trimer 9 was identified by a GC/MS analysis [15]. We have also observed the formation of 9 in the reaction between 5 and BiCl₃ alone.

With heptanal, in CH_2Cl_2 under the same conditions, the reaction of 5 was slower and the products also consisted of the Mukaiyama adduct (7, R = Hex) in 50% yield and the aldehyde trimer 10 (7/10 = 70/30). Taking into account this in situ trimerization of the aldehyde, we suggest for the silyl aldol condensation an alternative pathway involving the trimer as an intermediate. However, no reaction was observed between 5 and 9 under the usual conditions of the BiCl₃, 3NaI-catalysis. In the case of the reaction between 5 and a more reactive aldehyde, such as benzaldehyde, the Mukaiyama adduct was the sole product (7, R = Ph) (95% yield), without formation of the aldehyde trimer [8a,b].

Finally, with the reactive enoxysilane derived from acetophenone [Ph C(OSiMe₃) = CH₂, 11] the cross-aldol reaction with butanal gave only the expected aldol adducts [Ph COCH₂CHOHPr] in 95% yield [8], without formation of 9.

We have shown that BiCl₃ is an efficient catalyst in carbonyl-ene reactions, and also in aldehyde trimerization, a subject still under consideration [18]. However, an H-ene process was not detected in the BiCl₃, 3NaI-catalyzed Mukaiyama-aldol condensation for which a mechanistic study is currently in progress.

References and notes

[1] (a) A. Laporterie, J. Dubac and M. Lesbre, C.R. Acad. Sci. Fr., 278 (1974) 375; (b) M. Lesbre, A. Laporterie, J. Dubac and P. Mazerolles, J. Organomet. Chem., 101 (1975) 187.

[2] J. Dubac and A. Laporterie, Chem. Rev., 87 (1987) 319.

[3] I. Fleming, J. Dunoguès and R. Smithers, Org. React. (NY), 37 (1989) 57–575.

[4] (a) E.W. Abel and R.J. Rowley, J. Organomet. Chem., 84 (1975) 199; (b) Ref. [3], p. 113; (c) A. Hosomi and H. Sakurai, Tetrahedron Lett., (1976) 1295.

[5] (a) J. March, Advanced Organic Chemistry, Wiley, 4th edn., 1992, p. 940; (b) T. Mukaiyama, Angew. Chem. Int. Ed. Engl., 16 (1977) 817.

[6] (a) H. Shoda, T. Naqkamura, K. Tanino and I. Kuwajima, Tetrahedron Lett., 34 (1993) 6281; (b) K. Mikami and S. Matsukawa, J. Amer. Chem. Soc., 115 (1993) 7039; (c) K. Maruoka, A.B. Conception, N. Murase, M. Oishi, N. Hirayama and H. Yamamoto, J. Amer. Chem. Soc., 115 (1993) 3943.

[7] (a) H. Ohki, M. Wada and K. Akiba, Tetrahedron Lett., 29 (1988) 4719; (b) M. Wada, E. Takeichi and T. Matsumoto, Bull. Chem. Soc. Jpn., 64 (1991) 990.

[8] (a) C. Le Roux, Thesis, University Paul Sabatier, Toulouse, 1993, no 1532; (b) C. Le Roux, H. Gaspard-Iloughmane, J.

Dubac, J. Jaud and P. Vignaux, *J. Org. Chem.*, 58 (1993) 1835; (c) C. Le Roux, H. Gaspard-Iloughmane and J. Dubac, *J. Bull. Soc. Chim. Fr.*, 130 (1993) 832.

[9] K.H. Shulte-Elte and G. Ohloff, *Helvetica Chim. Acta, 50* (1967) 153.

[10] Y. Natakati and K. Kawashima, *Synthesis*, (1978) 147.

[11] (a) J.P. Benner, G.B. Gill, S.J. Parrot and B. Wallace, *J. Chem. Soc. Perkin. Trans. 1.*, (1984) 291; (b) J.P. Benner, G.B. Gill, S.J. Parrot, B. Wallace and M.:. Begley, *J. Chem. Soc. Perkin. Trans. 1*, (1984) 315; (c) G.B. Gill and B. Wallace, *J. Chem. Soc. Chem. Comm.*, (1977) 382.

[12] Experimental procedure: to a mixture of 1.47 g (10 mmol) chloral and 0.06 g (0.2 mmol) BiCl$_3$ in 10 ml CH$_2$Cl$_2$/Et$_2$O (9/1) is added, under argon atmosphere, at room temperature, a solution of 1.36 g (10 mmol) of (−)-β-pinene in the same solvent. After stirring for 5 h and hydrolysis with aqueous NaHCO$_3$, the mixture of the two diastereoisomers is separated from impurities on a short silica column (eluent:pentane, then Et$_2$O). Yield: 1.39 g (49%). The ^{1}H NMR spectrum (250 MHz) agrees well with the values given by Gill. [11] The two signals at 4.00 and 4.08 ppm of C$_{11}$(R) and C$_{11}$(S) isomers, respectively, permit an estimate of the ratio (11 R)-4/(11 S)-4 = 64/36.

[13] M. Vilkas, G. Dupont and R. Dulou, *Bull. Soc. Chim. Fr.*, (1955) 799.

[14] M.V. Deaton and M.A. Cinfolini, *Tetrahedron Lett.*, 34 (1993) 2409.

[15] A typical procedure is given in Ref. [8]. After the usual workup, 2-(1-trimethylsiloxybutyl)-cyclohexanone (7, R = Pr) and 2,4,6-tripropyl-1,3,5-trioxane 9 are identified (7/9 = 88/12) by comparison with the data given in the literature [8,16] and by GC/MS analysis after distillation (Eb = 80–85°/0.1 mm). 7: M/z (relative intensity) 242 (M$^+$) (3), 227 (37), 199 (30), 155 (42), 145 (34) 75 (76) 73 (100%), 41 (35). 9: m/z (relative intensity) 215 (M–1) (1), 145 (25), 73 (100%), 55 (46), 43 (32).

[16] (a) M. Cossu and E. Ucciani, *C. R. Acad. Sci., Série C, 277* (1973) 1145. (b) M.J. Astle and M. Pinns, *J. Org. Chem., 24* (1959) 56.

[17] S.E. Denmark and N.G. Almstead, *Tetrahedron Lett., 48* (1992) 5565.

[18] T. Wakasugi, T. Miyakawa, N. Tonouchi, F. Suzuki and T. Yamauchi, Eur. Pat. Appl. EP 621, 274 (Cl. C07D 323/04), 1994, JP Appl. 93/117, 810, 1993; *Chem. Abstr., 122* (1995) 56058.