A *triangulo*-Copper(II) Cluster Compound Derived from a Bibracchial Tetraimine Schiff Base Macrocycle: a First Generation Model for Ascorbate Oxidase?

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The synthesis and X-ray crystal structure of a *triangulo*-copper(II) complex which may be regarded as a first generation model for the triangular copper(II) site in ascorbate oxidase is described.

The multicopper oxidase laccase contains four copper atoms:[1] a Type 1 ('blue'), a Type 2 (normal) and a coupled binuclear Type 3 centre.[2] Low-temperature magnetic circular dichroism studies of *Rhus vernicifera* laccase have led to the definition of a trinuclear active site composed of the Type 2 and Type 3 centres.[3] Such a trinuclear site has been confirmed in the crystal structure of ascorbate oxidase from zucchini which shows an approximately isosceles triangle of copper atoms composed of a dinuclear pair of Type 3 copper atoms, with a 3.4 Å separation, and a single Type 2 copper atom at distances of 3.9 and 4.0 Å from the Type 3 copper atoms (Fig. 1).[4]

Structural studies on mononuclear barium and dinuclear silver(I) complexes of a series of bibracchial tetraimine Schiff base macrocycles have shown that the macrocycles fold to present molecular clefts into which the metal ions coordinate.[5] Investigation of the structures suggested that suitable modification of the pendant arms would lead to the opportunity to synthesise trinuclear metal complexes. We now report the intentional synthesis and the crystal structure of a *triangulo*-copper(II) complex derived from the disilver(I) complex **2** *via* transmetallation.

The disilver(I) complex **2** was prepared from **1**[6] by reaction with salicylaldehyde; transmetallation was then effected with hydrated copper(II) salts in methanol–acetonitrile to give the crystalline product $[Cu_3(OH)L^2(OH_2)](ClO_4)_3{\cdot}2H_2O$ **3**, in 71% yield. The compound **3** was characterised by satisfactory micro-analysis and fast atom bombardment mass spectrometry [$P^{\cdot+}$, $Cu_3(OH)L^2(ClO_4)_2$, $m/z = 1159$].

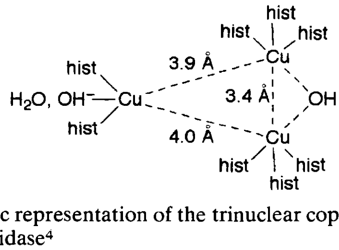
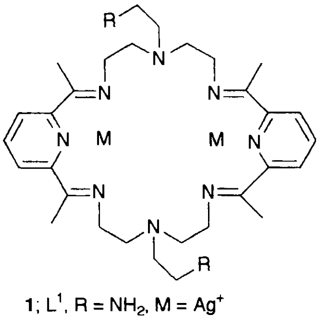
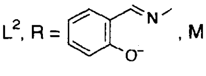


Fig. 1 Schematic representation of the trinuclear copper(II) site found in ascorbate oxidase[4]

The structure of **3**, determined by X-ray crystallographic analysis[†] (Fig. 2), shows a *triangulo*-copper(II) cluster held within the ligand perimeter. The cluster consists of a Type 3-like centre, Cu(1) and Cu(2), and a Type 2-like atom Cu(3). The Type 2-like copper atom is 4.9 and 5.9 Å distant from the two copper atoms of the Type 3-like centre. The two copper atoms of the Type 3-like centre are 3.6 Å apart and bridged by a hydroxy group, the origin of which appears to be water from the reaction medium, with the two copper(II) atoms acting in concert, as a super acid pair, to promote the generation of a nucleophile. The presence of this bridge lends credence to the



1; L^1, R = NH_2, M = Ag^+

2; L^2, R = , M = Ag^+

[†] *Crystal data* for $[Cu_3(OH)L^2(OH_2)](ClO_4)_3{\cdot}2H_2O$. $M = 1313.01$, space group $P2_1$, (C_2^2, No. 4), $a = 13.997(21)$, $b = 16.043(8)$, $c = 14.353(10)$ Å, $\beta = 118.97(9)°$, $U = 2820(5)$ Å^3, $Z = 2$, $D_m = 1.571$, $D_c = 1.546$ g cm^{-3}, $F(000) = 1289.72$, μ(Mo-Kα) = 13.35 cm^{-1}, R, R_w = 0.109, 0.098 respectively [$w^{-1} = \sigma^2(F) + 0.0015(F)^2$] for 1744 independent reflections (of 5167 measured for which $|F|/\sigma(|F|) \geq 4.0$), collected on a Nicolet R3 diffractometer. The perchlorate anions were disordered. The hydrogen atoms of the coordinated water have been positioned on identified hydrogen bonds which form part of an extensive hydrogen-bonded network.

Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre. See Notice to Authors, Issue No. 1.

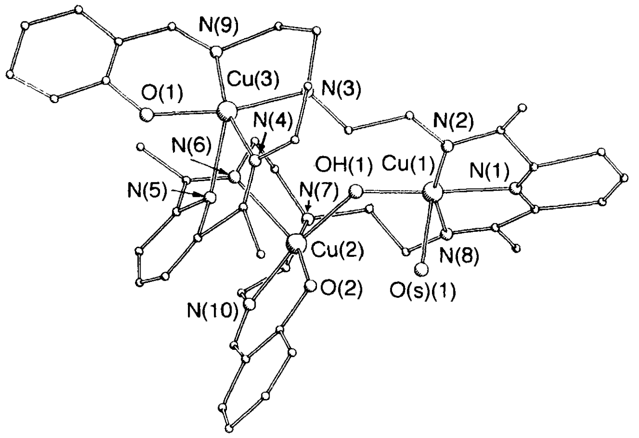


Fig. 2 The molecular geometry of the cation $[L^2Cu_3(OH)(OH_2)]^{3+}$: Cu(1)–OH(1) 1.887(23), Cu(1)–O(s)(1) 2.304(34), Cu(1)–N(1) 2.054(41), Cu(1)–N(2) 2.087(33), Cu(1)–N(8) 2.078(30); Cu(2)–Oh(1) 1.993(25), Cu(2)–N(6) 2.266(44), Cu(2)–N(7) 2.171(36), Cu(2)–N(10) 2.009(42), Cu(2)–O(2) 1.939(06); Cu(3)–N(3) 2.028(40), Cu(3)–N(4) 1.983(30), Cu(3)–N(5) 2.269(42), Cu(3)–N(9) 1.901(45), Cu(3)–O(1) 1.980(34), Cu(1) · · · Cu(2) 3.62 Å; Cu(1)–OH(1)–Cu(2) 137.8(14)°

statement by Lippard[7] that the stability and ubiquity[8,9] of the Cu_2OH^{3+} moiety (in Type 3 centre models) suggests that the endogenous protein bridging ligand (proposed as present in Type 3 biosites[10]) might simply be the hydroxide anion itself generated from accompanying water molecules. The room temperature magnetic moment of the *triangulo*-complex was 1.66 μ_B per Cu atom suggesting that some magnetic coupling is occurring, presumably within the Type 3-like centre.

The two copper atoms, Cu(1) and Cu(2), comprising the Type 3-like centre are found in distorted square pyramidal coordination geometries. The former is derived from the pyridine-diimine head unit [N(1), N(2), N(8)], the bridging hydroxide, OH(1), and a water molecule, O(s)(1); the latter from the second chelating salicylideneimine pendant, O(2) and N(10), its tertiary nitrogen of attachment to the macrocyclic periphery N(7), the bridging hydroxide, OH(1), and one of the imine nitrogen atoms, N(6), of the second macrocyclic head unit.

The Type 2-like copper atom also has a distorted square pyramidal coordination environment derived from the second chelating salicylideneimine pendant, O(1) and N(9), the tertiary nitrogen of attachment to the macrocyclic periphery N(3), together with the remaining imine nitrogen, N(4) from the second macrocyclic head unit and a pyridyl nitrogen N(5).

The nature of the complex suggests that it be regarded as a first generation model for the triangular copper(II) sites found in ascorbate oxidase and proposed for multicopper oxidases such as laccase.

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