CHEMISTRY LETTERS, pp. 1259-1262, 1994.

Enantioselective Aerobic Epoxidation of Acyclic Simple Olefins Catalyzed by the Optically Active β-Ketoiminato Manganese(III) Complex

Takushi NAGATA, Kiyomi IMAGAWA, Tohru YAMADA, and Teruaki MUKAIYAMA[†]
Basic Research Laboratories for Organic Synthesis, Mitsui Petrochemical Industries, Ltd.,
Nagaura, Sodegaura-shi, Chiba 299-02

Enantioselective aerobic epoxidation of acyclic *cis*-olefins into the corresponding optically active epoxides was carried out with good-to-high enantioselectivities by using a new class of optically active β-ketoiminato manganese(III) complex catalyst, *N,N'*-ethylenebis(α-mesitoyl-β-ketoiminato)manganese(III) chloride. The key intermediate of the present epoxidation is also discussed.

Development of an excellent metal-complex catalyst for an asymmetric epoxidation of unfunctionalized olefins has been of great synthetic concern. Metalloporphyrin$^{1)}$ or salen complex catalysts have been extensively studied as a model system of oxygen activation from the points of mechanistic and biological interests and optically active salen-manganese(III) complexes were recently found to be effective catalysts for the enantioselective epoxidation when terminal oxidants such as iodosylbenzene,$^{2)}$ sodium hypochlorite,$^{3)}$ and hydrogen peroxide$^{4)}$ were used. Besides salen-manganese(III) complexes, β-diketone-type ligand was also reported to form an effective manganese(III) catalyst for the enantioselective epoxidation of unfunctionalized olefins with combined use of molecular oxygen and pivalaldehyde.$^{5)}$ A structural study by X-ray crystallography of β-ketoiminato manganese(III) complex$^{6)}$ suggested that the enantioselection in the present aerobic epoxidation was enhanced by the steric bulkiness of the side chain of β-ketoiminato ligands (**R** in Fig. 1.).

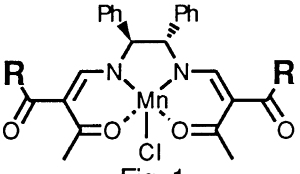


Fig. 1.

A: R=Alkoxy
B: R=Mesityl

Here we would like to report the preparation of a new class of optically active β-ketoiminato manganese(III) catalyst, *N,N'*-ethylenebis(α-mesitoyl-β-ketoiminato)manganese(III) complex **B**, and its advantage in catalytic enantioselective and aerobic oxygenation of acyclic *cis*-olefins to form the corresponding optically active epoxides.

Optically active β-ketoiminato manganese(III) chloride **B** was prepared$^{7)}$ from (*S,S*) or (*R,R*)-1,2-diphenylethylenediamine and the β-diketone derivative; that is, mesitoylacetone$^{8)}$ was formylated with trimethylorthoformate in acetic anhydride at refluxing temperature, and then reaction with the optically active diamine in ethanol / 1,2-dichloroethane at 60 °C afforded the β-diketone-type ligand (77% yield in 2 steps). Complex **B** was prepared by the treatment of the ligand with excess manganese triacetate and successively

---

[†] Address: Department of Applied Chemistry, Faculty of Science, Science University of Tokyo, Kagurazaka, Shinjuku-ku, Tokyo 162.

with lithium chloride. Pure β-ketoiminato manganese(III) complex **B** was provided by column chromatography on silica gel and recrystalization (chloroform-hexane) as dark brown needles (45% yield).

The examination of β-ketoiminato manganese(III) complex **A**5b) or **B** in the manganese(III)-catalyzed epoxidation of *cis*-β-methylstyrene (**1**) by using molecular oxygen and pivalaldehyde demonstrated that complex **B** afforded the corresponding optically active *cis*-epoxide with 80% ee while complex **A** did with 67% ee. It is assumed that the steric bulkiness of mesitylketo group in the ligand is effective to improve the enantioselectivity. It is particularly important to note that the present enantiofacial selection is opposite to that of reported method using oxidants other than molecular oxygen; that is, by using a terminal oxidant such as sodium hypochlorite, (*S,S*)-β-ketoiminato manganese(III) complex **B** afforded (*1S,2R*)-(+)-*cis*-epoxide with only 29% ee.3b) On the contrary, (*1R,2S*)-(-)-epoxide (80% ee) was obtained by the present aerobic epoxidation catalyzed by (*S,S*)-β-ketoiminato manganese(III) complex **B** with combined use of molecular oxygen and pivalaldehyde (Fig. 2).9) The results clearly indicate that the active species of the present aerobic epoxidation is different from the oxo-manganese complex which is widely accepted as an intermediate when terminal oxidants such as sodium hypochlorite and iodosylbenzene were used.10) Furthermore, (*1R,2S*)-(-)-epoxide was also formed in 67% ee corresponding to (*S,S*)-β-ketoiminato manganese(III) complex **B** by using peracetic acid as an oxidant instead of molecular oxygen and pivalaldehyde.11) Accordingly it is reasonable to assume that the acylperoxo-manganese complex generated from optically active manganese catalyst, molecular oxygen, and pivalaldehyde is a key intermediate in the present aerobic epoxidation.12) It is noted that the optically active β-ketoimine derivative is quite suitable ligand leading to high enantioselection in the manganese(III)-catalyzed aerobic epoxidation.

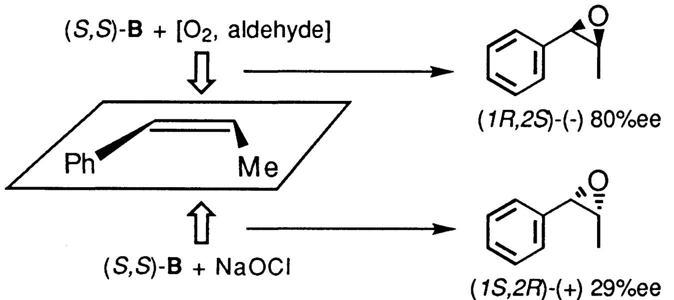
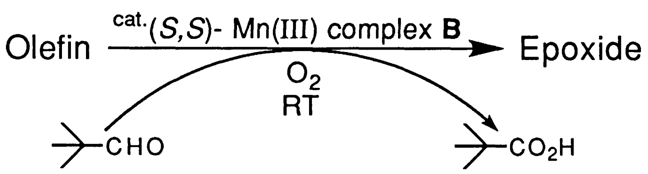
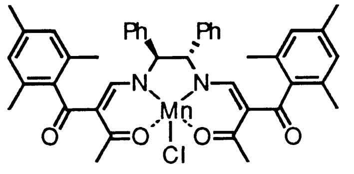


Fig. 2. Absolute Configuration of Epoxide Formed by Catalyst (*S,S*)-**B**.

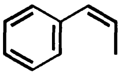
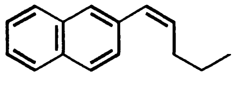
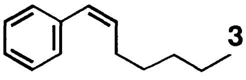
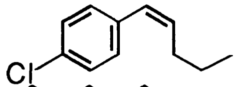
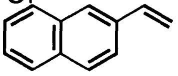
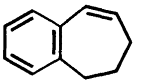
The present aerobic epoxidation catalyzed by β-ketoiminato manganese(III) complex was successfully applied to several acyclic unfunctionalized olefins. In the presence of pivalaldehyde, molecular oxygen and catalytic amount of manganese(III) complex **B**, *cis*-1-naphthylpentene (**2**) was converted into the corresponding optically active *cis*-epoxide with good enantioselection (76% ee, Entry 2) along with *trans*-epoxide.13) When atmospheric pressure of air was used instead of molecular oxygen, the formation of *trans*-epoxide was suppressed and the chemical yield of *cis*-epoxide was increased (Entry 3). These results were reasonably explained as follows: A radical intermediate is supposed to be initially formed from *cis*-olefin in the manganese(III)-catalyzed epoxidation by using a terminal oxidant such as sodium hypochlorite or iodosylbenzene and then cyclized to produce *cis*- epoxide along with *trans*-epoxide.10) It is also reported that the radical intermediate mentioned above could capture molecular oxygen to generate peroxy species and therefore the conversion of *cis*-olefin into *trans*-epoxide was enhanced to afford a mixture of *cis*- and *trans*-epoxides.14) When an atmospheric pressure of air was used as oxygen source, the trapping of the radical intermediate by molecular oxygen was suppressed to improve the formation of *cis*-epoxide against *trans*-epoxide and pivalaldehyde was properly employed as a reductant in the present aerobic enantioselective epoxidation catalyzed by manganese(III) complex. For example, *cis*-β-alkyl styrene derivatives **1**, **3**, and **4**, were converted into the corresponding *cis*-epoxides with high enantioselections, 80% ee, 81% ee, and 79% ee, respectively (Entries 1, 5, and 7). Terminal olefin **5** and cyclic olefin **6** were also converted into the corresponding optically active epoxides with good-to-high enantioselections (Entries 8 and 9).

Table1. Asymmetric Epoxidation of Simple Olefins





Mn(III) complex **B**

Entry$^{a)}$	Olefin$^{b)}$		Optical yield / %ee$^{c)}$	Yield /%$^{d)}$ (*cis/trans* ratio$^{e)}$)
1		**1**	80	28(63/37)
2$^{f)}$		**2**	76$^{g)}$	45(65/35)
3			80$^{g)}$	40(88/12)
4$^{h)}$			76$^{g)}$	57(79/21)
5		**3**	81	22(84/16)
6$^{h)}$			78	34(74/26)
7		**4**	79	31(69/31)
8$^{f)}$		**5**$^{i)}$	48$^{j)}$	49
9$^{f)}$		**6**$^{k)}$	79	57

a) Reaction conditions; olefin 0.8 mmol, pivalaldehyde 2.0 mmol(2.5 equiv.), Mn(III) catalyst **B** 0.104 mmol(13 mol%) in benzene 2 ml, RT, 1 atm Air, 1 h. b) Olefins were prepared from the corresponding acetylene derivatives unless otherwise noted. See Ref. 15. c) As for acyclic disubstituted olefins, ee of *cis*-epoxides were shown. Determined by GC analysis (Chiraldex B-PH (30 m x 0.32 mm ID x 0.125 μm film), ASTEC Co.) unless otherwise noted. d) Isolated yield. e) *Cis/trans* ratio of formed epoxides. Determined by NMR. f) 1 atm O_2 was used. g) Determined by HPLC analysis (Chiralpak AD, Daicel, Ltd.). h) Pivalaldehyde 4.0 mmol(5.0 equiv.) was used in two portions. i) Purchased from Aldrich Co. j) Determined by HPLC analysis (Chiralcel OB, Daicel, Ltd.). k) Prepared from 1-benzosuberone.

The typical procedure is described as follows: to a solution of (*S*,*S*)-β-ketoiminato manganese(III) complex **B** (76 mg, 0.104 mmol) in benzene (1.0 ml) was added a solution of olefin **2** (158 mg, 0.8 mmol) and pivalaldehyde (172 mg, 2.0 mmol) in benzene (1.0 ml) under argon atmosphere, and was stirred for 10 min. The resulting reaction mixture was further stirred for 1 h at 25 °C under an atmospheric pressure of air. The solution was poured into saturated sodium hydrogencarbonate and extracted with ether. The organic layer was dried over sodium sulfate. Purification by column chromatography on silica gel (hexane-ethyl acetate) afforded the corresponding optically active epoxide in 40% yield. The optical yield was determined to be 80% ee by HPLC analysis (Chiralpak AD, Daicel, Ltd.).

Further studies on the structural elucidation of the optically active β-ketoiminato manganese(III) complex **B** and detailed reaction mechanism are in progress.

References

1) a) J. T. Groves and R. S. Myers, *J. Am. Chem. Soc.*, **105**, 5791 (1983); b) J. T. Groves and P. Viski, *J. Org. Chem.*, **55**, 3628 (1990); c) Y. Naruta, F. Tani, N. Ishihara, and K. Maruyama, *J. Am. Chem. Soc.*, **113**, 6865 (1991); d) K. Konishi, K. Oda, K. Nishida, T. Aida, and S. Inoue, *ibid.*, **114**, 1313 (1992); e) E. N. Jacobsen, "Asymmetric Catalytic Epoxidation of Unfunctionalized Olefins," in "Catalytic Asymmetric Synthesis," ed by I. Ojima, VCH Inc., New York (1993), Chap. 4.2, pp. 159. References are cited therein.

2) W. Zhang, J. L. Loebach, S. R. Wilson, and E. N. Jacobsen, *J. Am. Chem. Soc.*, **112**, 2801 (1990); R. Irie, K. Noda, Y. Ito, N. Matsumoto, and T. Katsuki, *Tetrahedron Lett.*, **31**, 7345 (1990).

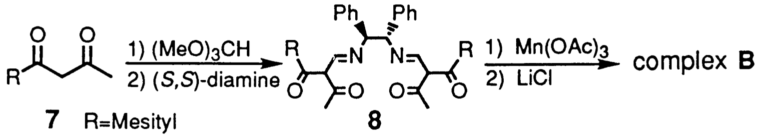
3) a) H. Yoon and C. J. Burrows, *J. Am. Chem. Soc.*, **110**, 4087 (1988); b) W. Zhang and E. N. Jacobsen, *J. Org. Chem.*, **56**, 2296 (1991).

4) T. Schwenkreis and A. Berkessel, *Tetrahedron Lett.*, **34,** 4785 (1993).

5) a) Salen-complexes; T. Yamada, K. Imagawa, T. Nagata, and T. Mukaiyama, *Chem. Lett.*, **1992**, 2231; b) β-Diketone-type-complexes; T. Mukaiyama, T. Yamada, T. Nagata, and K. Imagawa, *ibid.*, **1993**, 327.

6) T. Nagata, K. Imagawa, T. Yamada, and T. Mukaiyama, *Inorg. Chim. Acta*, **220**, 283 (1994).

7) Preparation of the Mn(III) catalyst **B** was depicted in the scheme. References are cited in Ref. 5a and 6.



8) β-Diketone **7** was prepared by the literature method. V. V. Popic, S. M. Korneev, V. A. Nikolaev, and I. K. Korobitsyna, *Synthesis*, **1991**, 195.

9) The absolute configuration of *cis*-epoxide was assigned to be (*1R,2S*) by polarimetry analysis compared with reported results (Ref. 1a). In addtion, the minor *trans*-isomer was obtained in 47% ee with (*1S, 2S*)-(-) configuration. Jacobsen *et al.* explained mechanistically what causes the difference in the degree of enantioselectivities for both *cis*- and *trans*- isomers. W. Zhang, N. H. Lee, and E. N. Jacobsen, *J. Am. Chem. Soc.*, **116**, 425 (1994).

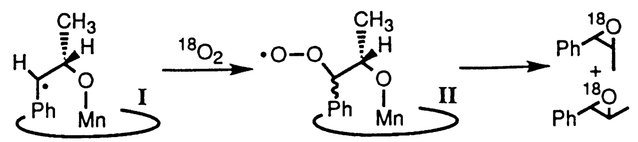
10) R. D. Arasasingham, G.-X. He, and T. C. Bruice, *J. Am. Chem. Soc.*, **115**, 7985 (1993).

11) To a solution of (*S,S*)-Mn(III) complex **B** and *cis*-β-methylstyrene in benzene was added peracetic acid (2 equiv., 32 wt% in acetic acid, Aldrich Co.) at room temperature under argon atmosphere to afford the corresponding epoxide in 18% yield. The optical yield of *cis*-epoxide was determined by GC analysis .

12) Recently, it was reported that similar acylperoxo-metal porphyrin complexes directly contribute the epoxidation when the oxo-intermediate is less favorable process. Y. Watanabe, K. Yamaguchi, I. Morishima, K.Takehira, M. Shimizu, T. Hayakawa, and H. Orita, *Inorg. Chem.*, **30**, 2581 (1991).

13) The optical purity of the *trans*-epoxide was determined to be less than 20% ee by the ^{1}H NMR analysis using Eu(hfc)3 as chiral shift reagent.

14) It was confirmed that the intermediate **I** was trapped by molecular oxygen to generate peroxy radical **II** that lead to both *cis*- and *trans*-epoxides under the condition of the $^{18}O_2$ experiments. T. Groves and M. K. Stern, *J. Am. Chem. Soc.*, **110**, 8628 (1988). Therefore the formation of *trans*-epoxide was enhanced by using an atmospheric pressure of oxygen.



15) K. Tani, N. Ono, S. Okamoto, and F. Sato, *J. Chem. Soc., Chem. Commun.*, **1993**, 386.

(Received March 22, 1994)