Asymmetric Catalysis of Diels–Alder Cycloaddition by a β-Amino Alcohol Derived Boron Complex: Reasonable Transition-state Assembly for One-directional Diene Approach

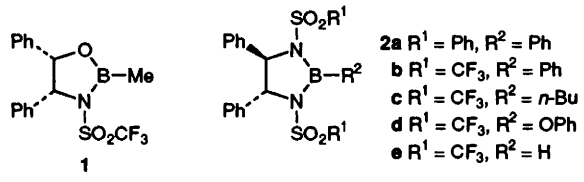
Yukihiro Motoyama and Koichi Mikami*

Department of Chemical Technology, Tokyo Institute of Technology, Meguro-ku, Tokyo 152, Japan

Asymmetric Diels–Alder reactions of glyoxylate with acid-labile Danishefsky dienes are catalysed in high enantio- and *cis*(*endo*)-diastereo-selectivity by a chiral amino alcohol derived boron complex, *via* the favourable transition-state assembly for one-directional diene-approach from the site proximal to the sulfonylamino moiety.

Asymmetric catalysis, particularly of carbon–carbon bond forming reactions, is one of the most challenging and formidable aspects of organic synthesis.[1] The Diels–Alder (DA) reaction forms six-membered rings with the potential to control the absolute and relative stereochemistry at all four newly created chiral centres.[2,3] We envisioned the use of the β-amino alcohol derived boron complex, (1*S*,2*R*)-**1** as a mild Lewis acid for asymmetric catalysis of this reaction. In this paper, we report the highly enantioselective hetero DA cycloaddition of glyoxylate **4** with the acid-labile Danishefsky dienes **3a,b** catalysed by chiral complex **1**, which might proceed by the favourable transition state assembly for one-directional diene approach **A** from the site proximal to the sulfonylamino moiety (Fig. 1).

The reaction of methyl glyoxylate **4** with the Danishefsky diene **3a** was promoted by a catalytic (10 mol%) amount of complex **1** at −78 °C to give **5a** in 69% isolated yield after acid treatment (trifluoroacetic acid) (Scheme 1). The remarkably high (94%) ee of **5a** was determined by HPLC analysis using a chiral column (DAICEL CHIRALPAK AS, hexane–propan-2-ol, 3 : 1). The absolute configuration of the adduct **5a** was determined from its optical rotation after transformation to the known compound **6a**.[4] The high enantioselectivity compares favourably to the moderate level of enantioselectivity (up to 62% ee) obtained with the bis-sulfonamide complexes **2**



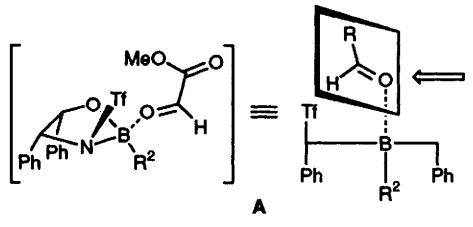
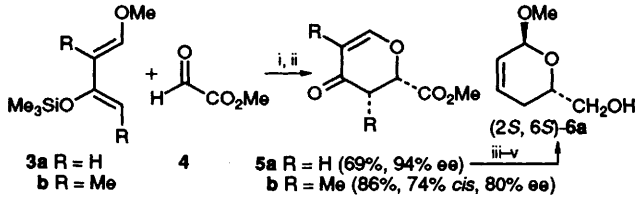


Fig. 1



Scheme 1 *Reagents and conditions*: i, toluene, **1**, −78 °C; ii, CF_3CO_2H; iii, $NaBH_4$, $CeCl_3$; iv, HCl, MeOH; v, $LiAlH_4$

Table 1 Yield and enantiomeric excess (ee) of product **5a** on treatment of reagents **3a** and **4** with various catalysts[a]

Entry	Catalyst	Yield (%)	ee (%)[b]
1	**2a**	69	29
2	**2b**	76	61
3	**2c**	78	58
4	**2d**	77	25
5	**2e**	88	38
6[c]	**2e**	71	62
7[c,d]	**1**	69	94

[a] All reactions were carried out using 1.2 mmol of diene, 1.0 mmol of methyl glyoxylate and 0.05 mmol of chiral catalyst. [b] Determined by HPLC analysis [DAICEL CHIRALPAK AS (hexane–PrⁱOH, 3 : 1)]. [c] In toluene. [d] 0.1 mmol of chiral catalyst was used.

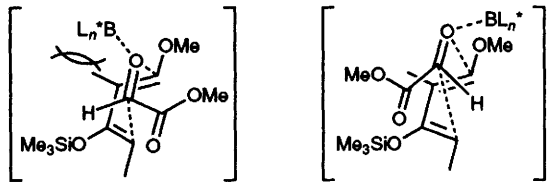


Fig. 2

under the same reaction conditions† (Table 1) and is consistent with our hypothesis that the DA reaction would proceed *via* the transition-state assembly **A**.

Use of complex **1** leads also to *endo*-diastereoselectivity in the reaction with the diene **3b**. The DA reaction of methyl glyoxylate **4** proceeds smoothly to give the 5,6-*cis*-*endo*-adduct **5b** with high enantioselectivity (Scheme 1), providing a further mechanistic insight into the transition-state assembly of the reaction. As implicated in **A** (Fig. 1) the *exo* mode of cycloaddition would be disfavoured by interactions with R^2 in BL_n* **B** (Fig. 2). Furthermore, the glyoxylate should possess the s-*trans* conformation because of dipolar repulsion between the two carbonyl groups. Therefore, the boron catalyst **1** should be complexed to glyoxylate **4** in an *anti* (monodentate) fashion and the DA reaction should proceed with *endo*-orientation **C**.

We are grateful to Professor Kazuhiko Saigo of Tokyo University for kindly providing (1*S*,2*R*)-(+)-2-amino-1,2-diphenylethanol. This work was supported by the Grant-in-Aid for Scientific Research on Priority Area of Asymmetric Synthesis from the Ministry of Education, Science and Culture, Japan.

Received, 30th March 1994; Com. 4/01947D

Footnote

† The use of a more polar solvent, propionitrile, leads to a lower level of enantioselectivity (20% ee, 71% yield) than that obtained for CH_2Cl_2 (entry 2).

References

1 Reviews: J. D. Morrison, *Asymmetric Synthesis*, Academic Press, New York, 1984, vol. 3B; R. Noyori and M. Kitamura, in *Modern Synthetic Methods* 1989, ed., R. Scheffold, Springer–Verlag, Berlin, 1989, vol. 5; B. Bosnich, *Asymmetric Catalysis*, Martinus Nijhoff Publishers, Dordrecht, 1986; H. B. Kagan, in *Comprehensive Organometallic Chemistry*, ed, G. Wilkinson, Pergamon, Oxford, 1982, vol. 8; K. Narasaka, *Synthesis*, 1991, 1; Y. Hayashi and K. Narasaka, *J. Synth. Org. Chem. Jpn.*, 1990, **48**, 280; K. Mikami, M. Terada, S. Narisawa and T. Nakai, *Synlett*, 1992, 255; K. Mikami, M. Terada and T. Nakai, *Yukagaku*, 1990, **39**, 837.

2 (*a*) Reviews on asymmetric DA reactions: L. A. Paquette, in *Asymmetric Synthesis*, ed., J. D. Morrison, Academic Press, New York, 1984, vol. 3B; W. Oppoizer, in *Comprehensive Organic Synthesis*, ed. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, vol. 5, p. 315; M. J. Taschner, in *Organic Synthesis: Theory and Applications*, ed. T. Hudlicky, JAI Press, London, 1989, vol. 1; H. B. Kagan and O. Riant, *Chem. Rev.*, 1992, **92**, 1007. For asymmetric catalytic DA reactions: (*b*) K. Narasaka, N. Iwasawa, M. Inoue, T. Yamada, M. Nakashima and J. Sugimori, *J. Am. Chem. Soc.*, 1989, **111**, 5340; (*c*) K. Furuta, S. Shimizu, Y. Miwa and H. Yamamoto, *J. Org. Chem.*, 1989, **54**, 1481; (*d*) E. J. Corey, R. Imwinkelried, S. Pikul and Y. B. Xiang *J. Am. Chem. Soc.*, 1989, **111**, 5493; (*e*) D. Kaufmann, R. Boese, *Angew. Chem., Int. Ed. Engl.*, 1990, **29**, 545; (*f*) F. Rebiere, O. Riant and H. B. Kagan, *Tetrahedron Asymmetry*, 1990, **1**, 199; (*g*) E. J. Corey, N. Imai, H.-Y. Zhang, *J. Am. Chem. Soc.*, 1991, **113**, 728; (*h*) J. M. Hawkins and S. Loren, *J. Am. Chem. Soc.*, 1991, **113**, 7794; (*i*) E. J. Corey and T.-P. Loh, *J. Am. Chem. Soc.*, 1991, **113**, 8966; (*j*) S. Kobayashi, M. Murakami, T. Harada and T. Mukaiyama, *Chem. Lett.*, 1991, 1341; (*k*) P. N. Devine and T. Oh, *J. Org. Chem.*, 1992, **57**, 396; (*l*) K. Maruoka, N. Murase and H. Yamamoto, *J. Org. Chem.*, 1993, **58**, 2938; (*m*) J. Bao and W. D. Wulff, *J. Am. Chem. Soc.*, 1993, **115**, 3814; (*n*) K. Mikami, Y. Motoyama and M. Terada, *J. Am. Chem. Soc.*, 1994, **116**, 2812.

3 Reviews on asymmetric hetero-DA reactions: M. D. Bednarski and J. P. Lyssikatos, in *Comprehensive Organic Synthesis*, ed. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, vol. 2, p. 661; D. L. Boger and S. M. Weinreb, *Hetero-Diels–Alder Methodology in Organic Synthesis*, Academic Press, New York, 1987. For asymmetric catalytic hetero-DA reactions: M. Bednarski, C. Maring and S. Danishefsky, *Tetrahedron Lett.*, 1983, **24**, 3451; M. Bednarski, C. Maring and S. Danishefsky, *J. Am. Chem. Soc.*, 1983, **105**, 6968; K. Maruoka, T. Itoh, T. Shirasaka and H. Yamamoto, *J. Am. Chem. Soc.*, 1988, **110**, 310; K. Maruoka and H. Yamamoto, *J. Am. Chem. Soc.*, 1989, **111**, 789; A. Togni, *Organometallics*, 1990, **9**, 3106; Q. Gao, T. Maruyama, M. Mouri and H. Yamamoto, *J. Org. Chem.*, 1992, **57**, 1951; see also ref. 2(*n*).

4 (2*S*,6*S*)-**6a**: $[\alpha]_D^{15}$ −80.5 (*c* 2.0 benzene); J. Jurczak, T. Bauer, S. Filipek, M. Tkack and K. Zygo, *J. Chem. Soc., Chem. Commun.*, 1983, 538.