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# Some binuclear acetonitrile 'solvated' complexes of copper(I) chloride and bromide with triphenylarsine

Robert D. Hart<sup>a</sup>, John D. Kildea<sup>a</sup>, Claudio Pettinari<sup>b,\*</sup>, Brian W. Skelton<sup>a</sup>, Allan H. White<sup>a</sup>

<sup>a</sup> Chemistry M313, School of Biomedical, Biomolecular and Chemical Sciences, University of Western Australia, Crawley, WA 6009, Australia <sup>b</sup> Dipartimento di Scienze Chimiche, Università degli Studi di Camerino, via S. Agostino 1, 62032 Camerino MC, Italy

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### Abstract

Reaction of copper(I) chloride and bromide, CuX (X = Cl or Br), with triphenylarsine in acetonitrile solution has resulted in two adducts, respectively, of 2:3:1,  $[(Ph_3As)_2Cu(\mu-Cl)_2Cu(AsPh_3)(NCMe)]$  (1), and 1:1:2 stoichiometry,  $[(Ph_3As)(MeCN)Cu(\mu-Br)_2Cu(NC-Me)(AsPh_3)] \cdot 2MeCN$  (2), characterized by elemental analysis, IR, ESI MS and NMR spectroscopy, and room temperature single crystal X-ray structure determinations. The environments of the two four-coordinate copper(I) atoms in 1 are different, being As<sub>2</sub>Cu( $\mu$ -Cl)<sub>2</sub> and As<sub>3</sub>NCu( $\mu$ -Cl)<sub>2</sub>. (2) is also binuclear, being a centrosymmetric dimer with the two four-coordinate, symmetry-related copper atoms having As<sub>3</sub>NCu( $\mu$ -Br)<sub>2</sub>-environments.

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# 1. Introduction

1:2 Adducts of coinage metal(I) halides, MX, M = Cu, Ag; X = Cl, Br, I with triphenylpnicogens, EPh<sub>3</sub>, E = P, As, Sb, are commonly found in two structural types: mononuclear [(Ph<sub>3</sub>E)<sub>2</sub>MX] with quasi-trigonal planar/threecoordinate E<sub>2</sub>MX metal atom environments [1–3], also found in their gold(I) analogues [2,4,5], and binuclear [(Ph<sub>3</sub>E)<sub>2</sub>M( $\mu$ -X)<sub>2</sub>M(EPh<sub>3</sub>)<sub>2</sub>], with four coordinate E<sub>2</sub>M( $\mu$ -X)<sub>2</sub> environments [3]. More recently, it has become evident that complexes of the former type may be obtained with systems involving the smaller metal atom (Cu(I)) and/or the smaller pnictide(s) (P), while systems of the latter binuclear type, may be obtained with larger metal atoms and/or the larger pnictides [6–9]. Systems [(Ph<sub>3</sub>E)<sub>2</sub>MX] have thus far been obtained for [(Ph<sub>3</sub>P)<sub>2</sub>CuX], X = all Cl, Br, I [1,2], and [( $Ph_3P$ )<sub>2</sub>AgBr] [3]; binuclear [( $Ph_3E$ )<sub>2</sub>M( $\mu$ -X)<sub>2</sub>M(EPh<sub>3</sub>)<sub>2</sub>] have been recorded previously only for M = Ag, X = Cl, Br as chloroform solvates in systems in which there is a pronounced complex/solvent interaction [3]. The origins of this dichotomy may be possibly steric in origin, a consequence of possible difficulty in accommodating four Ph<sub>3</sub>E ligands around the  $M(\mu-X)_2M$  core, with the four E atoms coplanar; although the  $E_4$  disposition differs, a similar situation is evident in the extreme situation of collapse of the array to a single metal atom, Cu at the limit, resulting in an ME<sub>4</sub> environment distorted relative to those found in 'larger' systems where M is Ag or E is As or Sb [10,11]. This viewpoint is reinforced by noting the propensity of CuX:PPh<sub>3</sub> systems to form 2:3 rather the 2:4 dimers, incorporating  $E_2M(\mu-X)_2$  environments in combination with the less crowded (µ-X)<sub>2</sub>ME array [12-16].

More recently, we have described 1:2 binuclear MX:EPh<sub>3</sub> adducts for combinations of MX:E of CuX:Sb, AgX:As, Sb [6–9]. At the interface between those circumstances favouring the formation of mononuclear 1:2

<sup>\*</sup> Corresponding author. Tel.: +39 0737 402234; fax: +39 0737 637345. *E-mail address:* claudio.pettinari@unicam.it (C. Pettinari).

adducts and their binuclear counterparts, it therefore seems that the unusual may be encountered, as evidenced by the occurrence of the 2:3 species mentioned above [12–16]. Given the availability of less sterically demanding donors, the possibility of the formation of solvated species may exist, thus accessing the potential maximum four-coordinate possibility in a binuclear array without undue steric strain, as an intermediate in the further spectrum possible in the mixed-ligand array

$$\begin{split} [LL'M(\mu-X)_2MLL'] &\rightleftharpoons [LL'M(\mu-X)_2ML_2] \\ &\rightleftharpoons [L_2M(\mu-X)_2L_2]. \end{split}$$

The former have been obtained for  $R_3P/N$ -base combinations for N-base = 'one-', 'two-,' or 'three-' dimensional' arrays such as nitriles [17,18], pyridine [19,20] and piperidine bases [21], the intermediate type as yet undescribed. An initial essay in the present exercise was the attempted synthesis of 1:2 CuX:AsPh<sub>3</sub> adducts [6]; in the event binuclear arrays were obtained for the chloride and bromide as chloroform solvates, but, in the process, attempts involving other solvents, in particular acetonitrile, were undertaken, leading to the formation of adducts of the [LL'M( $\mu$ -X)<sub>2</sub>MLL'] and [LL'M( $\mu$ -X)<sub>2</sub>ML<sub>2</sub>] types, as described herein, respectively, for the CuBr/Ph<sub>3</sub>As/MeCN and CuCl/ Ph<sub>3</sub>As/MeCN combinations.

In an accompanying contribution [22], we define the nature of an array of solvated species obtained by the crystallization of diverse CuX:dpex combinations from acetonitrile ('dpex' =  $Ph_2E(CH_2)_xEPh_2$ , E = P, As, Sb), a context in which it is appropriate to record the results of the present study.

## 2. Experimental

All syntheses and handling were carried out in the atmosphere. All chemicals were purchased from Aldrich and used without further purification. Elemental analyses (C, H, N) were performed in-house with a Fisons Instruments 1108 CHNS-O Elemental Analyser. IR spectra were recorded from 4000 to 100 cm<sup>-1</sup> with a Perkin–Elmer System 2000 FT-IR instrument. <sup>1</sup>H and <sup>13</sup>C NMR spectra were recorded on a Mercury Plus Varian 400 NMR spectrometer (400 MHz for <sup>1</sup>H and 100 MHz for <sup>13</sup>C). H and C chemical shifts are reported in ppm versus SiMe<sub>4</sub>. The electrical conductances of the acetonitrile solutions were measured with a Crison CDTM 522 conductimeter at room temperature. Positive and negative electrospray mass spectra were obtained with a Series 1100 MSI detector HP spectrometer, using an acetonitrile mobile phase. Solutions (3 mg/mL) for electrospray ionization mass spectrometry (ESI-MS) were prepared using reagent grade acetone or acetonitrile. For the ESI-MS data, masses and intensities were compared to those calculated by using the IsoPro Isotopic Abundance Simulator Version 2.1 [23]; peaks containing copper ions are identified as the centres of isotopic clusters.

#### 2.1. Syntheses

## 2.1.1. Synthesis of copper(I)

# chloride:triphenylarsine:acetonitrile (2:3:1) (1)

Triphenylarsine (AsPh<sub>3</sub>) (0.92 g, 3.0 mmol) was added at room temperature to a suspension of CuCl (0.198 g, 2.0 mmol) in MeCN (10 ml). After the addition, a colourless precipitate slowly formed and the suspension was stirred for 24 h under reflux. The precipitate was then filtered off and identified as complex 1 (75% yield), a few more substantial crystals depositing from the mother liquor on standing. M.p. 154–157 °C dec. <sup>1</sup>H NMR (CD<sub>3</sub>CN, 293 K):  $\delta$  2.2 (br, 3H, CH<sub>3</sub>CN), 7.3–7.5 (m, 45H, C<sub>6</sub>H<sub>5</sub>). <sup>13</sup>C NMR (CD<sub>3</sub>CN, 293 K):  $\delta$  129.95s, 130.04, 134.50, 139.53. IR (nujol, cm<sup>-1</sup>): 3060w, 2300br, 1585w, 1579w, 1076m, 1023m, 998m, 734s, 690s, 482m, 469m, 325m. 266br. ESI MS (+): 145(10)  $[Cu(MeCN)_2^+]$ ; 410(55)  $[Cu(AsPh_3)(MeCN)^+]; 426(10) [Cu(AsPh_3)(MeCN)^+ + O];$ 675(100)  $[Cu(AsPh_3)_2^+];$  719(10)  $[Cu(AsPh_3)_2(MeCN)^+];$ 775(25) [Cu<sub>2</sub>(AsPh<sub>3</sub>)<sub>2</sub>(Cl)<sup>+</sup>]. Anal. Calc. for C<sub>56</sub>H<sub>48</sub>As<sub>3</sub>Cl<sub>2-</sub> Cu<sub>2</sub>N: C, 58.10; H, 4.18; N, 1.21. Found: C, 58.23; H, 4.36; S, 1.10%.  $\Lambda_{\rm m}$  (CH<sub>2</sub>Cl<sub>2</sub>, 10<sup>-3</sup> M): 1.0  $\Omega^{-1}$  mol<sup>2</sup> cm<sup>-1</sup>.

# 2.1.2. Copper(I) bromide:triphenylarsine:acetonitrile (2:2:2) · 2MeCN (2 · 2MeCN)

Triphenylarsine (AsPh<sub>3</sub>) (0.61 g, 2.0 mmol) was added at room temperature to a suspension of CuBr (0.286 g, 2.0 mmol) in MeCN (20 ml). After the addition, a colourless precipitate immediately formed and the suspension was stirred for 12 h at 40 °C. The precipitate was then filtered off and identified as complex  $2 \cdot 2$ MeCN (55% yield), a few more substantial crystals depositing from the mother liquor on standing. M.p. 164-166 °C dec. <sup>1</sup>H NMR (CD<sub>3</sub>CN, 293 K): δ1.98 (s, 6H, CH<sub>3</sub>CN), 2.17 (s, 6H,  $CH_3CN$ ), 7.3–7.5 (m, 30H,  $C_6H_5$ ). <sup>13</sup>C NMR (CD<sub>3</sub>CN, 293 K): δ 129.90s, 130.02, 134.49, 139.36. IR (nujol, cm<sup>-1</sup>): 3050w, 2290br sh, 1582w, 1576w, 1077m, 1023m, 998m, 736s, 692s, 482m, 469m, 458sh, 333m, 324m, 315sh, 247w, 226w, 205w. ESI MS (+): 145(85) [Cu(MeCN)<sub>2</sub><sup>+</sup>]; 410(90) [Cu(AsPh<sub>3</sub>)(MeCN)<sup>+</sup>]; 675(100) [Cu(AsPh<sub>3</sub>)<sub>2</sub><sup>+</sup>]; 719(20)  $[Cu(AsPh_3)_2(MeCN)^+]; 818(30) [Cu_2(AsPh_3)_2 (Br)^+$ ]. Anal. Calc. for C<sub>44</sub>H<sub>42</sub>As<sub>2</sub>Br<sub>2</sub>Cu<sub>2</sub>N<sub>4</sub>: C, 49.69; H, 3.98; N, 5.27. Found: C, 49.76; H, 3.83; NS, 5.33%. Λ<sub>m</sub>  $(CH_2Cl_2, 10^{-3} \text{ M}): 1.5 \Omega^{-1} \text{ mol}^2 \text{ cm}^{-1}.$ 

#### 2.2. Structure determinations

General procedures are given in Ref. [22]; specific details are as follows, a single counter instrument being used to acquire unique data sets at ca. 295 K. CCDC 286436, 286437.

# 2.2.1. $[(Ph_3As)_2Cu(\mu-Cl)_2Cu(AsPh_3)(NCMe)]$ (1) = $C_{56}H_{48}As_3Cl_2Cu_2N$ , M = 1157.8

Triclinic, space group,  $P\bar{1}(C_i^1 \text{No. 2})$ , a = 21.857(2) Å, b = 12.763(7) Å, c = 10.013(3) Å.  $\alpha = 71.46(5)^\circ$ ,  $\beta = 81.88(1)^\circ$ ,  $\gamma = 73.56(3)^\circ$ ,  $V = 2540 \text{ Å}^3$ .  $D_c (Z = 2 \text{ dimers}) = 1.51_6 \text{ g cm}^{-3}$ .  $\mu_{Mo} = 28 \text{ cm}^{-1}$ ; specimen:  $0.22 \times 0.24 \times 0.52 \text{ mm}$ ;  $T_{min,max} = 0.50, 0.60$  (Gaussian correction).  $2\theta_{max} = 50^{\circ}$ ;  $N = 8475, N_o = 5673$ ;  $R = 0.041, R_w = 0.042$ .

2.2.2.  $[(Ph_3As)(MeCN)Cu(\mu-Br)_2Cu(NCMe)(AsPh_3)]$  ·  $2MeCN(2) \equiv C_{40}H_{36}As_2Br_2Cu_2N_2 \cdot 2CH_3CN, M = 1063.2$ Monoclinic, space group  $P2_1/c$  ( $C_{2h}^5$ , No. 14), a = 9.239(1) Å, b = 13.682(2) Å, c = 17.265(2) Å,  $\beta = 93.572(8)^\circ$ , V = 2178 Å<sup>3</sup>.  $\mu_{Mo} = 43.6$  cm<sup>-1</sup>; specimen:  $0.70 \times 0.22 \times 0.16$  mm;  $T_{min,max} = 0.38$ , 0.54 (analytical correction).  $2\theta_{max} = 50^\circ$ ; N = 4066,  $N_o = 3123$ ; R = 0.039,  $R_w = 0.047$ .

## 3. Results and discussion

Reaction of three equivalent of triphenylarsine (AsPh<sub>3</sub>) with two equivalents of CuCl in refluxing acetonitrile resulted in the formation of derivative **1** (Chart 1). A 3:2 ligand to metal molar ratio and reaction times greater than 12 h are rigorously required. When a ligand to metal ratio greater than 2:1 was employed the well-known dinuclear  $[(AsPh_3)_2Cu(\mu-Cl)_2Cu(AsPh_3)_2]$  formed. The 3:2 adduct **1** was afforded only when the reaction was carried out in MeCN, whereas in MeOH the 2:1 species always formed.

Reaction between CuBr and AsPh<sub>3</sub> in MeCN in 1:1 ligand to metal molar ratio yielded the derivative  $2 \cdot 2$ MeCN (Chart 1); a similar iodide analogue has been previously recorded [24].

Compounds 1 and 2 are air-stable, colourless materials, insoluble in diethyl ether and ethanol and soluble in acetone, acetonitrile, DMSO. The conductivity measurements are in accordance with a non-ionic formulation also in solution,  $\Lambda$  being in acetonitrile, for 1 and 2, 1.0 and 1.5  $\Omega^{-1}$  cm<sup>2</sup> mol<sup>-1</sup>, respectively.

The infrared spectra (Section 2) are consistent with the formulations proposed, showing all of the bands required by the presence of the arsine ligand [25]. In the far-IR spectra we assigned, on the basis of previous reports, the broad absorptions near 500 cm<sup>-1</sup> and those at 480–400 cm<sup>-1</sup> to Whiffen's *y* and *t* vibrations [26]. No bands assignable to terminal Cu–Cl and Cu–Br stretching vibrations have been found. On the other hand two broad bands at ca. 160 and 180 cm<sup>-1</sup> have been detected in the spectrum of **1**. Analogous bands have been previously assigned to v(Cu-Cl) in complexes containing a bridging halide group [27] in accordance with the Cu( $\mu$ -X)<sub>2</sub>Cu (X = Cl or Br) environments found in the solid state. Broad signals due to CN stretching



vibrations have been found in the 2300–2280  $\text{cm}^{-1}$  region, as expected.

In the <sup>1</sup>H and <sup>13</sup>C NMR spectra of **1** and **2** in CD<sub>3</sub>CN (or in CDCl<sub>3</sub>) (see Section 2), the signals due to the arsine show a different pattern with respect to those found for the free donor, confirming the existence, at least partial, of the complexes in solution. The presence of coordinated MeCN is confirmed by the presence of broad signals at ca 2.2 ppm [28]. In the <sup>1</sup>H NMR spectrum of **2** a sharp signal at  $\delta$  ca. 2 ppm, likely due to the non-coordinated MeCN, is also present.

The positive electrospray mass spectra of complexes 1 and 2 (the most relevant data are reported in Section 2 and a typical spectrum is reported in Fig. 1) indicate that these derivatives exist as dinuclear species also in solution. The isotopic distribution of these species is in accord with the calculated composition. However, the major peaks are those derived from mononuclear species containing one or two AsPh<sub>3</sub> and one or two MeCN ligands bonded to a copper centre. The aggregation behaviour is dependent on the solvent employed, no adducts containing MeCN being detected in acetone or alcohols, and also dependent on the concentration, the dinuclear species  $[Cu_2(AsPh_3)_2(X)^+]$ increasing with increasing concentration of 1 or 2 in solution. Under our conditions the linear aggregate containing a copper centre and two triphenylarsine donors dominates significantly over adducts containing different ligand to metal ratio. Oxidation of the arsine is evident in solution, some weak peaks due to  $[Cu(AsPh_3)(MeCN)^+ + O]$  being often present [29]. No fragments containing two positive charges have been detected. The negative electrospray spectra of 1 and 2 are dominated by the presence of peaks due to  $[CuX_2]^-$ .

The results of the room-temperature single crystal X-ray studies described herein are consistent with the description of the above complexes as an interesting pair of binuclear arrays with  $Cu(\mu-X)_2Cu$  molecular cores involving four-coordinate copper(I) atoms, the latter coordination environments being completed by different aggregates of Group V/15 unidentate ligands.

Complex 2, [(Ph<sub>3</sub>As)(MeCN)Cu(µ-Br)<sub>2</sub>Cu(NCMe)(As-Ph<sub>3</sub>)], Fig. 2, has close counterparts in (o-tolyl)Ph<sub>2</sub>P/CuBr and Ph<sub>3</sub>As/CuI arrays [17,24]; in all three complexes one half of the binuclear, centrosymmetric dimer comprises the asymmetric unit of the structure, a crystallographic inversion centre lying at the centre of the  $Cu(\mu-X)_2Cu$  core. Core geometries are presented comparatively in Table 1 (together with those of complex 1), those of the present array disposed largely as expected with respect to those of the two counterpart complexes in consequence of the different component differences. Complex 1, [(Ph<sub>3</sub>As)<sub>2-</sub>  $Cu(\mu-Cl)_2Cu(NCMe)(AsPh_3)$ ], an adduct of 2:3:1 CuX:-Ph<sub>3</sub>E:MeCN stoichiometry, appears to be the first structurally authenticated example of the intermediate solvated species (Fig. 2). The geometries about the two different copper atoms are tabulated independently in Table 1, again showing broadly the anticipated variations consequent upon their different substitution patterns.



Fig. 1. ESI MS spectrum (positive mode) of compound 2.



Fig. 2. Projections of (a)  $[(Ph_3As)_2Cu(\mu-Cl)_2Cu(NCMe)(AsPh_3)]$ , (b)  $[(Ph_3As)(MeCN)Cu(\mu-Br)_2Cu(NCMe)(AsPh_3)]$  (i) normal to the central  $Cu(\mu-X)_2Cu$  plane, and (ii) through the central  $Cu(\mu-X)_2Cu$  planes, normal to the  $Cu\cdots Cu$  line in each case.

Table 1	
Molecular core geometries	

E/X	[(Ph <sub>3</sub> E)(MeCN)Cu(µ-X) <sub>2</sub> Cu(NCMe)(EPh <sub>3</sub> )]			$[(Ph_3As)_2Cu(\mu\text{-}Cl)_2Cu(NCMe)(AsPh_3)]^b$	
	P/Br <sup>a</sup>	As/Br <sup>b</sup>	As/I <sup>c</sup>	As/Cl(As(11,12))	As/Cl(As(21))
Distances (Å)					
Cu–X	2.569(2)	2.529(1)	2.690(1)	2.340(2)	2.338(2)
Cu–X′	2.465(2)	2.4568(9)	2.637(1)	2.362(2)	2.377(2)
$Cu\cdots Cu$	3.215(2)	2.950(1)	2.779(1)	2.965(1)	
$X \cdots X'$	3.827(2)	4.0204(8)	4.545(1)		
Cu–E	2.228(3)	2.3562(9)	2.381(1)	2.355(2)	2.353(2)
Cu–N	2.008(10)	2.029(5)	2.022(3)	2.357(1)(As)	2.019(5)
Angles (°)					
Cu–X–Cu	79.35(5)	72.53(3)	62.88(2)	77.89(6)	78.22(7)
X-Cu-X'	100.65(6)	107.47(3)	117.12(2)	101.82(6)	101.42(6)
X–Cu–E	108.69(9)	107.10(3)	102.99(2)	104.25(6)	117.66(7)
X–Cu–N	103.6(3)	104.0(2)	104.1(1)	112.19(6)(As)	105.9(2)
X'-Cu-E	118.01(9)	114.70(2)	111.4(2)	110.79(6)	115.01(5)
X'-Cu-N	107.2(3)	113.0(2)	108.6(1)	102.46(6)(As)	111.7(2)
E-Cu-N	116.5(3)	109.8(1)	112.5(1)	123.41(4)(As)	105.0(1)
Cu–N–C	174.3(6)	164.4(5)	176.0(3)		166.3(4)
N–C–C	178(1)	178.2(7)	179.6(3)		178.5(7)
Torsion angles (°) (	cation atoms denoted by	number only)			
Cu-E-11-12	-51(1)	-23.0(5)	36.3(1)	17.4(5), 66.0(7)	9.7(7)
Cu-E-21-22	-46.4(9)	-19.4(4)	35.3(2)	21.4(6), -10.3(7)	62.2(6)
Cu-E-31-32	-36(1)	-24.7(4)	58.6(2)	52.2(5), 57.0(6)	30.0(5)
Deviations from the	$Cu(\mu-X)_2Cu$ plane $(\mathring{A})$				
$\delta E$	1.737(2)	1.874(2)	1.954(2)	2.182(2)	-1.505(2)
$\delta N$	-1.824(2)	-1.704(6)	-1.702(3)	-1.934(2)(As)	

<sup>a</sup> Ref. [17],  $R_3 = (o-tolyl)Ph_2$ .

<sup>b</sup> This work.

<sup>c</sup> Ref. [24].

### References

- [1] P.H. Davis, R.L. Belford, L.C. Paul, Inorg. Chem. 12 (1973) 213.
- [2] G.A. Bowmaker, J.C. Dyason, P.C. Healy, L.M. Engelhardt, C. Pakawatchai, A.H. White, J. Chem. Soc., Dalton Trans. (1987) 1089.
- [3] G.A. Bowmaker, Effendy, J.V. Hanna, P.C. Healy, B.W. Skelton, A.H. White, J. Chem. Soc., Dalton Trans. (1993) 1387.
- [4] N.C. Baenziger, R.M. Dittemore, J.R. Doyle, Inorg. Chem. 13 (1974) 805.
- [5] M. Khan, C. Oldham, C.G. Tuck, Can. J. Chem. 59 (1981) 2714.
- [6] G.A. Bowmaker, R.D. Hart, J.D. Kildea, E.N. de Silva, B.W. Skelton, A.H. White, Aust. J. Chem. 50 (1997) 605.
- [7] G.A. Bowmaker, R.D. Hart, E.N. de Silva, B.W. Skelton, A.H. White, Aust. J. Chem. 50 (1997) 621.
- [8] G.A. Bowmaker, Effendy, J.D. Kildea, E.N. de Silva, A.H. White, Aust. J. Chem. 50 (1997) 627.
- [9] G.A. Bowmaker, Effendy, E.N. de Silva, A.H. White, Aust. J. Chem. 50 (1997) 641.
- [10] L.M. Engelhardt, C. Pakawatchai, A.H. White, P.C. Healy, J. Chem. Soc., Dalton Trans. (1985) 125.
- [11] G.A. Bowmaker, Effendy, R.D. Hart, J.D. Kildea, E.N. de Silva, B.W. Skelton, A.H. White, Aust. J. Chem. 50 (1997) 539.
- [12] J.T. Gill, J.J. Mayerle, P.S. Welcker, D.F. Lewis, D.A. Ucko, D.J. Barton, D. Stowens, S.J. Lippard, Inorg. Chem. 15 (1976) 1155.
- [13] H. Negita, M. Hiura, Y. Kushi, M. Kuramato, T. Okuda, Bull. Chem. Soc., Jpn. 54 (1981) 1247.
- [14] V.G. Albano, P.L. Bellon, G. Ciani, M. Manassero, J. Chem. Soc. A (1972) 171.
- [15] P.G. Eller, G.J. Kubas, R.R. Ryan, Inorg. Chem. 16 (1977) 2454.

- [16] J.C. Dyason, L.M. Engelhardt, C. Pakawatchai, P.C. Healy, A.H. White, Aust. J. Chem. 38 (1985) 1243.
- [17] L.M. Engelhardt, P.C. Healy, J.D. Kildea, A.H. White, Aust. J. Chem. 42 (1989) 945.
- [18] G.A. Bowmaker, J.V. Hanna, R.D. Hart, P.C. Healy, A.H. White, Aust. J. Chem. 47 (1994) 25.
- [19] L.M. Engelhardt, P.C. Healy, J.D. Kildea, A.H. White, Aust. J. Chem. 42 (1989) 913.
- [20] S. Gotsis, L.M. Engelhardt, P.C. Healy, J.C. Kildea, A.H. White, Aust. J. Chem. 42 (1989) 923 [Corrigendum (also to Ref. [19]): Effendy, L.M. Engelhardt, P.C. Healy, B.W. Skelton, A.H. White, Aust. J. Chem. 44 (1991) 1585.].
- [21] G.A. Bowmaker, J.V. Hanna, R.D. Hart, P.C. Healy, A.H. White, J. Chem. Soc., Dalton Trans. (1994) 2621.
- [22] C. di Nicola, G.A. Koutsantonis, C. Pettinari, B.W. Skelton, N. Somers, A.H. White, Inorg. Chim. Acta 359 (2006) 2159.
- [23] M.W. Senko, IsoPro Isotopic Abundance Simulator, v.3.03 (1998); National High Magnetic Field Laboratory, Los Alamos National Laboratory, Los Alamos, NM.
- [24] M.R. Churchill, J.R. Missert, Inorg. Chem. 20 (1981) 619.
- [25] K. Shobatake, C. Postmus, J.F. Ferraro, K. Nakamoto, Appl. Spectrosc. 23 (1969) 12.
- [26] A. Cingolani, Effendy, F. Marchetti, C. Pettinari, B.W. Skelton, A.H. White, J. Chem. Soc., Dalton Trans. (1999) 4047.
- [27] K. Nakamoto, Coordination compounds, in: Infrared and Raman Spectra of Inorganic and Coordination Compounds, 4th ed., Wiley Interscience, New York, 1986, pp. 328–331.
- [28] H.-C. Liang, E. Kim, C.D. Incarvito, A.L. Rheingold, K.D. Karlin, Inorg. Chem. 41 (2002) 2209.
- [29] M.G. Fitzpatrick, L.R. Hanton, W. Henderson, P.E. Kneebone, E.G. Levy, L.J. McCaffrey, D.A. McMorran, Inorg. Chim. Acta 281 (1998) 101.