

Scheme 3. Synthesis of griseoviridin (**1**). a) [Pd(PPh<sub>3</sub>)<sub>4</sub>], pyrrolidine; allyl amine, HOBT, EDCI, DMF, 82 %; b) PPTS, acetone/H<sub>2</sub>O, 68 %. HOBT = 1-hydroxy-1*H*-benzotriazole, EDCI = *N*'-(3-dimethylaminopropyl)-*N*-ethylcarbodiimide, PPTS = pyridinium-*p*-toluenesulfonate.

omer in 68% yield. The entire sequence was performed in 24 linear steps from (*S*)-malic acid. The material thus obtained was shown to be identical in all respects to natural griseoviridin<sup>[20]</sup> (<sup>1</sup>H, <sup>13</sup>C NMR,  $[\alpha]_D$ , etc.).

The sequence leading to C-8 *epi*-griseoviridin<sup>[21]</sup> was performed in exactly the same manner and led to a product, in comparable yields, that was distinctly different from natural griseoviridin in its spectroscopic properties. Attempts to ascertain whether ene–thiol lactone **5** could be interconverted to its C-8 epimer proved fruitless due to decomposition when strong bases were employed. Further, attempts to incorporate deuterium into the C-8 position of **5** also failed. In summary, griseoviridin and its C-8 epimer have been synthesized for the first time employing a novel ring-closing metathesis which involved a highly diastereoselective triene to diene macrocyclic ring formation.

Received: January 3, 2000 [Z14501]

*dron Lett.* **1983**, 24, 4391; e) L. Liu, R. S. Tanke, M. J. Miller, *J. Org. Chem.* **1986**, 51, 5332.

- [8] G. I. Birnbaum, S. R. Hall, *J. Am. Chem. Soc.* **1976**, 98, 1926.
- [9] B. W. Bycroft, T. J. King, *J. Chem. Soc. Perkin Trans. 1* **1976**, 1996. Professor Bycroft informed us after the appearance of his paper that the configuration at C-18 was *R* rather than *S* and we confirmed this by inserting the atomic coordinates obtained by the British group into the SHELXTL program, version 5, which showed that both hydroxy groups at C-18 and C-20 were indeed *syn* as shown in **1**.
- [10] Another version of this lactone **5** was prepared 20 years ago by a slightly different procedure. However the benzamide and methyl ester in **5** proved to be worthless in proceeding with the synthesis of griseoviridin. A. I. Meyers, R. A. Amos, *J. Am. Chem. Soc.* **1980**, 102, 870.
- [11] H. W. Yang, D. Romo, *J. Org. Chem.* **1998**, 63, 1344.
- [12] D. B. Dess, J. C. Martin, *J. Am. Chem. Soc.* **1991**, 113, 7277.
- [13] T. Kurihara, Y. Nakajima, O. Mitsunobu, *Tetrahedron Lett.* **1976**, 2455.
- [14] Confirmation of complete inversion at C-5 was provided by comparison of the <sup>1</sup>H NMR spectrum with that of the C-Me diastereomeric lactone prepared by cyclization under Yamamoto lactonization conditions; see: K. Ishihara, M. Kubota, A. Kurihara, H. Yamamoto, *J. Org. Chem.* **1996**, 61, 4560.
- ng, C. E. Anderson, M. A. Ciufolini, *Tetrahedron Lett.* **1995**, 36, 369.
- onnet, *Tetrahedron* **1980**, 36, 557, and references therein.
- König, R. Geiger, *Chem. Ber.* **1973**, 106, 3626; b) J. C. Sheehan, P. A. Cruickshank, *J. Am. Chem. Soc.* **1965**, 87, 2492.
- riel, *Tetrahedron Lett.* **1987**, 28, 4371.
- Grubbs, S. Chang, *Tetrahedron* **1998**, 54, 4413, and references therein.
- ank Professor Bycroft for sending us a sample of **1** (over 25 years old) which arrived totally intact, and gave a very clean <sup>13</sup>C and IR spectrum.
- ple of the heretofore unknown C-8 *epi*-griseoviridin has been tested for antibacterial screening (Aventis) and found to be only poorly active (courtesy of Dr.S. Dutka-Malen).

## A Structural Model for the Galactose Oxidase Active Site which Shows Counteranion-Dependent Phenoxy Radical Formation by Disproportionation\*\*

Yuichi Shimazaki, Stefan Huth, Akira Odani, and  
Osamu Yamauchi\*

Galactose oxidase (GO) contains one copper ion at its active site and performs a two-electron oxidation of primary alcohols to aldehydes, coupled with a reduction of O<sub>2</sub> to

- [1] a) "The Streptogramin Family of Antibiotics", D. Vasquez in *Antibiotics III* (Eds.: J. W. Corcoran, F. H. Hahn), Springer, New York, **1975**; b) for recent antibacterial activity see: R. C. Möllering, P. K. Linden, J. Reinhardt, E. Blumberg, G. Bompert, G. H. Talbot, J. *Antimicrob. Chemother.* **1999**, *44*, 251.
- [2] F. Tavares, J. P. Lawson, A. I. Meyers, *J. Am. Chem. Soc.* **1996**, *118*, 3303.
- [3] R. H. Schlessinger, Y. Li, *J. Am. Chem. Soc.* **1996**, *118*, 3301.
- [4] Etamycin (**2**) has been synthesized: J. C. Sheehan, S. L. Ledis, *J. Am. Chem. Soc.* **1973**, *95*, 875.
- [5] Denver Rocky Mountain News, Sept. 22, **1999**: "FDA approved Synercid to treat vancomycin-resistant enterococcal and Staph infections". Synercid is a trade name for the combination of Group A and B streptogramins manufactured by Rhone-Poulenc Rorer.
- [6] D. A. Entwistle, S. I. Jordan, J. Montgomery, G. Pattenenden, *J. Chem. Soc. Perkin Trans. I* **1996**, 1315.
- [7] a) A. I. Meyers, J. P. Lawson, D. G. Walker, R. J. Linderman, *J. Org. Chem.* **1986**, *51*, 5111; b) P. Helquist, M. Bergdahl, R. Hett, A. R. Gangloff, M. Demillequand, M. Cottard, M. M. Mader, T. Friebe, J. Iqbal, Y. Wu, B. Åkermark, T. Rein, N. Kann, *Pure Appl. Chem.* **1994**, *66*, 2063; c) R. H. Schlessinger, E. J. Iwanowicz, J. P. Springer, *Tetrahedron Lett.* **1988**, *29*, 1489; d) R. D. Wood, B. Ganem, *Tetrahedron*

- [\*] Prof. Dr. O. Yamauchi, Y. Shimazaki, S. Huth,<sup>[+]</sup> Dr. A. Odani  
Department of Chemistry  
Graduate School of Science and Research Center for Materials  
Science  
Nagoya University, Nagoya 464-8602 (Japan)  
Fax: (+81) 52-789-2953  
E-mail: b42215a@nucc.cc.nagoya-u.ac.jp
- [+] On leave of absence from the University of Bremen
- [\*\*] This work was supported by Grants-in-Aid for Scientific Research  
(No. 09304062 and 0149219 (Priority Areas) to O.Y. and No.  
07CE2004(COE) to A.O.) from the Ministry of Education, Science,  
Sports, and Culture of Japan, for which we express our thanks.

$\text{H}_2\text{O}_2$ .<sup>[1]</sup> Structural studies of the inactive form of GO have revealed that there exist two distinct tyrosine residues in the active site, one of which is a cysteine-modified phenol moiety of tyrosine 272 ( $\text{Y}_{272}$ ) coordinated to the copper center as an equatorial ligand, while the other is a phenol group of tyrosine 495 ( $\text{Y}_{495}$ ) bound at an apical position.<sup>[2]</sup> The  $\text{Cu}^{\text{II}}$  ion and a phenoxyl radical together effect the two-electron oxidation reaction.<sup>[3]</sup> The proposed mechanism of catalysis involves a cycle of the  $\text{Cu}^{\text{I}}$ –phenol and  $\text{Cu}^{\text{II}}$ –phenoxyl radical states; no  $\text{Cu}^{\text{II}}$ –phenolate form has been detected during catalysis.<sup>[1, 2, 4]</sup>

Recent synthetic studies afforded well-characterized mononuclear  $\text{Cu}^{\text{II}}$ –phenoxyl radical species, which provided further insights into the reactivity of the GO active site.<sup>[5]</sup> Tripodal ligands introduced by Karlin<sup>[6]</sup> have been developed for use as GO model ligands in a number of studies.<sup>[5c, f, h, 7, 8]</sup> Model complexes of ligands with two or more phenol moieties have also been synthesized by several groups.<sup>[5b, d, e, f, k–m]</sup> However, modeling of the coordination structure and roles of the two coordinated phenol moieties with monomeric  $\text{Cu}^{\text{II}}$  complexes has not yet been fully achieved, and dimerization of the complexes often occurs.<sup>[5f, h, 7, 8]</sup> We report here the synthesis and characterization of a novel mononuclear  $\text{Cu}^{\text{II}}$  complex of a tetradentate tripodal ligand, which is similar to that prepared by Pierre et al.,<sup>[5f]</sup> with two phenol moieties and two *tert*-butyl groups introduced. The coordination structure has been found to closely resemble that of the inactive GO form.<sup>[2]</sup> Preliminary studies showed that, while  $\text{Cu}(\text{OAc})_2$  gives a stable GO-mimicking complex with two phenol moieties coordinated, the  $\text{CuCl}_2$  and  $\text{Cu}(\text{ClO}_4)_2$  ligand systems react differently and the latter spontaneously gives the phenoxyl radical species by disproportionation.

*N*-(2-pyridylmethyl)-*N,N*-bis(2'-hydroxy-3',5'-di-*tert*-butylbenzyl)amine ( $\text{H}_2\text{L}$ ) was treated with  $\text{Cu}(\text{OAc})_2 \cdot 2\text{H}_2\text{O}$  in  $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{CN}$  in air at room temperature to give  $[\text{Cu}(\text{HL})(\text{OAc})] \cdot \text{H}_2\text{O}$  (**1**) as brown crystals (Scheme 1). X-ray crystal

structure analysis revealed that **1** contains two phenol moieties coordinated to  $\text{Cu}^{\text{II}}$  in different ways (Figure 1), and the unit cell consists of two crystallographically independent complex molecules.<sup>[9]</sup> The  $\text{Cu}^{\text{II}}$  center is in a distorted

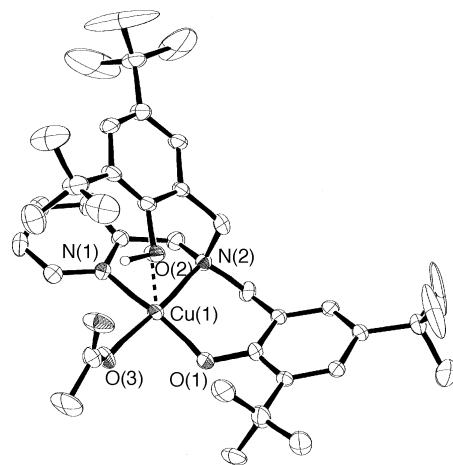
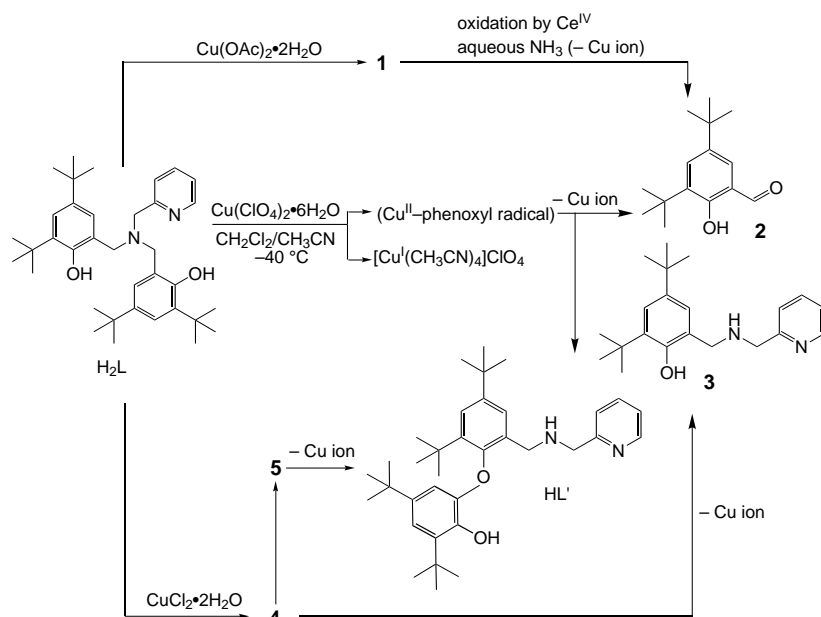


Figure 1. ORTEP view of  $[\text{Cu}(\text{HL})(\text{OAc})]$  **1** (drawn with the thermal ellipsoids at the 30% probability level) and atomic labeling scheme. Selected bond lengths [Å] and angles [°]: Cu(1)–N(1) 2.001(6), Cu(1)–N(2) 2.043(5), Cu(1)–O(1) 1.883(4), Cu(1)–O(2) 2.418(5), Cu(1)–O(3) 1.957(5); N(1)–Cu(1)–N(2) 83.2(2), N(1)–Cu(1)–O(1) 159.6(2), N(1)–Cu(1)–O(2) 90.5(2), N(2)–Cu(1)–O(2) 86.6(2), N(1)–Cu(1)–O(3) 93.1(2), O(1)–Cu(1)–O(2) 109.6(2), O(1)–Cu(1)–O(3) 88.5(2).

square-pyramidal geometry formed by a phenolate oxygen, a pyridine nitrogen, a tertiary amine nitrogen, and an acetate oxygen in the coordination plane with a protonated phenol oxygen at an axial position with an average Cu–O bond length of 2.40 Å.

The brown solution of **1** exhibited the phenolate– $\text{Cu}^{\text{II}}$  charge transfer band at 470 nm ( $\epsilon = 1300$ ), which disappeared upon oxidation with  $\text{Ce}^{\text{IV}}$  in  $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{CN}$  at low temperature ( $-40^\circ\text{C}$ ), but formation of the phenoxyl radical could not be detected. Decomposition products **2** and **3** were isolated from the reaction mixture, both in 15% yield (Scheme 1). Cyclic voltammetry in  $\text{CH}_2\text{Cl}_2$  with tetrabutylammonium perchlorate revealed an irreversible oxidation at 0.62 V against Ag/AgCl (scan rate = 100  $\text{mV s}^{-1}$ ). Complex **1** was found to be inactive for oxidation of ethanol.

On the other hand,  $\text{Cu}(\text{ClO}_4)_2 \cdot 6\text{H}_2\text{O}$  underwent a reaction with  $\text{H}_2\text{L}$  in  $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{CN}$ , to rapidly form a deep green color. After exposure to air at room temperature, the deep green reaction mixture turned colorless, and yielded colorless crystals of  $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{ClO}_4$  (yield of the first crop, 35%; subsequent small crops were also obtained). The deep green intermediate solution at  $-40^\circ\text{C}$  exhibited an absorption band centered at 403 nm ( $\epsilon = 2000$ ) with a shoulder and at 654 nm ( $\epsilon = 400$ ); no X-band EPR signals were observed, which is consis-



Scheme 1. Reaction scheme for  $\text{Cu}^{\text{II}}$ – $\text{H}_2\text{L}$  system which shows the dependence on the counterion.

tent with a  $\text{Cu}^{\text{II}}$ -phenoxyl radical species as these are known to give typical absorption peaks, for example, at 410 ( $\epsilon = 4000$ ), 422 ( $\epsilon = 3800$ ), and 672 nm ( $\epsilon = 1000$ ).<sup>[5d]</sup> The radical species was also detected under an inert gas atmosphere, and colorless crystals of  $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{ClO}_4$  were isolated, showing that the radical formation is not due to oxidation by dioxygen. The deep green reaction intermediate was short lived relative to some of the reported oxidized species,<sup>[5]</sup> decaying by a first order process at  $-20^\circ\text{C}$  with  $k = (9.3 \pm 0.2) \times 10^{-4} \text{ s}^{-1}$  (UV-Visible monitoring). No such reactions were observed for a solution containing methanol, which gave the dimeric complex  $\text{Cu}_2\text{L}_2$  as brown powder upon addition of triethylamine.<sup>[5f]</sup> Decomposition products **2** and **3** (yields less than 10%) were also detected in the colorless reaction mixture of the  $\text{Cu}(\text{ClO}_4)_2\text{-H}_2\text{L}$  system (Scheme 1). As they are identical with those from complex **1**, we may infer that similar reactions have occurred in both systems.

When  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$  was used in place of  $\text{Cu}(\text{ClO}_4)_2 \cdot 6\text{H}_2\text{O}$ , it underwent a reaction with  $\text{H}_2\text{L}$  in  $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{CN}/\text{hexane}$  in air to give  $[\text{Cu}(\text{H}_2\text{L})\text{Cl}_2]$  (**4**) as green crystals, where the  $\text{Cu}^{\text{II}}$  ion binds two nitrogen atoms and two chloride ions in the coordination plane and the two phenol hydroxyl groups are protonated, one is also weakly coordinated ( $\text{Cu}\text{-O}(1)$  2.677(7) Å; Figure 2). Addition of triethylamine to **4** afforded

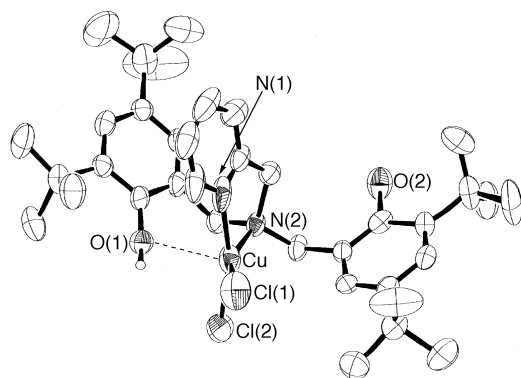


Figure 2. ORTEP view of  $[\text{Cu}(\text{H}_2\text{L})\text{Cl}_2]$  **4** (drawn with the thermal ellipsoids at the 30% probability level) and atomic labeling scheme. Selected bond lengths [Å] and angles [ $^\circ$ ]: Cu–N(1) 1.955(9), Cu–N(2) 2.099(7), Cu–Cl(1) 2.254(4), Cu–Cl(2) 2.230(3), Cu–O(1) 2.677(7); N(1)–Cu–N(2) 82.3(5), N(1)–Cu–Cl(1) 94.3(4), Cl(1)–Cu–Cl(2) 93.7(2), N(1)–Cu–O(1) 80.5(3), N(2)–Cu–O(1) 87.5(3).

the same dimeric complex as obtained from the  $\text{Cu}(\text{ClO}_4)_2\text{-H}_2\text{L}$  system.<sup>[5f]</sup> In connection with this,  $\text{Cu}^{\text{II}}$ -tripodal ligand complexes with an  $\text{N}_3\text{O}$  chromophore have been isolated with different anions.<sup>[8]</sup> By analogy with  $\text{CuCl}_2$ ,  $\text{Cu}(\text{ClO}_4)_2$  most probably initially forms a protonated complex such as **4**, and since the perchlorate ions can dissociate easily from  $\text{Cu}^{\text{II}}$  even when they are bound,  $\text{Cu}_2\text{L}_2$  should be more rapidly formed in the  $\text{Cu}(\text{ClO}_4)_2\text{-H}_2\text{L}$  system than from **4**. Upon standing at room temperature for a few weeks, **4** gave **2**, **3**, and complex **5** which coordinates a new product  $\text{HL}'$  (Figure 3); this was also detected in a small amount in the  $\text{Cu}(\text{ClO}_4)_2\text{-H}_2\text{L}$  system. These results indicate that the  $\text{Cu}^{\text{II}}$ -phenoxyl radical in this system was produced together with  $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{ClO}_4$  as a result of a disproportionation reaction,<sup>[10]</sup> which may take

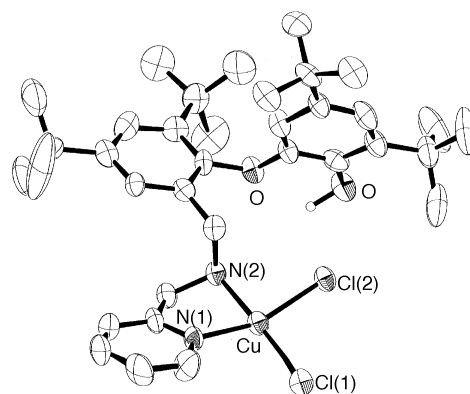


Figure 3. ORTEP view of  $[\text{Cu}(\text{HL}')\text{Cl}_2]$  **5** (drawn with the thermal ellipsoids at the 30% probability level) and atomic labeling scheme. Selected bond lengths [Å] and angles [ $^\circ$ ]: Cu–N(1) 2.002(8), Cu–N(2) 2.024(8), Cu–Cl(1) 2.266(3), Cu–Cl(2) 2.268(3); N(1)–Cu–N(2) 80.2(3), N(1)–Cu–Cl(1) 96.2(3), N(1)–Cu–Cl(2) 158.0(3), N(2)–Cu–Cl(1) 176.2(2), N(2)–Cu–Cl(2) 89.1(2), Cl(1)–Cu–Cl(2) 94.0(1).

place by rapid dimer formation from **4** where the phenol moieties are unbound or only weakly bound.

In conclusion, we obtained a new GO model  $\text{Cu}^{\text{II}}$  complex **1** of a tripodal ligand  $\text{H}_2\text{L}$ , where the two side-chain phenol moieties coordinated at an equatorial and an axial position in the phenolate and the phenol form, respectively. Different counteranions of the metal sources not only caused a large structural difference in the complexes relative to that reported earlier<sup>[8]</sup> but also affected the reactivity of the complexes, which increases as the order of anion basicity decreases:  $\text{CH}_3\text{COO}^- > \text{Cl}^- > \text{ClO}_4^-$ .<sup>[11]</sup> In the  $\text{Cu}(\text{ClO}_4)_2\text{-H}_2\text{L}$  system, spontaneous formation of a phenoxyl radical species and  $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{ClO}_4$  due to disproportionation has been observed. To the best of our knowledge, this is the first observation of  $\text{Cu}^{\text{II}}$ -phenoxyl radical formation by disproportionation of  $\text{Cu}^{\text{II}}$  complexes.

## Experimental Section

**Synthesis of  $N$ -(2-pyridylmethyl)- $N,N$ -bis(2'-hydroxy-3',5'-di-*tert*-butylbenzyl)amine ( $\text{H}_2\text{L}$ ):** 2,4-di-*tert*-butylphenol (4.12 g, 20 mmol) and paraformaldehyde (0.60 g, 20 mmol) were added to a solution of 2-pyridylmethylamine (1.08 g, 10 mmol) in ethanol (100 mL). The reaction mixture was refluxed for two days to give a white powder which, after isolation, was recrystallized from ethyl acetate to yield 2.01 g (56.3%).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 1.28 (s, 18H;  $(\text{CH}_3)_3\text{C}$ ), 1.40 (s, 18H;  $(\text{CH}_3)_3\text{C}$ ), 3.80 (s, 4H; phenol- $\text{CH}_2$ ), 3.84 (s, 2H; py- $\text{CH}_2$ ), 6.93 (d, 2H; phenol-H), 7.13 (d, 1H; py-H), 7.22 (d, 2H; phenol-H), 7.27 (m, 1H; py-H), 7.69 (td, 1H; py-H), 8.69 (d, 1H; py-H), 10.55 (br s, 2H; phenol-OH).

**Synthesis of **1**:** The complex was prepared from  $\text{H}_2\text{L}$  and  $\text{Cu}(\text{OAc})_2 \cdot 2\text{H}_2\text{O}$  in  $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{CN}$  (1:1) to give brown crystals. Elemental analysis (%) calcd for  $\text{C}_{38}\text{H}_{57}\text{N}_2\text{O}_5\text{Cu}$ : C 66.59, H 8.38, N 4.09; found: C 66.13, H 8.450, N 4.08.

**Synthesis of the dimer  $\text{Cu}_2\text{L}_2$ :**  $\text{H}_2\text{L}$  (0.545 g, 1.0 mmol) was dissolved in  $\text{CH}_2\text{Cl}_2$  (10 mL) which contained a few drops of triethylamine and was added to a solution of  $\text{Cu}(\text{ClO}_4)_2 \cdot 6\text{H}_2\text{O}$  (0.370 g, 1.0 mmol) in methanol (10 mL), which caused a brown powder to separate immediately. This was collected and dried. Elemental analysis (%) calcd for  $\text{C}_{72}\text{H}_{100}\text{N}_4\text{O}_4\text{Cu}_2$ : C 71.31, H 8.31, N 4.62; found: C 70.99; H 8.153; N 4.619.

**Synthesis of **4**:** Small green crystals were obtained from a solution of  $\text{H}_2\text{L}$  and  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$  in  $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{CN}/\text{hexane}$  (1/1/1). Elemental analysis (%) calcd for  $\text{C}_{36}\text{H}_{52}\text{N}_2\text{O}_2\text{CuCl}_2$ : C 63.66, H 7.72, N 4.12; found: C 63.29, H 7.596, N 4.07.

Typical recovery of reaction products:<sup>[12]</sup> compound **4** (0.350 g, 0.514 mmol) was dissolved in CH<sub>3</sub>OH/CH<sub>3</sub>CN (1:1) and kept standing for a few weeks at room temperature. The green crystals which separated from the reaction mixture were collected, and the brown filtrate was evaporated in vacuo. The residue was dissolved in concentrated aqueous NH<sub>3</sub> (10 mL) and extracted with CHCl<sub>3</sub> (4 × 10 mL). The combined organic fractions were washed with concentrated aqueous NaCl (3 × 10 mL), dried over Na<sub>2</sub>SO<sub>4</sub>, filtered, and concentrated in vacuo to leave a brown oil. Compounds **2** and **3** were separated by column chromatography, and their structures and yields were determined by <sup>1</sup>H NMR. The structure of ligand HL' in **5** was determined by X-ray analysis of **5** and by <sup>1</sup>H NMR after removal of Cu<sup>II</sup> as described above. Compound **2**: Yield, 15%; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ = 1.33 (s, 9H; (CH<sub>3</sub>)<sub>3</sub>C), 1.43 (s, 9H; (CH<sub>3</sub>)<sub>3</sub>C), 7.34 (d, 1H; phenol-H), 7.59 (d, 1H; phenol-H), 9.87 (s, 1H; phenol-OH), 11.64 (s, 1H; CHO). Compound **3**: Yield, 15%; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ = 1.28 (s, 9H; (CH<sub>3</sub>)<sub>3</sub>C), 1.43 (s, 9H; (CH<sub>3</sub>)<sub>3</sub>C), 3.93 (s, 2H; CH<sub>2</sub>), 3.98 (s, 2H; CH<sub>2</sub>), 6.84 (d, 2H; phenol-H), 7.2 (m, 3H; py-H, phenol-H), 7.66 (td, 1H; py-H), 8.58 (d, 1H; py-H). Compound **5**: Yield, 12%; elemental analysis (%) calcd for C<sub>35</sub>H<sub>50</sub>N<sub>2</sub>O<sub>2</sub>CuCl<sub>2</sub>: C 63.19, H 7.58, N 4.21; found: C 63.07, H 7.532, N 4.27. HL': <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ = 1.11 (s, 9H, (CH<sub>3</sub>)<sub>3</sub>C), 1.33 (s, 9H, (CH<sub>3</sub>)<sub>3</sub>C), 1.37 (s, 9H, (CH<sub>3</sub>)<sub>3</sub>C), 1.47 (s, 9H, (CH<sub>3</sub>)<sub>3</sub>C), 3.47 (q, 2H; CH<sub>2</sub>), 3.73 (q, 2H; CH<sub>2</sub>), 6.27 (d, 1H; phenol-H), 6.90 (d, 1H; phenol-H), 7.14 (dd, 1H; py-H), 7.16 (d, 1H; phenol-H), 7.19 (d, 1H; py-H), 7.37 (d, 1H; phenol-H), 7.60 (td, 1H; py-H), 8.52 (d, 1H; py-H).

Received: November 11, 1999 [Z14258]

- [1] J. W. Whittaker, *Met. Ions Biol. Syst.* **1994**, 30, 315.
- [2] N. Itoh, S. E. V. Phillips, K. D. S. Yadav, P. F. Knowles, *J. Mol. Biol.* **1994**, 238, 794.
- [3] a) M. M. Whittaker, J. W. Whittaker, H. Milburn, A. Quick, *J. Biol. Chem.* **1990**, 265, 9610; b) M. L. McGlashen, D. D. Eads, T. G. Spiro, J. W. Whittaker, *J. Phys. Chem.* **1995**, 99, 4918; c) A. J. Baron, C. Stevens, C. Wilmot, K. D. Seneviratne, V. Blakeley, D. M. Dooley, S. E. V. Phillips, P. F. Knowles, M. J. McPherson, *J. Biol. Chem.* **1994**, 269, 25095; d) P. F. Knowles, R. D. Brown III, S. H. Koenig, S. Wang, R. A. Scott, M. A. McGuire, D. E. Brown, D. M. Dooley, *Inorg. Chem.* **1995**, 34, 3895; e) M. P. Reynolds, A. J. Baron, C. M. Wilmot, E. Vinecombe, C. Steven, S. E. V. Phillips, P. F. Knowles, M. J. McPherson, *J. Biol. Inorg. Chem.* **1997**, 2, 327; f) K. Clark, J. E. Penner-Hahn, M. Whittaker, J. W. Whittaker, *Biochemistry* **1994**, 33, 12553.
- [4] J. Stubbe, W. A. van der Donk, *Chem. Rev.* **1998**, 98, 705.
- [5] a) J. A. Halfen, V. G. Young Jr., W. B. Tolman, *Angew. Chem.* **1996**, 108, 1832; *Angew. Chem. Int. Ed. Engl.* **1996**, 35, 1687; b) Y. Wang, T. D. P. Stack, *J. Am. Chem. Soc.* **1996**, 118, 13097; c) M. M. Whittaker, W. R. Duncan, J. W. Whittaker, *Inorg. Chem.* **1996**, 35, 382; d) A. Halfen, B. A. Jazdzewski, S. Mahapatra, L. M. Berreau, E. C. Wilkinson, L. Que Jr., W. B. Tolman, *J. Am. Chem. Soc.* **1997**, 119, 8217; e) A. Sokolowski, H. Leutbecher, T. Weyhermüller, R. Schnepf, E. Bothe, E. Bill, P. Hildebrandt, K. Wieghardt, *J. Biol. Inorg. Chem.* **1997**, 2, 444; f) D. Zurita, I. Gautier-Luneau, S. Ménage, J.-L. Pierre, E. Saint-Aman, *J. Biol. Inorg. Chem.* **1997**, 2, 46; g) Y. Wang, J. L. DuBois, B. Hedman, K. O. Hodgson, T. D. P. Stack, *Science* **1998**, 279, 537; h) S. Itoh, S. Takayama, R. Arakawa, A. Furuta, M. Komatsu, A. Ishida, S. Takamuku, S. Fukuzumi, *Inorg. Chem.* **1997**, 36, 1407; i) J. Müller, T. Weyhermüller, E. Bill, P. Hildebrandt, L. Ould-Moussa, T. Glaser, K. Wieghardt, *Angew. Chem.* **1998**, 110, 637; *Angew. Chem. Int. Ed.* **1998**, 37, 616; j) B. A. Jazdzewski, V. G. Young, Jr., W. B. Tolman, *Chem. Commun.* **1998**, 2521; k) P. Chaudhuri, M. Hess, U. Flörke, K. Wieghardt, *Angew. Chem.* **1998**, 110, 2340; *Angew. Chem. Int. Ed.* **1998**, 37, 2217; l) P. Chaudhuri, M. Hess, T. Weyhermüller, K. Wieghardt, *Angew. Chem.* **1999**, 111, 1165; *Angew. Chem. Int. Ed.* **1999**, 38, 1095; m) P. Chaudhuri, M. Hess, J. Müller, K. Hildebrandt, E. Bill, T. Weyhermüller, K. Wieghardt, *J. Am. Chem. Soc.* **1999**, 119, 9599.
- [6] a) K. D. Karlin, B. I. Cohen, *Inorg. Chim. Acta* **1985**, 107, L17; b) K. D. Karlin, B. I. Cohen, J. C. Hayes, A. Farooq, J. Zubietta, *Inorg. Chem.* **1987**, 26, 147.
- [7] a) U. Rajendran, R. Viswanathan, M. Palaniandavar, M. Lakshminarayanan, *J. Chem. Soc. Dalton Trans.* **1992**, 3563; b) M. Vaidyanathan, R. Viswanathan, M. Palaniandavar, T. Balasubramanian, P. Prabhakaran, T. P. Muthiah, *Inorg. Chem.* **1998**, 37, 6418.
- [8] a) H. Adams, N. A. Bailey, D. E. Fenton, Q.-Y. He, M. Ohba, H. Okawa, *Inorg. Chim. Acta* **1994**, 215, 1; b) H. Adams, N. A. Bailey, I. K. Campbell, D. E. Fenton, Q.-Y. He, *J. Chem. Soc. Dalton Trans.* **1996**, 2233.
- [9] X-ray crystal structure determination: The X-ray diffraction data were collected at 295 K with a Rigaku AFC-5R four-circle diffractometer using graphite-monochromated CuK $\alpha$  radiation ( $\lambda = 1.54178 \text{ \AA}$ ). Crystal data for **1**: Formula C<sub>76</sub>H<sub>108</sub>N<sub>4</sub>O<sub>9</sub>Cu<sub>2</sub>,  $M_w = 1348.80$ , crystal size:  $0.3 \times 0.1 \times 0.1 \text{ mm}$ , monoclinic, space group  $P2_1/n$ ,  $a = 26.782(4) \text{ \AA}$ ,  $b = 10.672(2) \text{ \AA}$ ,  $c = 26.819(3) \text{ \AA}$ ,  $\beta = 94.33(1)^\circ$ ,  $V = 7643(2) \text{ \AA}^3$ ,  $Z = 4$ ,  $\rho_{\text{calcd}} = 1.352 \text{ g cm}^{-3}$ ,  $\mu = 12.39 \text{ cm}^{-1}$ ,  $F(000) = 3112.00$ , 13682 independent reflections, 8230 reflections used, 821 parameters,  $R = 0.074$ ,  $R_w = 0.085$  ( $I > 2.00\sigma(I)$ ). In the asymmetric unit there were two crystallographically independent complex molecules, which have very similar structures and may be regarded as mirror images arising from the coordination of the tertiary amine nitrogen to Cu<sup>II</sup>. Crystal data for **4**: Formula C<sub>37</sub>H<sub>56</sub>N<sub>2</sub>O<sub>3</sub>Cl<sub>2</sub>Cu,  $M_w = 711.31$ , crystal size:  $0.17 \times 0.10 \times 0.06 \text{ mm}$ , triclinic, space group  $P\bar{1}$ ,  $a = 13.865(4) \text{ \AA}$ ,  $b = 16.048(5) \text{ \AA}$ ,  $c = 10.378(5) \text{ \AA}$ ,  $\alpha = 98.69(5)^\circ$ ,  $\beta = 104.67(4)^\circ$ ,  $\gamma = 112.64(2)^\circ$ ,  $V = 1980(1) \text{ \AA}^3$ ,  $Z = 2$ ,  $\rho_{\text{calcd}} = 1.193 \text{ g cm}^{-3}$ ,  $\mu = 22.80 \text{ cm}^{-1}$ ,  $F(000) = 758.00$ , 5791 independent reflections, 5791 reflections used, 407 parameters,  $R = 0.083$ ,  $R_w = 0.128$  ( $I > 2.00\sigma(I)$ ). Crystal data for **5**: Formula C<sub>35</sub>H<sub>50</sub>N<sub>2</sub>O<sub>2</sub>Cl<sub>2</sub>Cu,  $M_w = 665.24$ , crystal size:  $0.20 \times 0.15 \times 0.03 \text{ mm}$ , monoclinic, space group  $P2_1/a$ ,  $a = 18.054(4) \text{ \AA}$ ,  $b = 12.712(7) \text{ \AA}$ ,  $c = 18.314(4) \text{ \AA}$ ,  $\beta = 116.00(1)^\circ$ ,  $V = 3783(2) \text{ \AA}^3$ ,  $Z = 4$ ,  $\rho_{\text{calcd}} = 1.168 \text{ g cm}^{-3}$ ,  $\mu = 23.35 \text{ cm}^{-1}$ ,  $F(000) = 2256.00$ , 5357 independent reflections, 4926 reflections used, 380 parameters,  $R = 0.069$ ,  $R_w = 0.107$  ( $I > 2.00\sigma(I)$ ). Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication nos. CCDC-136595, -136596, and -136821. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44) 1223-336-033; e-mail: deposit@ccdc.cam.ac.uk).
- [10] J. S. Thompson, J. C. Calabrese, *Inorg. Chem.* **1985**, 24, 3167.
- [11] *Acid-Base Dissociation Constants in Dipolar Aprotic Solvents* (Ed.: K. Izutsu), Chemical Data Series No. 35, Blackwell Scientific, Oxford, **1990**.
- [12] P. L. Holland, K. R. Rodgers, W. B. Tolman, *Angew. Chem.* **1999**, 111, 1210; *Angew. Chem. Int. Ed.* **1999**, 38, 1139.

## Reaction of Organic Selenocyanates with Hydroxides: The One-Pot Synthesis of Dialkyl Diselenides from Alkyl Bromides

Alain Krief,\* Willy Dumont, and Cathy Delmotte

Dedicated to Professor Bernd Giese on the occasion of his 60th birthday

Since the beginning of organoselenium chemistry, organoselenocyanates have occupied a privileged position.<sup>[1]</sup> They are easily prepared, are stable to atmospheric conditions, and have widely contributed to the use of organoselenium compounds in synthesis due to their exceptional versatility.<sup>[1]</sup> They react with a large variety of compounds, producing chemoselectively, in a single step and in almost quantitative

[\*] Prof. Dr. A. Krief, Dr. W. Dumont, Dipl.-Chem. C. Delmotte  
Laboratoire de Chimie Organique de Synthèse  
Département de Chimie  
Facultés Universitaires Notre-Dame de la Paix  
61 rue de Bruxelles, 5000 Namur (Belgium)  
Fax: (+32)81-724536  
E-mail: alain.krief@fundp.ac.be