Inorganica Chimica Acta, *108* (1985) L29–L30

A Heterobinuclear (Cu–Zn) Complex Containing an Endogenous Imidazolate Bridge

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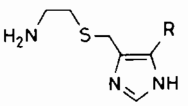
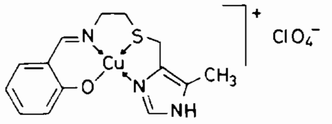
Received June 25, 1985

Imidazole-containing ligands may be viewed as providing versatile models for copper protein environments [1]. For example, Casella [2] has recently shown that the ligand derived from the reaction of 4-[(2-aminoethyl)thiomethyl]-5-methylimidazole, (**1a**) – an intermediate in the production of the anti-ulcer drug cimetidine [3] – and 1-phenyl-3-formyl-2(H)-pyridinethione readily gives a copper(II) complex containing an N_2SS^* donor set, thus providing a model for the Type I copper environment in 'blue' proteins such as plastocyanin [4].



1a: R = CH_3
1b: R = H

The copper(II) complex, (**2**), of the Schiff base derived from (**1a**) and salicylaldehyde has the metal present in an N_2SO donor set [2, 5]. The X-ray structure of (**2**) shows that the copper(II) is in an unusually distorted square planar environment where the sulphur atom lies out of the plane containing the Cu, N, and O atoms [6]. This geometry is not unlike that found for the Type II copper site in bovine erythrocyte superoxide dismutase (BESOD) [7]. The pyrrolic N atom of the imidazole present in (**2**) is available for further metal coordination upon deprotonation, and would thus give rise to an imidazolate-bridged binuclear compound. It would therefore be possible to imitate the Cu–imidazolate–Zn bridge (**3**) present at the active site of BESOD.



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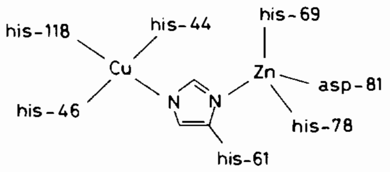

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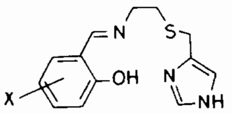
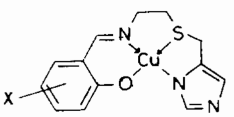
In order to eliminate any possible steric interference to bridge formation from the methyl group in (**1a**) it is preferable to work with the non-methylated species 4(5)-[(2-aminoethyl)thiomethyl]imidazole, (**1b**). The reaction of (**1b**) with a range of salicylaldehydes yields the Schiff bases (**4**) and these, on reaction with equal molarities of copper(II) perchlorate and sodium hydroxide produce monocationic complexes (*cf.* (**2**)). If, however, the ligands (**4**) are reacted with copper(II) acetate in acetonitrile solution then the neutral complexes (**5**) are formed in which the imidazole has also been deprotonated. Satisfactory microanalyses have been obtained throughout this series of reactions.

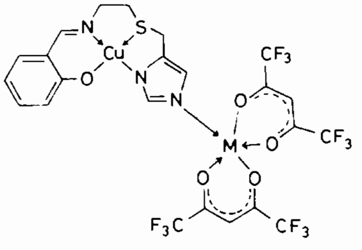


4 X = (a), H; (b), 5-Br; (c), 5-Cl; (d), $5-NO_2$; (e), $3-NO_2$; (f), 3-Cl-5-Cl.

Treatment of (**5a**) with $Cu(hfac)_2$, or $Zn(hfac)_2$ (hfac = 1,1,1,5,5,5-hexafluoropentane-2,4-dionate) – chosen because of the enhanced Lewis acidity of the metal ions therein [8] – leads to the isolation of the green homobinuclear, and the purple-grey heterobinuclear complexes (**6**) as microcrystalline precipitates formed during slow evaporation of the solvent chloroform.



5 X = (a), H; (b), 5-Br; (c), 5-Cl; (d), $5-NO_2$; (e), $3-NO_2$; (f), 3-Cl-5-Cl.



6a: M = Cu
6b: M = Zn

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The complexes have been characterised by microanalysis (*Anal.* $C_{23}H_{15}F_{12}N_3O_5SCu_2$: found, C = 34.52, H = 2.09, N = 5.00%; calc., C = 34.51, H = 1.89, N = 5.25%. $C_{23}H_{15}F_{12}N_3O_5SCuZn$: found, C = 34.55, H = 2.11, N = 5.15%; calc., C = 34.43, H = 1.88, N = 5.24%), IR and optical spectroscopy. The IR spectra are different from each other and from both those of the starting materials and of deliberately constructed physical mixtures of these materials. The optical spectra, in $CHCl_3$, show shifts to shorter wavelength for the copper d–d transitions of the dominant Schiff base chromophore in the binuclear series [(**5a**), $\lambda_{max} = 573$ nm ($\epsilon = 160$); (**6a**), $\lambda_{max} = 566$ nm ($\epsilon = 350$); (**6b**), $\lambda_{max} = 566$ nm ($\epsilon = 350$)]. These shifts are similar to those reported by Sato *et al.* for an imidazolate-bridged copper(II)–zinc(II) complex in which the copper is coordinated by diethylenetriamine, the zinc by tris(2-aminoethyl)-amine and the bridging unit is the simple imidazolate anion [9]. The magnetic properties of (**6a**) and (**6b**) differ dramatically; the copper–zinc complex (**6b**) exhibits normal behaviour for a mononuclear copper-(II) species with a moment, at ambient temperature, of 1.90 BM. In contrast the copper–copper complex (**6a**) has a reduced moment of 1.24 BM per copper atom at ambient temperature, and $-2J = 76.85$ cm^{-1}. This latter value, indicating a degree of antiferromagnetic coupling between the copper atoms, is quite comparable to the values found in related systems bearing bridging imidazolate groups [10].

The complex (**6b**) was also formed by the reaction of $Cu(hfac)_2$ with the neutral zinc complex of (**4a**). This neutral complex was prepared by the reaction of zinc acetate with (**4a**) in ethanol. A metal exchange reaction has occurred, presumably driven by the site requirements of the individual metals. The complex prepared in this way has identical IR, optical and EPR spectra (a broad signal, $g_\perp = 2.10$, with barely resolved fine structure was obtained from frozen $CHCl_3$ solutions in each case) to that prepared by the direct route.

The complex (**6b**) is seen to reproduce features of the heterobinuclear site present in BESOD in that there is a defined endogenous imidazolate bridge between the Type II copper and the zinc ions, and that there are preferred coordination sites for each metal. However it is recognised that the donor sets and the geometric features of the zinc site require further modification before a closer reproduction can be achieved.

Acknowledgements

We thank the Department of Education of Northern Ireland for the award of a Science Research Studentship (to C.H.McL.), Dr Brian P. Murphy for assistance with the EPR spectra, Dr John C. Emmett (Smith Kline and French Research Limited) for a gift of (**1a**)·2HCl and Dr Jean-Marc Latour (C.E.N.G.) for the magnetic measurements.

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