Pergamon

Tetrahedron Letters, Vol. 35, No. 6, pp. 941-944, 1994
Elsevier Science Ltd
Printed in Great Britain
0040-4039/94 $6.00+0.00

0040-4039(93)E0350-S

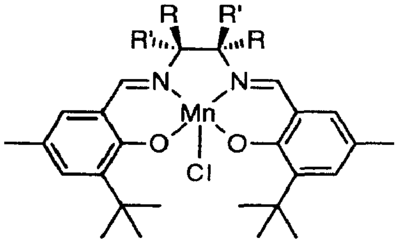
Catalytic and Asymmetric Epoxidation of Unfunctionalized Alkenes with Hydrogen Peroxide and (Salen)Mn(III) Complexes[1]

Pekka Pietikäinen

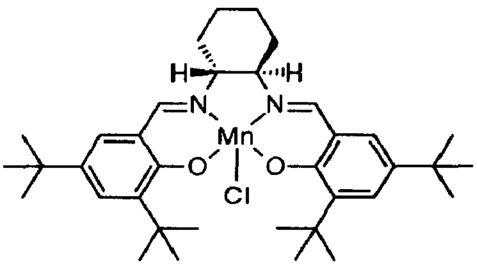
Department of Chemistry, University of Helsinki,
P. O. BOX 6, FIN-00014 University of Helsinki

Abstract: Catalytic epoxidation of two unfunctionalized alkenes, 1,2-dihydronaphthalene and *trans*-β-methylstyrene, is reported using achiral and chiral (Salen)Mn(III) complexes **1-3** together with a nitrogen heterocycle as axial ligand in the presence of 30 % aqueous hydrogen peroxide as oxidant. Typically, the reaction system consisted of the substrate, oxidant, ligand, and salen in a ratio of 1: 2-3.5: 0.4: 0.025-0.05. The best ligands were imidazole and *N*-methyl imidazole. The highest ee-values obtained were 60 % for 1,2-dihydronaphthalene oxide and 47 % for *trans*-β-methylstyrene oxide.

During recent years (salen)Mn(III) complexes[2,3] have emerged as promising catalysts for the asymmetric epoxidation of unfunctionalized olefins. High yields of epoxides and moderate to excellent enantiomeric excesses (e.e.) have been reported for reactions of unfunctionalized *cis*-alkenes with oxidants like iodosylarenes,[2] sodium hypochlorite,[3] or molecular oxygen[4] using catalysts such as **2**[3a] and **3**[3b] introduced by Jacobsen *et al.* The epoxidation of *trans*-alkenes with salen complexes has not been equally successful. Recently, hydrogen peroxide has also been applied for the salen-catalyzed asymmetric oxidation reactions,[5,6] and it has been earlier used widely in the metalloporphyrin-catalyzed epoxidations of various alkenes.[7] We have been working with hydrogen peroxide in the Mn(III)-porphyrin catalyzed biomimetic oxidative coupling reactions of phenols.[8] Hydrogen peroxide is an attractive oxidant because it is a "clean" reagent giving only water as a by-product. The problem in metal complex-catalyzed epoxidations with hydrogen peroxide is the homolytic cleavage of the weak O-O bond, which leads to the formation of radicals and therefore indiscriminate oxidation. The heterolytic bond cleavage producing the reactive metal-oxo species can be favoured by using a nitrogen heterocycle acting as axial ligand and as acid-base catalyst.[7] The most useful ligands have been imidazoles and pyridines.[9] Also, porphyrins with covalently attached ligands are efficient catalysts.[10] The beneficial effect of the axial ligand has been observed also in salen-catalyzed epoxidations.[4,11] Recently, Schwenkreis and Berkessel[6] introduced a chiral (dihydrosalen)Mn(III) complex carrying a covalently attached imidazole group.



1: R= R'= H
(*S,S*)-2: R= Ph, R'= H



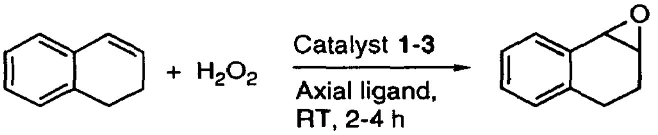
(*R,R*)-3

We chose a more straightforward approach and used the Jacobsen-type catalysts **1-3** to epoxidize two simple alkenes, 1,2-dihydronaphthalene (a *cis*-alkene) and *trans*-β-methylstyrene, with 30 % hydrogen peroxide (see Tables 1 and 2 for results). The salen complexes were easily synthesized in high yields from substituted salicylaldehydes and achiral[12] (**1**) or chiral[3] (**2** and **3**) diamines. Typically, the epoxidations were performed in 0.5 mmol scale of substrate in CH_2Cl_2-CH_3OH (1:1) at room temperature containing the substrate, oxidant, axial ligand, and salen in a ratio of 1: 2-3.5: 0.4: 0.025-0.05.[13]

The use of a nitrogen heterocycle as an axial ligand was found to be essential for succesful reaction (Table 1, entries 1-5). The ligands were first tested using the achiral catalyst **1**, and imidazole and *N*-methyl imidazole proved to be the best ligands (Table 1, entries 4 and 5). Also 4-dimethylaminopyridine together with benzoic acid co-catalyst worked well.[8,9b-c] Surprisingly, pyridine-*N*-oxide used succesfully by Katsuki *et al.*[11] gave the poorest result. In all these reactions unbuffered 30 % hydrogen peroxide was used as the oxidant. Diluted (1.5 %) oxidant in similar conditions (axial ligand imidazole) only produced a 22:78 mixture of epoxide and alkene (determined by ^{1}H NMR). Entries 6-9 in Table 1 show the results from asymmetric epoxidation of 1,2-dihydronaphthalene with the chiral catalysts **2** and **3**. The highest yield (59 %) and ee (60 %) were obtained by using the salen complex **2** (Table 1, entry 7). Catalyst **3** produced dihydronaphthalene oxide in 53 % yield and 52 % ee (Table 1, entry 10). As expected, the epoxide produced by the action of catalyst *S,S*-**2** showed opposite configuration to the one produced by *R,R*-**3**.

This methodology was also applied to the epoxidation of *trans*-β-methylstyrene. *Trans*-alkenes react much slower and with lower selectivity than *cis*-alkenes in metal complex-catalyzed epoxidations.[7,2] As expected, more (5 mol-% *vs* 2.5 mol-%) of the catalyst **1** was needed to induce complete reaction of *trans*-β-methylstyrene (Table 2, entry 2) compared to the oxidation of 1,2-dihydronaphthalene (Table 1 entry 3). The yields of the *trans*-epoxide were moderate (ca. 50 %) and in some cases trace amounts of 1-phenyl-2-propanone were detected (^{1}H NMR). The enantiomeric excesses obtained for the asymmetric epoxidation of this olefin with catalysts **2** and **3** are among the highest observed for *trans*-alkenes.[2] Complex **3** gave slightly better enantioselectivity than **2** (47 % *vs* 42 %). This is the first time catalyst **3** has been used for the epoxidation of *trans*-alkenes.[15,16]

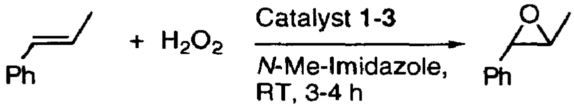
Table 1. Epoxidation of 1,2-Dihydronaphthalene with Catalysts **1-3**[a]



entry	catalyst	axial ligand	epox./alkene (%)[b]	yield (%)[c]	ee (%)[d]	epoxide config[e]
1	**1**	no ligand	31 : 69	nd	–	–
2	**1**	pyridine-*N*-oxide	53 : 47	nd	–	–
3	**1**	DMAP + BA[f]	> 90 : 10	62 (58)[g]	–	–
4	**1**	imidazole	> 90 : 10	64	–	–
5	**1**	*N*-Me-imidazole	100 : 0	67	–	–
6	*(S,S)*-**2**	imidazole	100 : 0	56	59	1*S*,2*R*-(–)
7	*(S,S)*-**2**	*N*-Me-imidazole	100 : 0	59 (63)[h]	60	1*S*,2*R*-(–)
8	*(R,R)*-**3**	DMAP + BA[i]	100 : 0	50	48	1*R*,2*S*-(+)
9	*(R,R)*-**3**	imidazole	100 : 0	51	50	1*R*,2*S*-(+)
10	*(R,R)*-**3**	*N*-Me-imidazole	100 : 0	53	52	1*R*,2*S*-(+)

a) Ratio of alkene: H_2O_2: ax. ligand: salen= 1: 2.3: 0.4: 0.025 (entries 1-5); 1: 3: 0.7: 0.05 (entries 6-9). b) Determined by ^1H NMR. c) Yield of the isolated product (nd= not determined). d) Determined by ^1H NMR in the presence of $Eu(hfc)_3$. e) Determined by comparison of the sign of $[\alpha]_D$ to literature values.[14] f) 4-Dimethylaminopyridine (12.5 mol-%) + benzoic acid (12.5 mol-%).[8] g) Yield without BA. h) Reaction was performed in 1 mmol scale of substrate. i) DMAP: BA: 3= 10: 5: 1.

Table 2. Epoxidation of *trans*-β-Methylstyrene with Catalysts **1-3**[a]



entry	catalyst	epoxide/alkene (%)[b]	yield (%)[c]	ee (%)[d]	epoxide config[e]
1[f]	**1**	57 : 43	nd	–	–
2	**1**	100 : 0	56	–	–
3	*(S,S)*-**2**	72 : 28	38	42	1*S*,2*S*-(–)
4	*(S,S)*-**2**[g]	100 : 0	49	42	1*S*,2*S*-(–)
5	*(R,R)*-**3**	97 : 3	34 (51)[h]	47	1*R*,2*R*-(+)

a) Ratio of alkene: H_2O_2: ax. ligand: salen= 1: 2.3-3.5: 0.7: 0.05. b)-e) See Table 1. f) Axial ligand was DMAP (+ BA).[8] Ratio of alkene: H_2O_2: DMAP: BA: 1= 1: 2.3: 0.5: 0.5: 0.025. g) 8 Mol-% of salen. h) Reaction was performed in 1 mmol scale of substrate.

In conclusion, it was shown that hydrogen peroxide together with conveniently synthesized salen complexes and imidazole ligand is an efficient system for catalytic and asymmetric epoxidation for both *cis*- and *trans*-alkenes. In all cases only a small excess of H_2O_2 was needed for complete reactions. Development of more effective salen catalysts to be used together with hydrogen peroxide is under way.

Acknowledgement: This work was supported by the Technology Development Centre of Finland (TEKES).

References and Notes

1. Parts of the results were presented in *1st National Symposium on Synthetic Chemistry*, Oulu, Finland, 28-29.5.1993, P24.
2. a) Zhang, W.; Loebach, J. L.; Wilson, S. R.; Jacobsen, E. N. *J. Am. Chem. Soc.* **1990**, *112*, 2801. b) Irie, R.; Noda, K.; Ito, Y.; Matsumoto, N.; Katsuki, T. *Tetrahedron Asymm.* **1991**, *2*, 481 and references therein.
3. a) Zhang, W.; Jacobsen, E. N. *J. Org. Chem.* **1991**, *56*, 2296. b) Jacobsen, E. N.; Zhang, W.; Muci, A. R.; Ecker, J. R.; Deng, L. *J. Am. Chem. Soc.* **1991**, *113*, 7063.
4. Yamada, T.; Imagawa, K.; Nagata, T.; Mukaiyama, T. *Chem. Lett.* **1992**, 2231.
5. Palucki, M.; Hanson, P.; Jacobsen, E. N. *Tetrahedron Lett.* **1992**, *33*, 7111.
6. Schwenkreis, T.; Berkessel, A. *Tetrahedron Lett.* **1993**, *34*, 4785.
7. Recent review on metalloporphyrin-catalyzed oxidations: Meunier, B. *Chem. Rev.* **1992**, *92*, 1411.
8. Chioccara, F.; Poli, S.; Rindone, B.; Pilati, T.; Brunow, G.; Pietikäinen, P.; Setälä, H. *Acta Chem. Scand.* **1993**, *47*, 610.
9. a) Battioni, P.; Renaud, J. P.; Bartoli, J. F.; Reina-Artiles, M; Fort, M.; Mansuy, D. *J. Am. Chem. Soc.* **1988**, *110*, 8462. b) Anelli, P. L.; Banfi, S.; Montanari, F.; Quici, S. *J. Chem. Soc., Chem. Commun.* **1989**, 779. c) Banfi, S.; Maiocchi, A.; Montanari, F.; Quici, S. *Gazz. Chim. Ital.* **1990**, *120*, 123.
10. Anelli, P. L.; Banfi, S.; Legramandi, F.; Montanari, F.; Pozzi, G.; Quici, S. *J. Chem. Soc., Perkin Trans. 1* **1993**, 1345 and references therein.
11. Irie, R.; Ito, Y.; Katsuki, T. *Synlett.* **1991**, 265.
12. Salen complex **1** was prepared from 3,5-di-*tert*-butyl-2-hydroxybenzaldehyde and 1,2-diaminoethane in 90 % yield according to ref. 3a.
13. Typical reaction procedure is as follows: To a solution of 1,2-dihydronaphthalene (65 mg, 0.499 mmol), imidazole (16 mg, 0.235 mmol), and catalyst **1** (6 mg, 0.012mmol) in CH_2Cl_2-CH_3OH (2.5 ml) was added 30 % aq. H_2O_2 (0.140 ml, 1.11 mmol) in four portions during 45 minutes. The mixture was stirred at room temperature and the reaction was monitored by TLC. After 2 hours, the mixture was diluted with CH_2Cl_2 and transferred into a separatory funnel containing water. The organic layer was separated, dried over Na_2SO_4, and concentrated. The residue was analysed by 200 MHz ^1H NMR and the epoxide was isolated by flash chromatography on silica gel (hexane/EtOAc).
14. Akhtar, M. N.; Boyd, D. R.; Hamilton, J. G. *J. Chem. Soc., Perkin Trans. 1* **1979**, 2437. Witkop, B.; Foltz, C. M. *J. Am. Chem. Soc.* **1957**, *79*, 197.
15. Hosoya, N.; Irie, R.; Katsuki, T *Synlett.* **1993**, 261.
16. The enantiomer of catalyst **3** has been used for the epoxidation of a conjugated *trans*-enyne: Lee, N. H.; Jacobsen, E. N. *Tetrahedron Lett.* **1991**, 32, 6533.

(*Received in UK* 12 *November* 1993; *revised* 2 *December* 1993; *accepted* 3 *December* 1993)