

## Reaction between Binuclear Iron(III) Compounds and DMPO (5,5-Dimethyl-3,4-dihydropyrrole *N*-Oxide)

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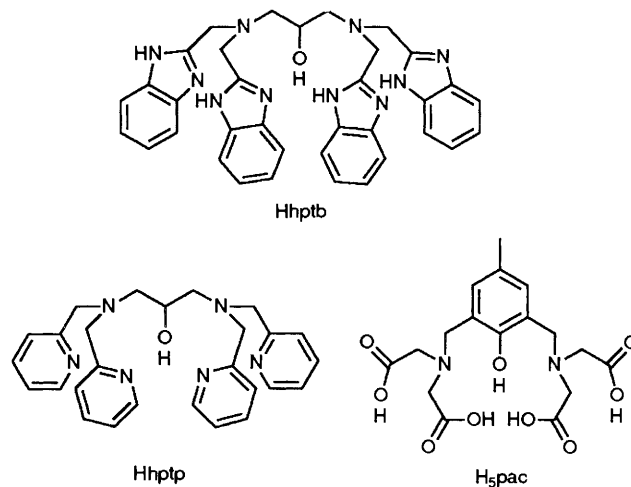
Several binuclear iron(III) compounds with a  $\mu$ -alkoxo or  $\mu$ -oxo bridge react with the spin-trapping reagent DMPO to yield DMPO-OH; the mechanism of the formation of DMPO-OH in solution is discussed.

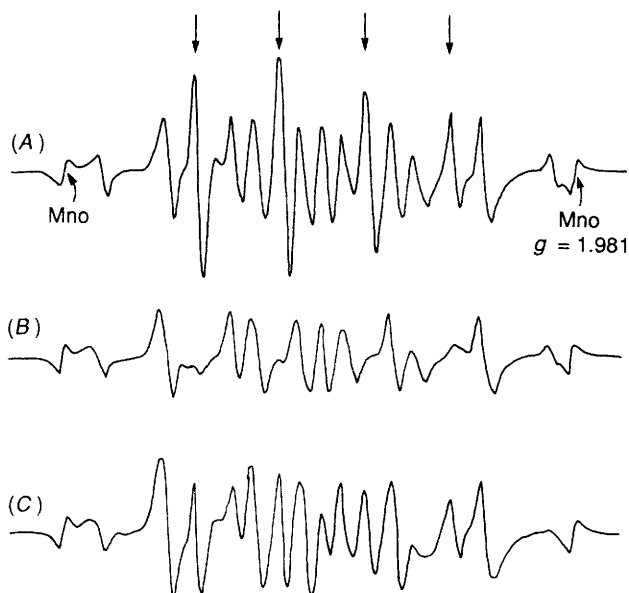
There has been much recent interest in the interpretation of the mechanism of activation of molecular oxygen by metal complexes. For this purpose spin-trapping reagents, thought to provide a most reliable method for detection of active oxygen radicals such as  $\text{OH}\cdot$  and  $\text{O}_2^-$ , have frequently been used,<sup>1</sup> but sometimes the results obtained by this method have led to confusion in determining the reaction intermediate.<sup>2</sup> Awai *et al.*<sup>3</sup> reported that several EPR-detectable DMPO derivatives are formed in reaction mixtures including DMPO and an  $\text{Fe}^{\text{III}}$ -nta complex ( $\text{H}_3\text{nta}$  = nitrilotriacetic acid). They also reported that the EPR features of the solution obtained were similar to those observed in a reaction mixture containing DMPO and Rose Bengal, for reasons which are not yet clear. We recently crystallized the  $\text{Fe}^{\text{III}}$ -nta complex,<sup>4</sup> and determined its crystal structure; the result clearly suggests that the iron(III) species which can generate the EPR-detectable species in reaction with DMPO is a binuclear compound with a  $\mu$ -oxo bridge. In this study we have investigated the reaction between DMPO and several binuclear iron(III) compounds in order to elucidate the mechanism of formation of EPR-detectable DMPO derivatives by binuclear iron(III) complexes.

The complexes used in this study are  $\text{Fe}_2(\text{hptb})(\text{OH})(\text{NO}_3)_4$ ,<sup>5</sup>  $[\text{Fe}_2(\text{pac})(\text{AcO})_2]^-$ ,<sup>6</sup> and  $\text{Fe}_2(\text{hptp})(\text{OH})(\text{NO}_3)_2(\text{ClO}_4)_2$ .<sup>7</sup>

Fig. 1 shows EPR spectra obtained for reaction mixtures containing DMPO (Mitsui Toatsu Chemical Co.) and the binuclear iron(III) compounds. The three spectra are similar, except for the intense four lines observed for  $[\text{Fe}_2(\text{hptb})(\text{OH})(\text{NO}_3)_2]^{2+}$  and  $[\text{Fe}_2(\text{hptb})(\text{OH})(\text{NO}_3)_2]^{2+}$  [see Fig. 1, traces (A) and (C)]. Based on the peak-to-peak separation (average separation, 1.5 mT) and  $g$ -value, these four lines can be attributed to DMPO-OH.<sup>1</sup> It should be noted here that the intensity of the EPR signal due to DMPO-OH is negligible in the mixed solution with  $[\text{Fe}_2(\text{pac})(\text{AcO})_2]^-$ .

We have previously observed<sup>5</sup> that the binuclear complex  $[\text{Fe}_2(\text{hptb})(\text{OH})(\text{NO}_3)_2]^{2+}$  exhibits high catalytic activity for oxidation of tmpd (*N,N,N',N'*-tetramethyl-*p*-phenylenediamine) by dioxygen, and assumed that the oxidation of tmpd would proceed *via* the intermediate complex in Fig. 2, on the basis of the very low activity of the corresponding mononuclear iron(III) complexes in this reaction. It is known that the binuclear iron(III) compounds used in this study react with hydrogen peroxide, to yield a 1:1 peroxide adduct.<sup>5-7</sup> We have already pointed out that the peroxide ion trapped by binuclear iron(III) complexes is activated and contains some degree of singlet oxygen ( $^1\Delta_g$ ) character,<sup>8</sup> exhibiting a unique reactivity through the direct interaction between the peroxide ion and organic substrates such as phenol,<sup>5</sup> alkenes<sup>6</sup> and DNA.<sup>9</sup> The degree of activation of the peroxide ion by the

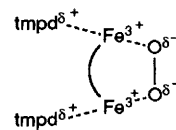




**Fig. 1** EPR spectra of solutions containing DMPO and iron(III) compounds [10  $\mu\text{l}$  of DMPO and 20  $\mu\text{l}$  of the metal complex (in water, 2  $\text{mmol l}^{-1}$ ) were mixed, and spectra measured 30 s after mixing]; X-band, 298 K, field,  $340 \pm 10$  mT, modulation width, 0.1 mT; gain,  $\times 100$ . The four arrows indicate the peaks due to DMPO-OH. (A):  $\text{Fe}_2(\text{hptp})(\text{OH})(\text{NO}_3)_2(\text{ClO}_4)_2$ ; (B):  $[\text{Fe}_2(\text{pac})(\text{AcO})_2]^-$ ; (C):  $\text{Fe}_2(\text{hptb})(\text{OH})(\text{NO}_3)_4$ .

binuclear iron(III) compound is dependent on the complex used, the activation of the peroxide ion being highest in the adduct with  $[\text{Fe}_2(\text{hptp})(\text{OH})(\text{NO}_3)_2]^{2+}$ ; the peroxide adduct of  $[\text{Fe}_2(\text{pac})(\text{AcO})_2]^-$  is much less reactive.<sup>7</sup> These considerations lead to assumption that the intermediate complex, as illustrated above, may show a unique reactivity, depending on the complex used, the order of reactivity being  $\text{hptp} > \text{hptb} \gg \text{pac}$ . Interestingly, this order is in good harmony with the order of EPR intensities due to DMPO-OH, as shown in Fig. 1.

Based on these discussions, it seems reasonable to infer that the generation of DMPO-OH observed in the present system occurs via formation of an intermediate complex similar to that described for the reaction with tmpd; the binuclear iron(III) compound participates in the oxidation of DMPO, and leads to activation of dioxygen via formation at an intermediate complex; the activated oxygen thus formed may react with DMPO directly, yielding DMPO-OH. The latter assumption is supported by the fact that the peroxide adduct of  $[\text{Fe}_2(\text{hptb})(\text{OH})(\text{NO}_3)_2]^{2+}$  or  $[\text{Fe}_2(\text{hptp})(\text{OH})(\text{NO}_3)_2]^{2+}$



**Fig. 2** Assumed intermediate complex

reacts with DMPO to give DMPO-OH as the main product. Similar EPR signals due to DMPO-OH were also observed in the reaction mixtures containing DMPO and binuclear iron(III) compounds with a  $\mu$ -oxo bridge such as  $[\text{Fe}_2\text{O}(\text{tpa})_2(\text{AcO})]^{3+}$ <sup>10</sup> [tpa = tris(2-pyridylmethyl)amine].

Our present results clearly indicate that formation of DMPO-OH occurs even when  $\cdot\text{OH}$  radicals are absent from the solution, and thus it seems doubtful that the use of DMPO is the most reliable method for detecting  $\cdot\text{OH}$  radicals in solution, as assumed in previous papers.<sup>1</sup>

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## References

- 1 B. Halliwell and L. M. C. Gutteridge, *Free Radicals in Biology and Medicine*, Oxford University Press, London, 1985, ch. 2.
- 2 S. T.-Kubota, Y. Ikegami, K. Sugioka and M. Nakano, *Biochem. Int.*, 1987, **14**, 879; J. Stubbe and J. W. Kozarich, *Chem. Rev.*, 1987, **87**, 1107.
- 3 T. Kawabata, M. Awai and M. Kohno, *Acad. Med. Okayama*, 1986, **40**, 163.
- 4 Y. Nishida, K. Yoshizawa and T. Akamatsu, *Chem. Lett.*, 1991, 1521.
- 5 Y. Nishida, M. Takeuchi, H. Shimo and S. Kida, *Inorg. Chim. Acta*, 1985, **96**, 115. The crystal structure of this complex was recently determined: B. A. Brennan, Q. Chen, C. J.-Garcia, A. E. True, C. J. O'Connor and L. Que, Jr., *Inorg. Chem.*, 1991, **30**, 1937.
- 6 B. P. Murch, F. C. Bradley and L. Que, Jr., *J. Am. Chem. Soc.*, 1986, **108**, 5027.
- 7 Y. Nishida, M. Nasu and T. Akamatsu, *Z. Naturforsch., Teil B*, 1991, in the press. Based on magnetic properties and conductivity data, the structure of this complex was assumed to be similar to that of the Hhptb complex.
- 8 Y. Nishida and M. Takeuchi, *Z. Naturforsch., Teil B*, 1987, **42**, 52; Y. Nishida and K. Takahashi, *J. Chem. Soc., Dalton Trans.*, 1988, 2003; Y. Nishida, *Inorg. Chim. Acta*, 1988, **152**, 73.
- 9 Y. Nishida and T. Yokomizo, *Inorg. Chim. Acta*, 1989, **163**, 9.
- 10 R. E. Norman, S. Yan, L. Que, Jr., G. Backes, J. Ling, J. S.-Loehr, J. H. Zhang and C. J. O'Connor, *J. Am. Chem. Soc.*, 1990, **112**, 1554.