Synthesis and transition-metal complexes of new cross-bridged tetraamine ligands

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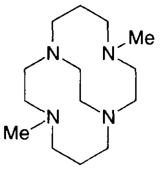
New cross-bridged tetraamine ligands (bicyclo[6.6.2], [6.5.2] and [5.5.2] systems) are synthesized; complexation of Cu^{II} and Ni^{II} demonstrates that the ligands coordinate selected metals in a cleft.

The design and synthesis of new polyamine ligands is a subject of intense worldwide effort.[1] Wainwright[2,3] and Hancock and coworkers[4–6] have prepared 'structurally reinforced' macrocyclic tetraamines [adjacent nitrogens bridged with ethylene ($-CH_2CH_2-$)] to favour *trans*-coordination of transition-metal cations. We previously demonstrated the synthesis of **1**, the first member of a new class of 'cross-bridged' tetraamine ligands, which have nonadjacent nitrogens bridged by ethylene.[7] Bencini *et al.* subsequently reported the synthesis of **2** by a different synthetic route.[8] We now report the synthesis of six new members of the class of cross-bridged ligands, *N,N'*-dibenzyl derivatives **6a–c** and parent ligands **7a–c**, and our preliminary results on coordination to Cu^{II} and Ni^{II}.



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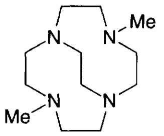

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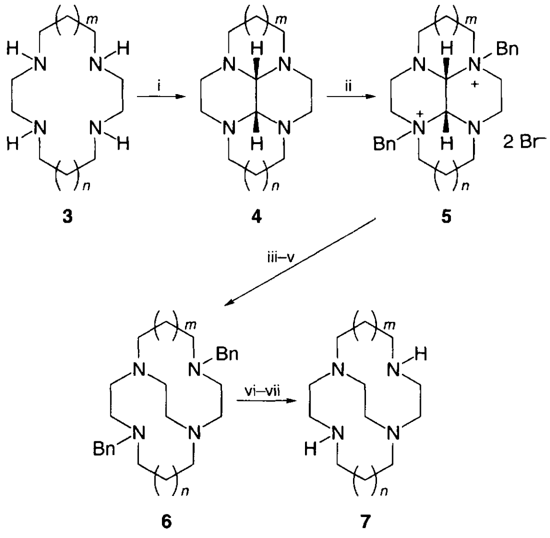
Our route to the cross-bridged tetraamines is shown in Scheme 1 and yields are given in Table 1. The route involves (*a*) condensation of glyoxal and cyclic tetraamines **3** to give tetracyclic, *cis*-fused bisaminals **4**,[9] (*b*) highly regioselective dibenzylation of **4** to give bisquaternary ammonium bromides **5**,† (*c*) reductive cleavage to give double-ring-expanded *N,N'*-dibenzyl bicyclic systems **6**,† and (*d*) debenzylation by hydrogenolysis to give the parent ligands **7**.† Like **1**,[7] **6a–c** are remarkably basic (proton sponges). **7a–c** are crystalline, sublimable solids (**7a**, mp 48–49 °C; **7b**, mp 28–30 °C; **7c**, mp 102–104 °C).

It was anticipated that [6.6.2], [6.5.2] and [5.5.2] bicyclic ligands such as **6a–c** and **7a–c** would be able to adopt low-energy conformations having all four nitrogen lone-pairs convergent upon a cleft, making them ideal for *cis*(V) coordination[10] of small metal ions. Indeed, such ligands may be thought of as 'clamshells' of the well known facially coordinating nine- and ten-membered triazacycloalkanes.[11] Reaction of **6a** with $CuCl_2 \cdot 2H_2O$ in methanol afforded dark-green crystals of the 1 : 1 complex [CuCl(**6a**)]Cl·H_2O **8**.† The molecular structure (Fig. 1) revealed a copper centre with a distorted octahedral coordination geometry consisting of all four nitrogens of the bicyclic ligand, one of the chlorides, and an interesting agostic interaction with an *ortho*-hydrogen of one benzyl arm (Cu··H–C distance 2.74 Å).‡ The ligand adopts a slightly distorted [2323]/[2323] conformation as anticipated by its design.[7]

Reaction of ligand **7a** with $CuCl_2 \cdot 2H_2O$ in aqueous ethanol gave dark-blue crystals of [CuCl(**7a**)]Cl·$3H_2O$ **9**.† The crystal structure has been determined and the molecular geometry is shown in Fig. 2.§ The copper is in a distorted trigonal-bipyramidal coordination sphere including all four nitrogens of **7a** and one of the chlorides. Consistent with expectations for copper–secondary amine *vs.* copper–tertiary amine bond lengths,[12] the two axial Cu–N bonds of 1.996(5) and 2.003(5) Å are shorter than the two equatorial Cu–N bonds of 2.081(6) and 2.140(5) Å. Although the three equatorial angles add up to 360°, they are widely disparate, ranging from 87.8(2)° for N(4)–Cu–N(11), 122.0(1)° for Cl(1)–Cu–N(4), to 150.2(2)° for Cl(1)–Cu–N(11). This last angle contains the potential sixth ligand site, which is blocked by a water molecule hydrogen-bonded to both chlorides. The remaining waters form a Cl···H–O–H···Cl



a: $m = n = 1$; **b**: $m = 1$, $n = 0$; **c**: $m = n = 0$

Scheme 1 *Reagents and conditions*: i, 40% aq. glyoxal, MeCN; ii, excess BnBr, MeCN, room temp., 3–21 days; iii, excess $NaBH_4$, 95% EtOH, room temp., 4–16 days; iv, 3 mol dm^{-3} HCl, then remove EtOH; v, KOH, H_2O, PhH; vi, H_2 (1 atm.), 10% Pd/C, HOAc, room temp; vii, HOAc removal, then KOH, H_2O, PhH

Table 1 Yields of purified products from Scheme 1

			Yields (%)			
	m	*n*	**4**	**5**	**6**	**7**
a	1	1	72–93	75–93	83–96	72–96
b	1	0	33–56[a]	78–99	64–98	47–70
c	0	0	63–79	69–96	87–99	50–83

[a] After chromatography.

and O···H–O hydrogen bonding network. Again the ligand adopts a distorted [2323]/[2323] conformation.

We have also prepared copper(II) perchlorate complexes of both ligands **7a** and **7c**, a copper(II) chloride complex of ligand **6c** and a nickel dibromide complex of **7a**.† Although the report of Bencini *et al.* suggested *exo*-binding of copper(II) by ligand **1**,[8] these preliminary results clearly confirm the ability of these cross-bridged ligands to direct all four nitrogen lone pairs in a convergent manner and envelope selected metal cations. Further complexation and ligand elaboration studies including pendant-arm attachments are in progress.

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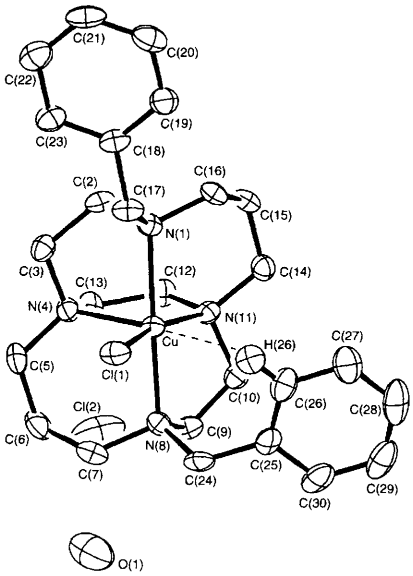

Fig. 1 Molecular structure of **8** showing the atomic numbering scheme. Selected bond lengths (Å) and angles (°): Cu–Cl(1) 2.296(1), Cu–N(1) 2.188(3), Cu–N(4) 2.166(4), Cu–N(8) 2.101(3), Cu–N(11) 2.082(3), Cl(1)–Cu–N(1) 94.74(9), Cl(1)–Cu–N(4) 107.2(1), Cl(1)–Cu–N(8) 89.23(9), Cl(1)–Cu–N(11) 166.0(1), N(1)–Cu–N(4) 84.7(1), N(1)–Cu–N(8) 176.0(2), N(1)–Cu–N(11) 90.7(1), N(4)–Cu–N(8) 94.2(1), N(4)–Cu–N(11) 86.1(1), N(8)–Cu–N(11) 85.4(1).

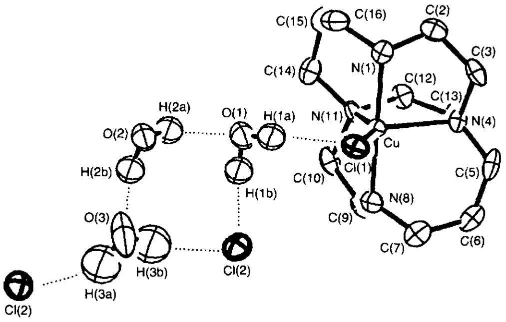

Fig. 2 Molecular structure of **9** showing the atomic numbering scheme. Selected bond lengths (Å) and angles (°): Cu–Cl(1) 2.304(2), Cu–N(1) 2.003(5), Cu–N(4) 2.140(5), Cu–N(8) 1.996(5), Cu–N(11) 2.081(6); Cl(1)–Cu–N(1) 90.3(2), Cl(1)–Cu–N(4) 122.0(1), Cl(1)–Cu–N(8) 92.8(2), Cl(1)–Cu–N(11) 150.2(2), N(1)–Cu–N(4) 85.0(2), N(1)–Cu–N(8) 176.9(2), N(1)–Cu–N(11) 92.3(2), N(4)–Cu–N(8) 93.0(2), N(4)–Cu–N(11) 87.8(2), N(8)–Cu–N(11) 85.2(2).

Footnotes

† All new organic compounds were characterised spectroscopically (IR, ^{1}H and ^{13}C NMR, MS) and gave satisfactory microanalytical CHN or high-resolution MS data. All new coordination complexes were characterised by CHN microanalysis, UV–VIS, and IR.

‡ *Crystal data* for **8**: $C_{26}H_{40}Cl_2CuN_4O$, M = 559.1, triclinic, space group $P\bar{1}$ (no. 2), a = 10.079(1), b = 14.487(1), c = 9.869(1) Å, α = 97.751(6), β = 111.072(4), γ = 98.433(5)°, T = 294 K, U = 1302.4 Å^3, Z = 2, D_c = 1.426 g cm^{-3}. 6259 data were collected (4.4 $\leqslant 2\theta \leqslant$ 48.2°) on a Rigaku RU300 R-AXIS image plate area detector, Mo-Kα radiation, max h,k,l = 11, 16, 11, no absorption correction, 2732 duplicates, 2368 unique reflections with $I \geqslant 3.0\sigma(I)$. Structure was solved by automated Patterson analysis (PHASE), H atoms were idealized with C–H = 0.95 Å. The water H were calculated in hydrogen-bonding positions with the chlorides refinement by full-matrix least squares on F. All non-H atoms were refined anisotropically, H atoms were fixed. 307 parameters, data/parameter ratio = 7.69, final R = 0.038, R_w = 0.035, error of fit = 0.86, max. Δ/σ = 0.01, largest residual density = 0.29 e Å^{-3}, between N(8) and C(7).

§ *Crystal data* for **9**: $C_{12}H_{32}Cl_2CuN_4O_3$, M = 414.9, orthorhombic, space group $Pna2_1$ (no. 33), a = 25.458(2), b = 7.659(1), c = 9.435(1) Å, T = 219 K, U = 1839.7 Å^3, Z = 4, D_c = 1.498 g cm^{-3}. 7240 data were collected (3.2 $\leqslant 2\theta \leqslant$ 48.2°) on a Rigaku RU-300, R-AXIS image plate area detector, Mo-Kα radiation, max. h,k,l = 8, 10, 29, no absorption correction, 1091 unique reflections with $I \geqslant 3.0\sigma(I)$. The structure was solved by direct methods (SHELXS). H atoms were idealized with C–H = 0.95 Å. Refinement was by full-matrix least squares on F. All non-H atoms were refined anisotropically while all H atoms were fixed. 198 parameters, data/parameter ratio = 5.44, final R = 0.029, R_w = 0.027, error of fit = 0.74, max. Δ/σ = 0.04, largest residual density = 0.42 e Å^{-3} near the water molecules. Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre (CCDC). See Information for Authors, Issue No. 1. Any request to the CCDC for this material should quote the full literature citation and the reference number 182/12.

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