Tetrahedron Letters,Vol.24,No.34,pp 3631-3634,1983   0040-4039/83 $3.00 + .00
Printed in Great Britain

MILD AND SELECTIVE OXYGEN ATOM TRANSFER: $^{n}Bu_4NIO_4$ WITH METALLOPORPHYRINS

Toshikazu Takata and Wataru Ando*

Department of Chemistry, University of Tsukuba
Sakura, Ibaraki 305, Japan

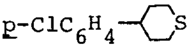
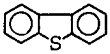
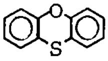
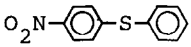
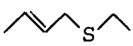
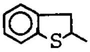
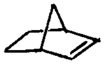
Abstract: Tetrabutylammonium periodate, $^{n}Bu_4NIO_4$, is a potent oxygen atom donor to substrates in the presence of catalytic amount of metalloporphyrin under neutral and homogeneous conditions, the results obtained suggesting the formation of oxo-metalloporphyrin as an active oxidizing intermediate.

Considerable attentions have been focused on metalloporphyrin-catalyzed oxidations with monooxygen donors, since the oxidations can well model monooxygenase reactions.[1] Oxo-metalloporphyrin as an actual oxidizing intermediate in the oxidations indeed corresponds to the active species in the monooxygenase reactions.[1] Although several model oxidation systems involving both oxygen donors such as iodosylarenes and peroxides and metalloporphyrins have been developed,[1,2] most of them do not satisfy the requirement of both neutrality and homogeneity for detail study on the oxidation in inert solvent.

Tetrabutylammonium periodate, $^{n}Bu_4NIO_4$, recently prepared,[3] is well soluble in dichloromethane, chloroform etc. but hardly soluble in water, alcohol etc., and is only used as a neutral weak oxidant for sulfides, α-bromoketones and α-hydroxycarboxylic acids.[3] Here, the authers wish to report that $^{n}Bu_4NIO_4$ can serve as a potent monooxygen donor by combining with metalloporphyrins under neutral and homogeneous conditions.

In a typical experiment, a homogeneous mixture of diphenyl sulfide(1.0 mmol), $^{n}Bu_4NIO_4$(1.1 mmol) and 5,10,15,20-tetraphenylporphinatoiron(III)chloride (TPPFe(III)Cl, 0.02 mmol, 2%) was stirred in chloroform(5 mL) for 1.5 h at r.t., monitoring the disappearance of diphenyl sulfide by TLC. The resulting mixture was directly subjected to column chromatography for purification(silica gel, $CHCl_3$).[4] Diphenyl sulfoxide as single product was obtained in 95% yield without any diphenyl sulfone. Selected results for several substrates are listed in Table 1.

Table 1 Oxidation with $^{n}Bu_4NIO_4$ - TPPFe(III)Cl system at r.t.$^{a)}$

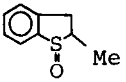
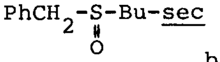
Entry	Substrate	Cat/%	Time/h	Sulfoxide yield/% Isolated(GC yield)	
1	PhSPh	0	8(reflux)	72	b)
2	PhSPh	3.0	2	95	
3		1.0	10	90	c)
4		2.0	1.5	84 (100)	
5		1.7	2.0	96	
6	$PhCH_2SCH_2Ph$	1.5	7	- (80)	
7		2.0	2.5	- (85)	
8		2.4	2	79 (95)	
9	$PhCH_2SBu$-sec	0.9	11	87	d)
10		1.0	8	93	c)
11	t-BuSSBu-t	1.3	20	90	e)
12		3.0	48	- (60)	f)

a) Solvent used was CH_2Cl_2 or $CHCl_3$, but there was no clear difference between both solvents. b) data from ref. 3. c) *cis* and *trans* mixture. d) *threo* and *erythro* mixture. e) The product was thiosulfinic S-ester, *t*-BuS(O)SBu-*t*. f) TPPMn(III)Cl(3.0%) was used and the yield is that of *exo*-epoxide as a sole product.

Clearly, TPPFe(III)Cl is shown to cause the strong acceleration for sulfide oxidation(Table 1, Entries 1 and 2), suggesting that it has high activity as a catalyst. At r.t., the oxidation did not proceed in the absence of the catalyst in more than ten hours. The oxidation of the sulfides resisting usual oxidation such as *p*-nitrophenyl phenyl sulfide and di-*t*-butyl disulfide, also occurred with high selectivity at r.t.(Table 1). Less amount of TPPFe(III)Cl than 1% vs. substrate often resulted in incomplete oxidation remaining the unreacted substrate. Presumably, the catalyst is slowly consumed under the reaction conditions.

TPPMn(III)Cl was much less effective than TPPFe(III)Cl in sulfide oxidation, producing diphenyl sulfoxide in 40 - 50% for a day with accompanying diphenyl sulfone(20 - 30%). However, in the case of olefin as a substrate TPPMn(III)Cl was superior to TPPFe(III)Cl(Table 1, Entry 12).^{5} So, olefinic function in

Table 2 Stereochemistry of sulfoxides formed in the oxidations with TPPFe(III)Cl - $^{n}Bu_4NIO_4$ system[a] and other systems.

Entry	Oxidation System	 cis / trans	 $\mathrm{PhCH_2\text{-}\underset{\underset{O}{\|}}{S}\text{-}Bu\text{-}\underline{sec}}$ threo / erythro[b]
1	$^{n}Bu_4NIO_4$/TPPFe(III)Cl[a]	23 / 77	46 / 54
2	Cytochrome P-450/NADPH/O_2[c]	19 / 81	34 / 66
3	PhIO/TPPMn(III)Cl[d]	21 / 79	39 / 61
4	$^{n}Bu_4NIO_4$[e]	38 / 62	-
5	$NaIO_4$[c]	48 / 52	58 / 42
6	MCPBA[c]	47 / 53	54 / 46

a) the reaction at r.t. b) Whether threo/erythro or erythro/threo is not clear. c) data from ref. 11. d) data from ref. 2b. e) the reaction under refluxing chloroform for 42 h.

allyl sulfide was inert to the oxidation with TPPFe(III)Cl but sulfide group was selectively converted to sulfoxide group(Table 1, Entry 8).

Alkyl sulfides were generally oxidized so rapidly than aromatic ones with $^{n}Bu_4NIO_4$,[3] but in the oxidation with TPPFe(III)Cl - $^{n}Bu_4NIO_4$, aromatic sulfides appeared to be more reactive than alkyl sulfides(Table 1). One would expect such metalloporphyrin - $^{n}Bu_4NIO_4$ system involves oxo-metalloporphyrin[7] formed as an actual oxidizing intermediate.[2b] Supporting result of the formation of the intermediate was observed in the reaction of N,N-dimethylaniline with TPPFe(III)Cl-$^{n}Bu_4NIO_4$, which yielded N-methylaniline(80%) and aniline(5%)(Eq. 1).[9] This oxidative demthylation mimics the enzyme reaction with cytochrome P-450.[9,10]

$$\mathrm{PhNMe_2} \xrightarrow[\mathrm{CHCl_3,\ r.t.,\ 3\ h,\ 90\%\ conversion}]{^{n}\mathrm{Bu_4NIO_4(1.5\ eq.)\ /\ TPPFe(III)Cl(3.0\%)}} \mathrm{PhNHMe} + \mathrm{PhNH_2} \qquad (1)$$

Furthermore, the ratios of two diastereomeric sulfoxides formed in the oxidations of racemic sulfides, 2-methyl-2,3-dihydrobenzothiophene and benzyl sec-butyl sulfide, with TPPFe(III)Cl - $^{n}Bu_4NIO_4$ system were similar to those with cytochrome P-450 enzyme but significantly different from those with $^{n}Bu_4NIO_4$, $NaIO_4$ and m-chloroperbenzoic acid(Table 2).[11]

Thus, metalloporphyrin - $^{n}Bu_4NIO_4$ is found to be a mild and selective oxidation system under neutral and homogeneous conditions, and one of the monooxygenase model systems, probably having oxo-metalloporphyrin as an actual oxidizing species.

REFERENCES AND FOOTNOTES

1)a) Bertin, I., Drago, R. S. Eds.," The Coordination Chemistry of Metalloenzymes ", D. Reidel Publishing, Dordrecht, Holland, 1983.

b) Coon, M. J., Conney, A. H., Estbrook, R. W., Gelboin, H. V., Gillette, J. R., O'Brien, P. J. Eds.," Microsomes, Drug Oxidations, and Chemical Carcinogenesis ", Academic Press, New York, New York, 1980.

c) Hayaishi, O. Ed.," Molecular Mechanism of Oxygen Activation ", Academic Press, New York, New York, 1974.

d) Sodium periodate as well as sodium chlorite and organic peroxides is known to be an effective monooxygen donor in the hydroxylation catalyzed by cytochrome P-450: Hrycay, E. G., Gustafsson, J.-Å, Ingelman-Sundberg, M., Ernster, L., FEBS Lett., 1975, 56, 161 - 5; idem, Eur. J. Biochem., 1976, 61, 43 - 52.

2)a) Sheldon, R. A., Kochi, J. K.," Metal-catalyzed Oxidations of Organic Compounds ", Academic Press, New York, New York, 1981.

b) Takata, T., Tajima, R., Ando, W., Phosphorus and Sulfur, in press(1983) and references cited therein; idem, Tetrahedron Lett., 1982, 23, 1685 - 8.

3) Santaniello, E., Mazocchi, A., Farachi, C., Synthesis, 1980, 563 - 4.

4) Reduced form of $^{n}Bu_4NIO_4$(probably $^{n}Bu_4NIO_3$) was not eluted through silica gel column with chloroform.

5) This difference of the catalytic ability between TPPFe(III)Cl and TPPMn(III)Cl may depend on the electronic states of the central metals.^{2b,6}

6) Groves, J. T., Nemo, T. E.," Models of Metalloenzymes: Peroxidase and Cytochrome P-450 ", Chapter 38 in ref. 1a.

7) Unfortunately, no observable change was confirmed in electronic spectra when $^{n}Bu_4NIO_4$ was added into TPPMn(III)Cl in CH_2Cl_2, although with the use of ArIO clear increase of absorption at 422 nm corresponding to oxo-TPPMn(V)Cl and decrease at 481 nm(TPPMn(III)Cl), were observed.^{2b,8}

8)a) Hill, C. L., Schardt, B. C., J. Am. Chem. Soc., 1980, 102, 6374 - 5.

b) Groves, J. T., Kruper Jr., W. T., Haushalter, R. C., ibid, 1980, 102, 6375 - 7.

9) Bruice et al. have demonstrated the demethylation of N,N-dimethylaniline with the system of TPPFe(III)Cl - PhIO(or N,N-dimethylaniline N-oxide): Shannon, P., Bruice, T. C., J. Am. Chem. Soc., 1981, 103, 4580 - 2; Nee, M. W., Bruice, T. C., ibid, 1982, 104, 6123 - 5.

10) Gorrod, J. W.," Biological Oxidation of Nitrogen ", Elsevier / North Holland Biomedical Press, New York, New York, 1978.

11) Takata, T., Yamazaki, M., Fujimori, K., Kim, Y. H., Oae, S., Iyanagi, T., Chem. Lett., 1980, 1441 - 4; idem, Bull. Chem. Soc. Jpn., in press(1983).

(Received in Japan 6 May 1983)