SHORT PAPER

J. Chem. Research (S),
2003, 489–490

Synthesis and structure of copper(II) calix[4]arene tetraimidazole complex†

Yu-Dong Cao, Qi-Yu Zheng*, Chuan-Feng Chen and Zhi-Tang Huang*

Laboratory of Chemical Biology, Center for Molecular Science, Institute of Chemistry, Chinese Academy of Sciences, Beijing 100080, China

A copper(II) complexes of calix[4]arene tetraimidazole (CTI) ligand has been prepared to mimic the active site of copper metalloproteins.

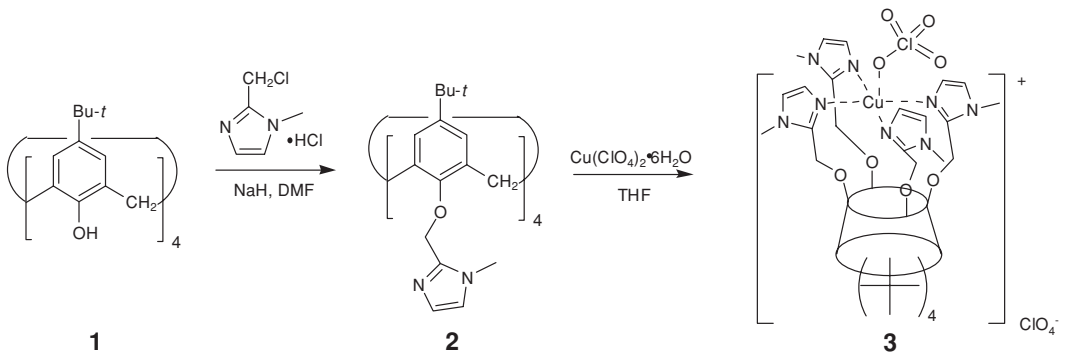
Keywords: calixarene, imidazole, copper

Copper plays a key role in many enzymes, which are related with various biological functions such as electron transfer in photosynthesis, oxygen transport, or substrate oxidation.[1] These functions are the consequence of the redox properties of the copper ion modulated by the protein ligands and of the selection of substrates by the active site.[2] Modelling of the metal-binding site of metalloproteins is a contribution to the understanding of their mechanism of action and to the developing of new enzyme-like catalysts. Recently, a lot of artificial ligands have been prepared to mimic the type 1 structure of copper metalloproteins, and some could reproduce both the spectral features and the reactivity of protein active sites.[3] The imidazole of histidine is a ubiquitous ligand which is present in all types of copper active sites. However, in very few model compounds are imidazole or polyimidazole ligands present.

Calixarenes, which form excellent platforms to build-up novel ligands or supramolecular structures, have attracted considerable interests recently.[4] The ligands based on calixarenes could also bind different metal cations to be applied in analysis, catalysis or material-preparation. Reinaud *et al*. have synthesised several copper complexes with calix[4]arene diimidazole or calix[6]arene triimidazole, which are models for monocopper sites in enzyme.[5] Here, we report a new calix[4]arene tetraimidazole ligand and its complex with copper(II).

We designed the novel ligand **2**, which could be prepared by a simple method starting from *p-tert*-butylcalix[4]arene (**1**) (Scheme 1). Reaction of compound **1** with 2-chloromethyl-1-methyl-1*H*-imidazole in the presence of NaH affords the tetradentate ligand **2** in 68 % yield. The calixarene moiety in **2** adopts a cone conformation in $CDCl_3$, which is demonstrated by the AB system for the methylene protons between two aromatic units in its ^{1}H NMR spectrum. Upon treatment of solutions of $Cu(ClO_4)_2$•$6H_2O$ in THF with ligand **2**, a spontaneous blue precipitate was obtained. Suitable crystals for X-ray diffraction analysis were grown from a cold solution in CH_2Cl_2/CH_3OH.

Place *et al*. have reported the crystallographic properties of a copper (II) tetraimidazoles complex: $[Cu(ClO_4)(TIM)](ClO_4)$ (TIM: bis-[4-(imidazol-4-ylmethyl)-imidazol-2-yl]methane).[6] The copper is bound by five ligands (N_4O), and the four nitrogens come from the four imidazoles of TIM, and the oxygen is from the bound perchlorato-counterion. Its geometry adopts a distorted square planar pyramid, and the four nitrogens strongly deviate from the plane. Very similarly, the crystal structure of **3** showed a five-coordinate mononuclear complex. Cu(II) is coordinated to four imidazoles of the calix[4]arene-based ligand and one perchlorato counter-anion. An ORTEP view is presented in Fig. 1, and selected interatomic bond lengths and angles are given in Table 1. The copper is surrounded by five ligands forming an N_4O environment. The four nitrogens belong to the four imidazoles of calix[4]arene tetraimidazole (CTI), and the oxygen is from the bound perchlorato-counterion. The Cu–N distances are short, with Cu–N(1), Cu–N(3), Cu–N(5) and Cu–N(7) being 1.999(7), 2.103(7), 2.003(7), 2.034(7) Å, respectively, which indicates that there is a stronger coordination of the imidazoles with copper. The oxygen with a Cu–O distance of 2.5393(5) Å is coordinated to the copper. The main angles show a almost tetragonal symmetry with N(1)CuN(5) 176.7(3)° and N(3)CuN(7) 177.5(3)°. The four nitrogens are located in the plane of the tetragonal geometry in which the perchlorato oxygen occupies an apical position. Since no interaction appears in the *trans*-apical position, the geometry of **3** can be seen as that of a square pyramid.



Scheme 1

* To receive any correspondence. E-mail: huangzt@public.bta.net.cn
† This is a Short Paper, there is therefore no corresponding material in *J Chem. Research (M)*.

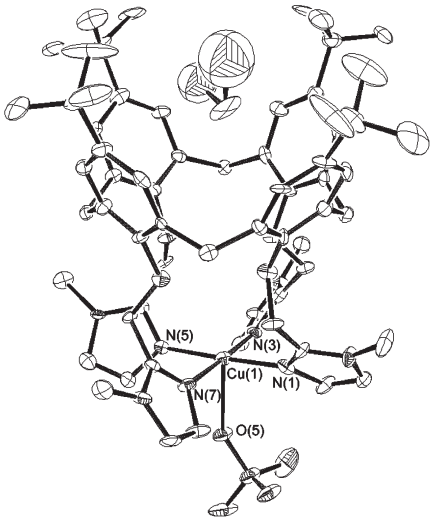


Fig. 1 ORTEP representations of $[Cu(ClO_4)(CTI)]$. (CH_2Cl_2) with the selective atomic labeling. For clarity, the hydrogens and solvent molecules are omitted.

Table 1 Selected interatomic bond lengths (Å) and angles (deg) for $[Cu(ClO_4)(CTI)](ClO_4)$, **3**

Cu(1)N(1)	1.999(7)	Cu(1)N(3)	2.103(7)
Cu(1)N(5)	2.003(7)	Cu(1)N(7)	2.034(7)
Cu(1)O(5)	2.393(5)		
N(1)Cu(1)N(3)	91.4(3)	N(1)Cu(1)N(5)	176.7(3)
N(5)Cu(1)N(3)	89.7(2)	N(1)Cu(1)N(7)	91.0(3)
N(3)Cu(1)N(7)	177.5(3)	N(5)Cu(1)N(7)	87.9(3)
N(1)Cu(1)O(5)	96.6(2)	N(3)Cu(1)O(5)	88.2(2)
N(7)Cu(1)O(5)	92.2(2)	N(5)Cu(1)O(5)	86.5(2)

Interestingly, in the crystal structure, the upper cavity of compound **3** includes a dichloromethane molecule. The distance between hydrogen atoms of dichloromethane and nearest aromatic rings are about 2.7 and 3.0 Å, which indicates that there are CH–π interactions between the substrate and the calixarene. As a result, the complexation at the upper rim is favourable to stabilise the cone conformation of calixarene.

In the FT–IR spectra of complex **3**, there is new very strong absorption in 1106 cm^{-1}, which is attributed to the ν(Cl–O). Compared with free ligand, some of the peaks of the coordinated imidazole ligands shifted to higher wave numbers (*e.g.* 1490 $cm^{-1} \rightarrow$ 1500 cm^{-1}, 980 $cm^{-1} \rightarrow$ 996 cm^{-1}), and the absorption intensity in 623 cm^{-1} has increased. In the UV-Vis absorption spectrum of **3** in CH_2Cl_2, λ_{max} are located at 276 nm (ε = 4970 l/mol/cm) and 570 nm (ε = 46 l/mol/cm, half-height width: 147 nm).

In conclusion, this study provides a novel five-coordinate copper(I) complex with calix[4]arene tetraimidazoles, which could be used as the structure model of copper metalloproteins.

Experimental

Melting points are uncorrected. IR spectra were determined with a JASCO 480plus FT-IR spectrometer as KBr pellets. UV-VIS absorption spectra were recorded on a Shimadzu 2401 spectrometer. NMR spectra were taken at a Bruker DMX 300 MHz with tetramethylsilane as an internal standard. MALDI-TOF (matrix-assisted laser desorption ionisation time-of-flight) mass spectra were recorded on a Bruker BIFLEX III spectrometer with the use of CCA (2-cyano-4'-hydroxycinamic acid) as matrix. Elemental analyses were carried out by the Analytical Laboratory of the Institute. Flash column chromatography was carried out with silica gel 60 spherical (150–325 mesh).

Preparation of calix[4]arene tetraimidazole **2**: To a solution of *p-tert*-butyl-calix[4]arene (**1**) (324 mg, 0.5 mmol) in dried DMF (20 ml) was added NaH (80 % in oil, 750 mg, 25 mmol) and this mixture was stirred for 0.5 h at ambient temperature. Then 2-chloromethyl-1-methyl-1*H*-imidazole hydrochloride (1.67 g, 10 mmol), which was prepared according to literature,[7] was added and the resulting mixture was allowed to warm up to 70 °C and stirred for 24 h. Methanol was slowly added to quench the reaction (**CAUTION!**), and the mixture was poured into water and extracted with dichloromethane. The organic layer was washed with water and brine, and dried over $MgSO_4$. After removal of the solvent under reduced pressure, flash column chromatography with CH_2Cl_2 : CH_3OH (25 : 1) and 1–2 drops of ammonia afforded **2** as a white solid (267 mg, 52 %), m.p. 251–253 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.05 (s, 36H, CCH_3), 2.81 (d, *J* = 12.9, 4H, $ArCH_2Ar$), 3.34 (s, 12H, NCH_3), 4.02 (d, *J* = 12.9, 4H, $ArCH_2Ar$), 5.01 (s, 8H, $ArOCH_2$), 6.70 (s, 8H, Im-H), 6.87 (s, 4H, ArH), 7.06 (s, 4H, ArH); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 30.4 ($ArCH_2Ar$), 31.1 ($C(CH_3)_3$), 32.6 ($C(CH_3)_3$), 33.6 (NCH_3), 66.0 ($ArOCH_2$), 121.6, 124.9, 127.2, 133.7, 144.9, 152.0 (ArC and Im-C); FT-IR (KBr): ν = 3428 (OH), 1636 (C=N), 1490, 1480, 1195, 980 cm^1; MS (MALDI-TOF, positive): *m/z*: 1025.2 $[M+H]^+$, 1047.2 $[M+Na]^+$. Elemental analysis calcd (%) for $C_{64}H_{80}N_8O_4 \cdot 2H_2O$ (1061.41): C, 72.42; H, 7.98; N, 10.56. Found: C, 72.56; H, 7.97; N, 10.41.

Preparation of complex **3**: A mixture of compound **2** (154 mg, 0.15 mmol) and $Cu(ClO_4)_2 \cdot 6H_2O$ (56 mg, 0.15 mmol) was solved in dried THF (1.5 ml) by warming, then this solution was slowly cooled down to room temperature. Blue crystals will separate out. After filtration and washing with water, the blue powder (95 mg, 41 %) was obtained. FT-IR (KBr): ν = 2960, 1628 (C=N), 1604, 1500, 1480, 1194, 1120, 1106, 996, 624 cm^{-1}; Elemental analysis calcd (%) for $C_{64}H_{80}Cl_2CuN_8O_{12}$ (1287.82): C, 59.69; H, 6.26; N, 8.70. Found: C, 59.38; H, 6.30; N, 8.44.

Crystal data **3**: $C_{68.50}H_{96}Cl_6CuN_8O_{14.50}$, *M*r = 1539.77, triclinic, P-1, *a* = 12.533(3), *b* = 13.305(3), *c* = 24.817(5) Å, α = 85.287(8)°, β = 78.197(7)°, γ = 65.219(13)°, *V* = 3677.8(14) $Å^3$, *D*x = 1.390 g cm^3, *Z* = 2, μ = 0.583 mm^{-1}, *T* = 293(2) K. A suitable blue crystal (0.88 × 0.25 × 0.10 mm^3) for X-ray analysis obtained by slow evaporation from CH_2Cl_2–CH_3OH was used for data collection on a Rigaku R-Axis Rapid IP diffractometer with graphite monochromated Mo-Kα radiation (λ = 0.71073 Å). A total of 19555 reflections were collected. The structure was solved by direct methods and expanded using Fourier technique. The final cycle of full-matrix least-squares refinement was based on 14359 observed reflections ($I > \sigma(I)$) and 856 variable parameters and converged with *R* = 0.0897 and *R*w = 0.1685. Full crystallographic details will be deposited at the Cambridge Crystallographic Data Centre (CDDC).

This work is supported by the National Science Foundation of China, the Major State Basic Research Development Program of China (Grant No. G2000078100) and the Chinese Academy of sciences.

Received 26 February 2003; accepted 19 May 2003
Paper 03/1780

References

1 R.H. Holm, P. Kennepohl and E.I. Solomon, *Chem. Rev*., 1996, **96**, 2239; W. Kaim and J. Rall, *Angew. Chem. Int. Ed. Engl*. 1996, **35**, 43.
2 E.I. Solomon, M.J. Baldwin and M.D. Lowery, *Chem. Rev*. 1992, **92**, 521.
3 Y.-J. Kim, S.-O. Kim, Y.-I. Kim and S.-N. Choi, *Inorg. Chem*., 2001, **40**, 4481;. P.L. Holland and W.B. Tolman, *J. Am. Chem. Soc*. 1999, **121**, 7270; P.L. Holland and W.B. Tolman, *J. Am. Chem. Soc*. 2000, **122**, 6331S; Knapp, T.P. Keenan, J. Liu, J.A. Potenza and H.J. Schugar, *Inorg. Chem*., 1990, **29**, 2189.
4 *Calixarene 2001*; Z. Asfari, V. Böhmer, J. Harrowfield and J. Vicens, Eds., Kluwer Academic: Dordrecht, 2001.
5 L. Le Clainche, M. Giorgi and O. Reinaud, *Eur. J. Org. Chem*., 2000, 1931; Y. Rondelez, O. Sénèque, M.-N. Rager, A. F. Duprat and O. Reinaud, *Chem. Eur. J*., 2000, **6**, 4218; L. Le Clainche, M. Giorgi and O. Reinaud, *Inorg. Chem*., 2000, **39**, 3436.
6 C. Place, J.-L. Zimmermann, E. Mulliez, G. Guillot, C. Bois and J.-C. Chottard, *Inorg. Chem*., 1998, **37**, 4030.
7 N. Wei, N.N. Murthy, Z. Tyeklár and K.D. Karlin, *Inorg. Chem*., 1994, 33, 1177.