Copper(I)–Histamine System: a Reversible Carbon Monoxide Carrier. Isolation and *X*-Ray Crystal Structure of Two Cu–Histamine–CO Complexes

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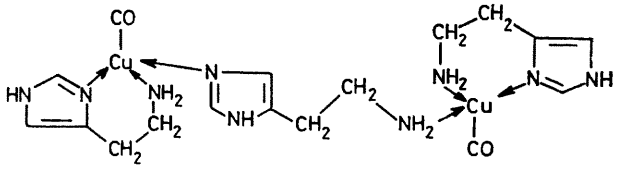
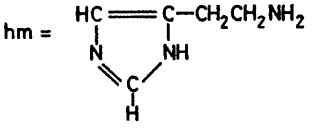
Summary Reaction of a methanolic suspension of CuCOCl with histamine (hm) at 0 °C gives a solution from which [Cu(hm)CO]BPh_4 [ν_{CO}(Nujol) 2091 cm^{-1}] is recovered, while a methanolic suspension of CuI in the presence of histamine reversibly absorbs carbon monoxide [1 CO per Cu] giving $[Cu_2(hm)_3(CO)_2]^{2+}$; *X*-ray analysis of $[Cu_2(hm)_3(CO)_2](BPh_4)_2$ [ν_{CO}(Nujol) 2055 and 2066 cm^{-1}] shows the presence of a dimeric cation with one histamine

chelated to each copper, and the other one bridging the two metal atoms.

ALTHOUGH the nature of the active sites of copper-proteins is poorly defined, imidazole groups of polypeptide histidines are assumed to play a pre-eminent role in binding copper(I).[1,2] The objective of the present study is to probe the reactivity and the co-ordination geometry of copper(I), complexed with histamine, which could simulate imidazole binding sites in certain metalloproteins.[1,3] Herein we report the reaction between a copper(I)–histamine system and carbon monoxide, which produces two Cu^{I}–histamine–CO complexes.



$[Cu_2(hm)_3(CO)_2]^{2+}$

hm = 

Copper(I) iodide suspended in a methanolic solution of histamine (hm) (histamine : Cu > 2) absorbs carbon monoxide at room temperature and atmospheric pressure (1 mol of CO per Cu), giving a slightly green solution (ν_{CO} 2040br cm^{-1}). *In vacuo* this solution releases CO depositing white microcrystals which redissolve under carbon monoxide. This reversibility was checked over several cycles. The addition of $NaBPh_4$ to this solution gives $[Cu_2(hm)_3(CO)_2](BPh_4)_2$ (I)† [ν_{CO}(Nujol), 2066 and 2055 cm^{-1}], see equation (1).

$$2CuI + 3\,hm + 2\,CO\ (1\ atm) \xrightarrow{i,\ ii,\ iii} [Cu_2(hm)_3(CO)_2](BPh_4)_2\ (I) \quad (1)$$

i, MeOH; ii, $+NaBPh_4$; iii, $-Na\ I$ (I)

With a CuI : histamine molar ratio < 1·0, CuI partially dissolved, and addition of $NaBPh_4$ to the solution gave a solid, which was shown to be a mixture of (I) and $[Cu(hm)CO]BPh_4$ (II) [ν_{CO}(Nujol) 2091 cm^{-1}]. The complex (II)† was synthesised independently from CuCOCl[4] by treatment at 0 °C with a methanolic solution of histamine, see equation (2).

$$CuCOCl + hm \xrightarrow{i,\ ii,\ iii,\ iv} [Cu(hm)CO]BPh_4\ (II) \quad (2)$$

i, 0 °C; ii, CO (1 atm); iii, + $NaBPh_4$; iv, − NaCl

According to these results the reaction between copper(I), histamine, and carbon monoxide can be summarized as in equation (3).

$$2Cu^{+} + 2hm + 2CO \rightarrow 2\,[Cu(hm)CO]^{+} + hm \rightarrow [Cu_2(hm)_3(CO)_2]^{2+} \quad (3)$$

Both (I) and (II) in the solid state do not release CO *in vacuo* and display a high thermal stability, which is unusual for copper carbonyl complexes.[5] A related investigation of the Cu^{I}–ethylenediamine–CO system has allowed the isolation of some solid state stable carbonyl complexes.[6]

The nature of the copper binding groups in these complexes was determined unequivocally by *X*-ray analysis of a crystal of (I) sealed under N_2 in a Lindemann capillary tube. *Crystal data:* $C_{65}H_{67}B_2Cu_2N_9O_2$; $M = 1155$; monoclinic; $a = 15{\cdot}901(2)$, $b = 13{\cdot}301(2)$, $c = 14{\cdot}826(2)$ Å, $\beta = 109{\cdot}3(1)°$; $U = 2959$ Å^3, $Z = 2$; $D_c = 1{\cdot}296$ g cm^{-3}, μ(Cu-K_α) = 12·5 cm^{-1}, space group $P2_1$ (from systematic absences and structural analysis). The intensities were measured in the θ—2θ scan mode using Ni-filtered Cu-K_α radiation on a Siemens on-line single-crystal diffractometer. 4595 Independent reflections were collected ($6° < 2\theta < 120°$) of which 2894 having $I > 2\sigma(I)$ were considered observed and used in the analysis. The structure was solved by direct methods and refined by full-matrix least-squares,[7] anisotropically for copper atoms only, to $R = 9{\cdot}4\%$.‡

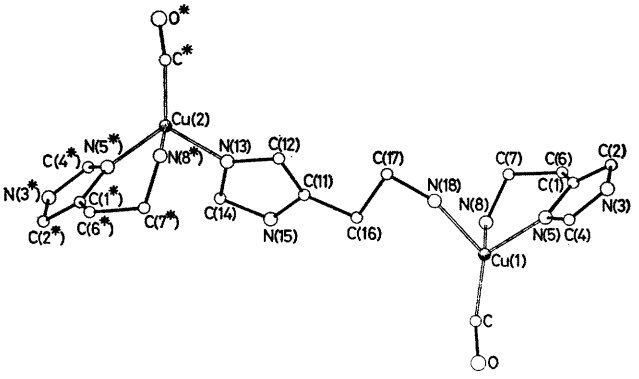


FIGURE. The pseudo-symmetric cation $[Cu_2(histamine)_3(CO)_2]^{2+}$. Bond distances: C–O, 1·12(3); C*–O*, 1·13(3); Cu(1)–C, 1·80(2); Cu(1)–N(5), 2·00(1); Cu(1)–N(8), 2·05(2); Cu(1)–N(18), 2·28(2); Cu(2)–C*, 1·79(2); Cu(2)–N(5*), 2·00(1); Cu(2)–N(8*), 2·10(2); and Cu(2)–N(13), 1·97(1) Å. Bond angles: Cu(1)–C–O, 169(2) and Cu(2)–C*–O*, 172(2)°.

The crystals comprise the cation $[Cu_2(hm)_3(CO)_2]^{2+}$ and the BPh_4^- anion. The structure of the cation is shown in the Figure, with the more relevant bond distances and angles. The two copper atoms, with pseudo-tetrahedral geometries, are bridged by a histamine molecule. The co-ordination sphere around each copper is completed by a chelating histamine and a carbon monoxide group. Both the possible tautomeric forms[8] of the free histamine are present in the macrocation, the 4-(2-aminoethyl)imidazole form chelating

† Satisfactory elemental analytical data were obtained for all the compounds reported.

‡ The atomic co-ordinates for this work are available on request from the Director of the Cambridge Crystallographic Data Centre, University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW. Any request should be accompanied by full literature citation for this communication.

both copper atoms and the 5-(2-aminoethyl)imidazole form bridging the two metal centres. In terms of the notation given in the Figure, the complex has H on N(3), while N(5) and N(8) are chelated to the metal. This bonding mode repeats the situation found in copper(II) complexes.[9] Bridging histamine binds Cu(1) with the amino group and Cu(2) with the imidazolic nitrogen N(13). Bridging histamine simulates the non-chelating bonding mode often supposed to be operating in copper-proteins.[1] Further structural interest depends on the values associated with the CuCO unit. Cu–C, C–O, and Cu–C–O bond distances and angles agree well with the values reported for the other few copper carbonyl complexes known.[5,6,10] The non-eqivalence of the co-ordination environment around Cu(1) and Cu(2) in the pseudo-centro-symmetric dinuclear cation is shown by two sharp i r. CO bands (Nujol) of the same intensity at 2066 and 2055 cm^{-1}. These values are unusually low for copper carbonyls[11] and very close to that found for carboxyhaemocyanin (2063 cm^{-1}).[12]

These results suggest a number of characteristics for copper(I) ions present in polyimidazole protein binding sites. These include the presence of different copper centres active in fixing CO and different bonding modes of imidazole derivatives.

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