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Epoxidation of Olefins by Superoxide in the Presence of Acyl Halide

Superoxide ($O_2^{\cdot-}$) generated by crown ether/KO_2 or electrochemical method undergoes epoxidation of olefins in the presence of acyl halide of benzenesulfonyl chloride. The reaction mechanisms are also discussed.

Keywords——superoxide; epoxidation; monooxygenase; electrolysis; mass-fragmentgraphy

The important effects of superoxide ($O_2^{\cdot-}$) in biological systems have been increasingly evident in recent years.[1] Particularly $O_2^{\cdot-}$ has been considered to be valuable as one of the active oxygen species in monooxygenases.[2] On the other hand, the epoxidation is one of the most notable reactions catalyzed by monooxygenases.[3]

In this paper, we wish to report that $O_2^{\cdot-}$ reacts with olefins in the presence of acyl halide to give their oxides.[4] It has been already reported that diacyl peroxides were produced in the reaction of KO_2 with acyl chlorides.[5] Peroxo compounds ($RC(O)OO\cdot$, $RC(O)OO^-$ etc) are presumed to be involved as the intermediates in this reaction.[6] There are also some reports[7] that enones were oxidized by $O_2^{\cdot-}$ to give oxides. But it is not obvious whether active oxygen species producing enone oxides are $O_2^{\cdot-}$ or O_2^{2-} because these reactions (except ref. 7c)) can proceed also from O_2^{2-} easily produced by the dismutation of $O_2^{\cdot-}$ ($2O_2^{\cdot-} \rightarrow O_2^{2-} + O_2$).

In a typical experiment, 1.065 g (15 mmol) of powdered potassium superoxide (KO_2) was added to a mixture of benzoyl chloride (5 mmol) and 18-crown-6-ether (0.5 mmol) dissolved in dry benzene (50 ml). *trans*-Stilbene (1 mmol) was added then to the reaction mixture. The resulting mixture was vigorously stirred for 10 hr at 5—10°. After filtering, the filtrate was evaporated to dryness under reduced pressure. Resulting *trans*-stilbene oxide was purified by alumina column chromatography and recrystallized from hexane. yield: 40.8%, mp 68° (lit. 68—69°), MS *m/e*: 196 (M^+), NMR ($CDCl_3$/TMS) δ: 3.85 (2H, singlet) 7.35 (10H, singlet) (Chart 1) This reaction also proceeded with superoxide ($O_2^{\cdot-}$) generated electrochemically.[8] The CH_3CN solution of superoxide (6×10^{-2} mmol) generated electrochemically was added to the CH_3CN soltion of *trans*-stilbene (1 mmol) and benzoyl chloride (2×10^{-2} mmol). Resul-

1) J.M. McCord and I. Fridovich, *J. Biol. Chem.*, **244**, 604 (1969); I. Fridovich, *Acc. Chem. Res.*, **5**, 321 (1972); I. Fridovich, *Science*, **201**, 875 (1978); E. Lee-Ruff, *Chem. Soc. Rev.*, **6**, 195 (1977); A.A. Frimer and I. Rosenthal, *Photochem. Photobiol.*, **25**, 711 (1978).
2) G.A. Hamilton, *Adv. Enzymol.*, **32**, 55 (1969); E.T. Kaiser, F.J. Kezdy, eds., "Progress in Bioorganic Chemistry," Vol. 1, Wiley, New York 1971, p. 83.
3) O. Hayaishi, ed., "Molecular Mechanisms of Oxygen Activation," Academic Press, New York, 1974; F. Hirata, O. Hayaishi, *J. Biol. Chem.*, **246**, 7825 (1971).
4) T. Nagano, K. Arakane, and M. Hirobe, 6th Symposium on Progress in Organic Reactions and Syntheses, Tokyo, Abstract pp. 114, 1979, A related investigation was recently shown in the following communication, in which our paper presented in the above symposium was cited; S. Oae and T. Takata, *Tetrahedron Lett.*, **1980**, 3689.
5) R.A. Johnson, *Tetrahedron Lett.*, **1976**, 331; W.C. Danen and R.L. Arudi, *J. Am. Chem. Soc.*, **100**, 3944 (1978).
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7) *a*) R. Diets, A.E.J. Forno, B.E. Larcombe, and M.E. Peover, *J. Chem Soc., B.* **1970**, 816; *b*) A.A. Frimer and P. Gilinsky, *Tetrahedron Lett.*, **1979**, 4331; *c*) I. Saito, T. Otsuki, and T. Matsuura, *Tetrahedron Lett.*, **1979**, 1693; *d*) M. Matsuo, S. Matsumoto, Y. Iitaka, A. Hanaki, and T. Ozawa., *J.C.S., Chem. Comm.*, **1979**, 105.
8) The electrolysis of oxygen was carried out according to the modification of the procedure used by J.M. McCord, I. Fridovich, and T. Ozawa *et al.*, cell: H type cell with a sintered glass disk; electrode: Pt (cathode), Pt (anode); solvent: CH_3CN (100 ml); supporting electrode: 0.1 M tetra-butyl ammonium bromide; constant potential: −0.87 V *vs.* SCE. J.M. McCord and I. Fridovich, *J. Biol. Chem.*, **244**, 6049 (1969); T. Ozawa, A. Hanaki, and H. Yamamoto, *FEBS Lett.*, **74**, 99 (1977).

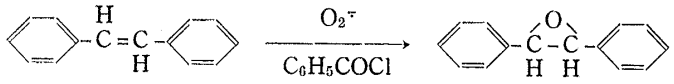

Chart 1

TABLE I.[a] The Yields of *trans*-Stilbene Oxide in the Reaction of *trans*-Stilbene with KO_2 in the Presence of Various Carboxylic Acid Derivatives RCOX and Crown Ether in C_6H_6

Entry	Stilbene	RCOX		Stilbene oxide	Recovery
1	1 mmol	C_6H_5COCl	5 mmol	40.8%	41.7%
2	1 mmol	2,4-diCl-C_6H_3COCl	5 mmol	38.3%	32.2%
3	1 mmol	4-NO_2-C_6H_4COCl	5 mmol	21.9%	51.9%
4	1 mmol	3,5-diNO_2-C_6H_3COCl	5 mmol	4.2%	79.4%
5	1 mmol	CH_3COCl	5 mmol	11.8%	81.1%
6	1 mmol	$(C_6H_5CO)_2O$	5 mmol	Trace (<1%)[b]	c)
7	1 mmol	$C_6H_5COOCH_3$	5 mmol	0%	c)
8	1 mmol	C_6H_5COOH	5 mmol	Trace	c)

a) KO_2: 15 mmol, crown ether: 0.5 mmol, solvent: benzene, reaction time: 10h, reaction temp.: 5—10°.
b) Recently a different result was reported.[9]
c) Not determined.

ting *trans*-stilbene oxide was detected by mass-fragmentography. (instrument: Shimadzu LKB 9000, col.: 3% SE-30 3 mm×1 m, col. temp.: 180°, sep. temp.: 300°, sample temp.: 240°, ion source temp.: 290°, elect. energy: 20 eV, A.V.A.: *m/e* 195, 196).

The yields of *trans*-stilbene oxide obtained by the reaction with KO_2 in the presence of various carboxylic acid derivatives RCOX are shown in Table I. Better yields were obtained by using aromatic acyl chloride (Entry 1,2 and 3) than acetyl chloride (Entry 5). The oxide yield was low in the case of 3,5-dinitrobenzoyl chloride (Entry 4).[10] Furthermore, even if $(C_6H_5CO)_2O$, $C_6H_5COOCH_3$ and C_6H_5COOH were used as RCOX hardly any oxide was formed (Entry 6, 7 and 8). Next the yields were examined with various KO_2/C_6H_5COCl ratio (Fig. 1). When the KO_2/C_6H_5COCl ratio is below 1, the yield was extremely low. However, yields increased remarkably at a ratio of $KO_2/C_6H_5COCl=2$. Beyond 2, there were observed no longer any increase in yield.

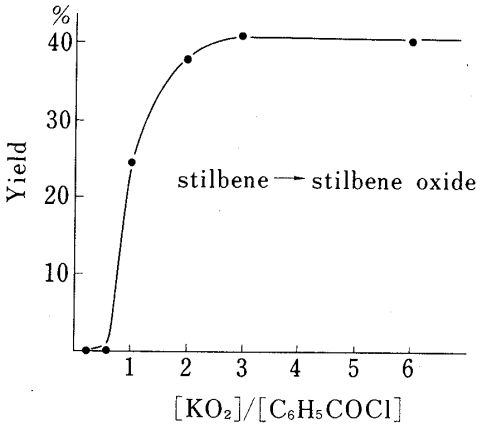

Fig. 1. The Relationship between the Yields of *trans*-Stilbene Oxide and the KO_2/C_6H_5COCl Ratio

C_6H_5COCl: 5 mmol, *trans*-stilbene: 1 mmol, crown ether: 0.5 mmol, solvent: benzene, reaction time: 10 h, reaction temp. 5—10°.

In addition, the yields of *trans*-stilbene oxide were obtained from the reactions of C_6H_5COCl/*trans*-stilbene ratio at the constant ratio of $KO_2/C_6H_5COCl=3$ (Table II). Here the yields increased as increasing the C_6H_5COCl/*trans*-stilbene ratio.

In the presence of Na_2O_2, H_2O_2 or *tert*-BuOOH in place of KO_2 none or trace amount of *trans*-stilbene oxide was found, and *trans*-stilbene was recovered.

Other olefin except *trans*-stilbene and amine were investigated. Cyclohexene and pyridine gave

9) J.P. Stanley, *J. Org. Chem.*, **45**, 1413 (1980).
10) The low yield in this reaction may be due to the formation of dinitrobenzene anion radical. A. Frimer and I. Rosenthal, *Tetrahedron Lett.*, **1976**, 2809.

Table II.[a] The Yields of *trans*-Stilbene Oxide by KO_2 at the Various C_6H_5COCl/*trans*-Stilbene Ratio

Entry	Stilbene	C_6H_5COCl	KO_2	Stilbene oxide
1	1 mmol	1 mmol	3 mmol	20.9%
2	1 mmol	3 mmol	9 mmol	31.1%
3	1 mmol	5 mmol	15 mmol	40.8%
4	1 mmol	10 mmol	30 mmol	45.9%
5	1 mmol	20 mmol	60 mmol	72.4%

a) crown ether/KO_2=1/30, solvent: benzene, reaction time: 10 h, reaction temp.: 5—10°.

cyclohexene oxide (34%) and pyridine N-oxide (7.2%), respectively, under the same conditions. (substrate: 1 mmol, C_6H_5COCl: 5 mmol, KO_2: 15 mmol, crown ether: 0.5 mmol, benzene: 50 ml).

The reaction mechanisms may be presumed as shown in Chart 2. C_6H_5COCl reacts with O_2^- to become $C_6H_5C(O)OO\cdot$ which is rapidly reduced by one electron transfer from O_2^- to produce $C_6H_5C(O)OO^-$. $C_6H_5C(O)OO^-$ seems to oxidize substrates (S) to give oxides (SO). On the other hand, C_6H_5COCl and O_2^{2-} afforded easily $(C_6H_5COO)_2O_2$ by nucleophilic substitution at the carbonyl carbon by O_2^{2-} without oxidation even if substrates such as olefins or pyridine were present in the reaction solution. It is because C_6H_5COCl may react slower with O_2^{2-} than O_2^- and the resulting intermediate $C_6H_5C(O)OO^-$ reacts not with olefins but with C_6H_5COCl remaining in the reaction solution to give $(C_6H_5COO)_2O_2$. However it is also possible that since 2 equimolar amounts of O_2^- reacts more rapidly with C_6H_5COCl to give $C_6H_5C(O)OO^-$, C_6H_5COCl does not survive in the reaction solution, and thus $C_6H_5C(O)OO^-$ reacts not with C_6H_5COCl but with olefins or pyridine.

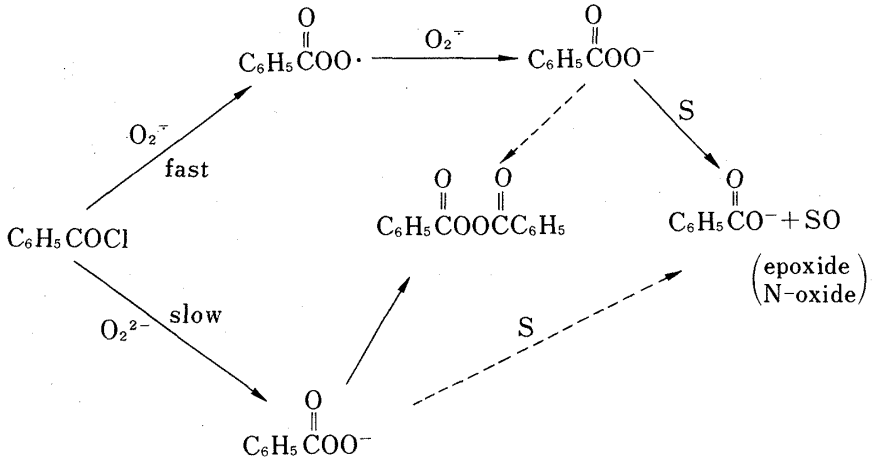

Chart 2

In addition, in the presence of $C_6H_5SO_2Cl$ instead of RCOCl, *trans*-stilbene, cyclohexene and pyridine were found to be oxidized by KO_2 to *trans*-stilbene oxide (30.0%), cyclohexene oxide (16.5%) and pyridine oxide (0.8%), respectively, under similar conditions. Studies on the scope and limitation of these reactions are in progress and detailed results will be reported in the following paper.

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