Oxidation of Primary Aromatic Amines to Nitro Derivatives catalysed by Iron(III) and Manganese(III) Tetraaryl Porphyrins

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The oxidation of primary aromatic amines to the corresponding nitro derivatives has been observed in catalytic systems (turnovers/hour up to 18 000) containing *tert*-butyl hydroperoxide and metallo-tetraaryl porphyrins (metal = Fe^{III} or Mn^{III}) in the presence of heterocyclic nitrogen bases acting as axial ligands.

It is well known that metallo-porphyrins catalyse the hydroxylation of alkanes, the epoxidation of alkenes[1] and the oxidative dealkylation of heteroatom-substituted organic compounds in the presence of various single oxygen atom donors.[2] Related to our interest in the oxidation reactions of amines,[3] we report here a study on the use of iron(III) and manganese(III) tetraaryl porphyrins as catalysts, M(**P**)Cl (**1–4**; 10^{-3} mmol),† in the oxidation of aromatic primary amines, $RC_6H_4NH_2$ (**5–12**; 0.1 mmol), which affords the corresponding nitro derivatives, $RC_6H_4NO_2$ (**5a–12a**), in the presence of Bu^tOOH (0.1 ml of a 3 mol l^{-1} isooctane solution; 0.3 mmol), and an axial ligand L [eqn. (1)].

$$\underset{\mathbf{5-12}}{RC_6H_4NH_2} \xrightarrow[Bu^tOOH,\ L]{M(\mathbf{P})Cl,\ \mathbf{1-4}} \underset{\mathbf{5a-12a}}{RC_6H_4NO_2} \qquad (1)$$

1, M(**P**) = Fe^{III} (tpp)
2, M(**P**) = Mn^{III} (tpp)
3, M(**P**) = Fe^{III} (2,6-Cl_2 tpp)
4, M(**P**) = Mn^{III} (2,6-Cl_2 tpp)

5, R = H
6, R = *p*-Me
7, R = *p*-Br
8, R = *p*-Cl
9, R = *p*-NO_2
10, R = *p*-F
11, R = *m*-Me
12, R = *p*-OMe

L = imidazole, 1-methylimidazole, 2-methylimidazole or 4-*tert*-butylpyridine.

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† H_2tpp = 5,10,15,20-tetraphenylporphyrin; H_2(2,6-Cl_2tpp) = 5,10,15,20-tetrakis (2,6-dichlorophenyl)porphyrin.

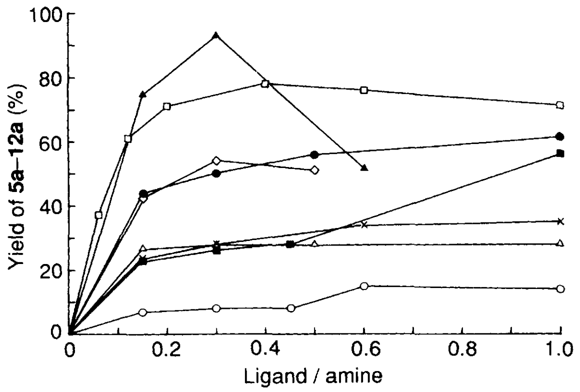

Fig. 1 Yields of nitro aromatic compounds from catalytic oxidation of aromatic amines **5–12** by Fe(tpp)Cl and Bu^{t}OOH in the presence of varying amounts of 1-methylimidazole: (◇) **5a**; (▲) **6a**; (●) **7a**; (□) **8a**; (■) **9a**; (△) **10a**; (×) **11a**; (○) **12a**. **1**, 10^{-3} mmol; amine, 0.1 mmol; Bu^{t}OOH, 0.3 mmol; solvent, CH_2Cl_2 (5 ml). Yields are for isolated nitro derivatives **5a–12a**.

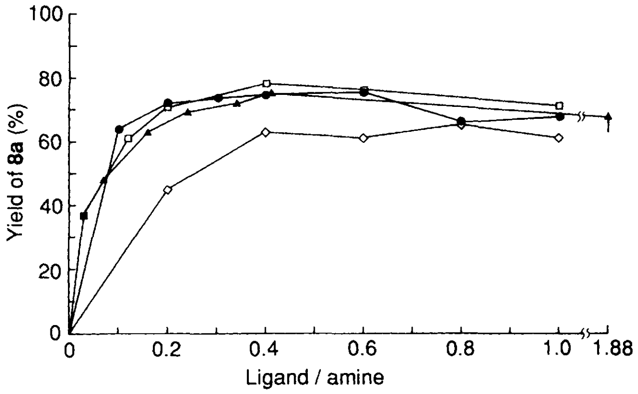

Fig. 2 Yields of *p*-$ClC_6H_4NO_2$ **8a** from catalytic oxidation of **8** by Fe(tpp)Cl and Bu^{t}OOH in the presence of varying amounts of axial ligands: (▲) imidazole; (●) 2-methylimidazole; (□) 1-methylimidazole; (◇) 4-*tert*-butylpyridine. **1**, 10^{-3} mmol; **8**, 0.1 mmol; Bu^{t}OOH, 0.3 mmol; solvent, CH_2Cl_2 (5 ml). Yields are for isolated **8a**.

Table 1 Yields of *p*-$ClC_6H_4NO_2$ **8a** from catalytic oxidation of **8** in the presence of varying amounts of Fe(tpp)Cl[a]

t/h	Cat. : **8** : Bu^{t}OOH : L	Conversion (%)	Yield of **8a** (%)	Turnover/ h^{-1}
0.25	1 : 10 : 30 : 4	99	73	27.6
0.25	1 : 100 : 300 : 40	100	78	312
0.25	1 : 1000 : 3000 : 400	100	64	2560
0.33	1 : 10000 : 30000 : 4000	100	63	18920
0.25	1 : 1000 : 3000 : 40	20	14	

[a] **8**, 0.1 mmol; Bu^{t}OOH, 0.3 mmol; 1-methylimidazole (L), 0.4 mmol; Fe(tpp)Cl, 10^{-2}, 10^{-3}, 10^{-4} and 10^{-5} mmol; solvent, CH_2Cl_2 (5 ml). Yields are for isolated **8a**. Turnover = mol of nitro compound/mol of catalyst.

At room temperature, in CH_2Cl_2 (5 ml) and in the presence of an appropriate amount of 1-methylimidazole, the conversion of **5–12** is total after 15 min, while the yields of **5a–12a** range between 93 and 15% (see Fig. 1). The products, detected by gas chromatography–mass spectrometry and gas chromatography and quantified after separation by flash chromatography were not appreciably different under aerobic or anaerobic conditions. Among the oxidation products, only the nitro aromatic compounds **5a–12a** were clearly identified.

Only in the oxidation of **12**, at −40 °C, were the corresponding azo and azoxy derivatives (arising from the intermediate formation of the hydroxylamine and the nitroso derivative) detected. This evidence and the molar ratio of amine to oxidant (1 : 3) suggest that the oxidation could follow the usual steps: amine → hydroxylamine → nitroso → nitro. However, none of these intermediate compounds was detected using higher molar ratios of amine to oxidant.

Blank experiments carried out on the amines **5** and **7–11** showed that, in the absence of catalyst or Bu^{t}OOH or axial ligand L, no oxidation to the nitro compounds occurs, although complete conversion of the substrates to unidentified products may occur. In contrast, **6** and **12**, even in the absence of L, gave the expected products but with longer reaction times (1.5 h). Under these conditions, the yields of *p*-nitrotoluene **6a** and *p*-nitroanisole **12a** were 64 and 17.5% respectively.

The effect of various ligands (imidazole, 1-methylimidazole, 2-methylimidazole, 4-*tert*-butylpyridine) on the yields of nitro derivatives was studied (Fig. 2). No significant differences were observed within the imidazole series, while the more weakly coordinating 4-*tert*-butylpyridine[4] gave lower yields. The amount of added ligand for optimum yields of the nitro derivatives **5a–12a**, obtained with Fe(tpp)Cl as catalyst (Fig. 1) depends on the amine, but the best results were obtained, as a rule, with molar ratios of ligand to amine in the range 0.3–0.5 : 1, which corresponds to an initial molar ratio of ligand to metallo-porphyrin of 30–50 : 1.

These results clearly indicate that an electron-donating axial substituent coordinated to the metal is essential to force the reaction pathway towards the desired products. Indeed, the best results were obtained by using the most strongly coordinating ligand, 1-methylimidazole, whose effect is analogous to that reported on olefin epoxidation by Fe^{3+} or Mn^{3+} porphyrins in the presence of hydrogen peroxide or hypochlorite.[5] The higher coordinative capability of the ligand L compared to the amines is evidenced by the spectral changes of the Fe(tpp)Cl Soret band at 416 nm, in the presence of 1-methylimidazole (0–40 mol. equiv.) or in the presence of toluidine (0–100 mol. equiv.), the presence of the former showing a tenfold greater effect.

The catalytic system still proved to be efficient when 10^4 mol equiv. of amine with respect to the catalyst were used (Table 1). Very high turnovers/hour (18 900) were observed. On increasing the molar ratio of amine to catalyst, longer reaction times are needed in order to obtain the highest yield of nitro compound (entry 4, Table 1). In this case, the ratio of axial ligand to substrate must be about 0.4 : 1, *i.e.* 4000 times the amount of metallo-porphyrin. It is interesting that a very large quantity of ligand has the opposite effect in olefin epoxidation promoted by hypochlorite, hydrogen peroxide and other oxidants, which may be explained by the formation of the poorly reactive bis-ligated $M(\mathbf{P})L_2$ species[6] [eqn. (2)].

$$M(\mathbf{P}) + L \rightarrow M(\mathbf{P})L + L \rightarrow M(\mathbf{P})L_2 \qquad (2)$$

The difference in the two systems could be due to the fact that the amine coordinates, albeit weakly, to the M(**P**) species whereas the olefin does not and therefore the imidazole must compete for the coordination with the amine [eqn. (3)]. Thus

$$M(\mathbf{P})\ (\text{amine}) + L \rightleftharpoons M(\mathbf{P})L + \text{amine} \qquad (3)$$

the equilibrium (3) is shifted far to the right only in the presence of a large excess of L.

The reactions of the manganese(III) porphyrins **2** and **4** with the amines **6**, **8** and **12** were carried out under the same conditions as for the iron(III) complexes. Good yields of the nitro derivatives **6a** and **8a** were obtained, but longer reaction times were needed for the highest conversions (2 and 5 h, respectively). Both the manganese(III) complexes **2** and **4** are less efficient in the oxidation of the aromatic amines to the nitro derivatives than the iron(III) complexes.

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References

1 B. Meunier, *Bull. Soc. Chim. Fr.*, 1985, 578; P. R. Ortiz de Montellano, *Cytochrome P-450, Structure, Mechanism and Biochemistry*, Plenum Press, New York and London, 1986; D. Mansuy, *Pure Appl. Chem.*, 1987, **59**, 759; I. Tabushi, *Coord. Chem. Rev.*, 1988, **86**, 1; T. C. Bruice, *Mol. Struct. Energ.*, 1989, **9**, 227; J. E. Baldwin and P. Perlmutter, *Top. Curr. Chem.*, 1984, **121**, 181; B. Morgan and D. Dolphin, *Struct. Bonding (Berlin)*, 1987, **64**, 115; C. L. Hill, *Activation and Functionalization of Alkanes*, Wiley, New York, 1989; D. Mansuy, P. Battioni and J. P. Battioni, *Eur. J. Biochem.*, 1989, **184**, 276; S. Banfi, A. Maiocchi, F. Montanari and S. Quici, *Chim. Ind. (Milan)*, 1990, **72**, 304; M. J. Gunter and P. Turner, *Coord. Chem. Rev.*, 1991, **108**, 115.

2 J. R. Lindsay Smith and D. N. Mortimer, *J. Chem. Soc., Chem. Commun.*, 1985, 64; J. R. Lindsay Smith and P. R. Sleath, *J. Chem. Soc., Perkin Trans. 2*, 1982, 1009; 1983, 1165; P. Shannon and T. C. Bruice, *J. Am. Chem. Soc.*, 1981, **103**, 4580; D. Ostovic, C. B. Knobler and T. C. Bruice, *J. Am. Chem. Soc.*, 1987, **109**, 3444; D. Mansuy and P. M. Dansette, *Biochem. Biophys. Res. Commun.*, 1980, **96**, 433.

3 S. Cenini, F. Porta and M. Pizzotti, *J. Mol. Cat.*, 1982, **15**, 297; F. Porta, C. Crotti, S. Cenini and G. Palmisano, *J. Mol. Cat.*, 1989, **50**, 333; F. Porta, S. Tollari, F. Ragaini and C. Crotti, *Dioxygen Activation and Homogeneous Catalytic Oxidation*, ed. L. I. Simandi, Elsevier, Amsterdam, 1991, p. 531.

4 F. A. Walker, N. W. Lo and M. T. Ree, *J. Am. Chem. Soc.*, 1976, **96**, 5552.

5 P. Battioni, J. P. Renard, J. F. Bartoli, M. Reina-Artiles, M. Fert and D. Mansuy, *J. Am. Chem. Soc.*, 1988, **110**, 8462; P. L. Anelli, S. Banfi, F. Montanari and S. Quici, *J. Chem. Soc., Chem. Commun.*, 1989, 779; S. Banfi, A. Maiocchi, F. Montanari and S. Quici, *Gazz. Chim. Ital.*, 1990, **120**, 123.

6 S. Banfi, F. Montanari and S. Quici, *J. Org. Chem.*, 1989, **54**, 1850.