Inorg. Chem. **1991**, *30*, 1677–1680

bond dissociation energies,[9-11] the propagator of the σ inductive effect,[1,10] heteropolar bond dissociation energies,[12] and bond energies of silicon compounds[8,13] and for proposing a theoretical model of bond fissions.[14] We have found that our new scale also correlates very well with the intrinsic Lewis acid strengths S_a. Table I gives the correlation coefficients for the seven best electronegativity models useful for the description of the intrinsic Lewis acid strengths. Among these it can be seen that our new scale gives the best correlation.

The linear equation in Figure 1 can be described by

$$S_a = -0.0207\ (\pm 0.0241) + 0.260\ (\pm 0.00676) V_X \qquad (5)$$

or be well approximated as

$$V_X = 4S_a \qquad (6)$$

It may be noted that the new electronegativity V_X scale gives excellent correlations with the energetic properties of polyatomic molecular systems, such as heats of formation, ionization potentials, Lewis acid strengths, and homopolar and heteropolar bond dissociation energies. Is there any reason for this?

There are over 20 available scales, including Pauling and Pauling-like semiempirical, nonempirical, and absolute scales, of atom electronegativity at present. All scales agree in the essential ordering of the elements in the periodic table. In this view, the periodic table itself may be considered the first and best table of atom electronegativity. One of the goals in developing an electronegativity theory is to correlate quantitatively with known properties so as to predict unknown properties.

Our electronegativity V_X is the core-shielded electrostatic potential of X at the covalent radius of X.[5] It was termed the covalent potential and was defined as the ratio between the number of valence electrons in the bonding atom in the atom or group X, n_X, and its covalent radius, r_X. Since the outermost or valence electrons of an atom are directly involved in chemical bonding, the chemical properties of an atom are the properties of its outermost or valence electrons at the bonding (covalent or ionic) distance. Consequently, the covalent potential should be a most basic parameter for the contributions of atoms to molecular properties.

Very recently, Luo and Pacey have pointed out[15] that a powerful theoretical support of the new electronegativity scale came from Parr–Pearson absolute electronegativity theory.[22] In this theory, r_m, the radial distances at which the electrostatic potential of the ground-state atoms do exactly equal their chemical potentials, and the covalent radii of the atoms in molecules are close to each other.[23] Any atom in a molecule is in its energetically optimum valence state. Luo and Pacey have found that the chemical potentials of an atom in both its free ground state and in its valence state correlate very well with the new scale of electronegativity.[15] This fact suggests that the new scale is theoretically reasonable.

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(9) Luo, Y. R.; Benson, S. W. *J. Phys. Chem.* **1989**, *93*, 3304.
(10) Luo, Y. R.; Pacey, P. D. Submitted for publication in *J. Phys. Chem.*
(11) Luo, Y. R.; Pacey, P. D. Submitted for publication in *J. Phys. Chem.*
(12) Luo, Y. R.; Pacey, P. D. Submitted for publication in *J. Phys. Chem.*
(13) Luo, Y. R.; Pacey, P. D. Submitted for publication in *J. Phys. Chem.*
(14) Luo, Y. R.; Pacey, P. D. Submitted for publication in *J. Phys. Chem.*
(15) Luo, Y. R.; Pacey, P. D. *J. Am. Chem. Soc.*, in press.
(16) Zhang, Y. *Inorg. Chem.* **1982**, *21*, 3886.
(17) Allred, A. L.; Rochow, E. G. *J. Inorg. Nucl. Chem.* **1958**, *5*, 264.
(18) Boyd, R. J.; Markus, G. E. *J. Chem. Phys.* **1981**, *75*, 5385.
(19) Allen, L. C. *J. Am. Chem. Soc.* **1989**, *111*, 9003.
(20) Pauling, L. *Nature of the Chemical Bond*, 3rd ed.; Cornell University Press: Ithaca, NY, 1960.
(21) Bratsch, S. G. *J. Chem. Educ.* **1988**, *65*, 33, 223.
(22) Parr, R. G.; Yang, W. *Density-Functional Theory of Atoms and Molecules*, Oxford University Press: New York, 1989.
(23) Politzer, P.; Parr, R. G.; Murphy, D. R. *J. Chem. Phys.* **1983**, *79*, 3859.

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Synthetic Analogue Approach to Metallobleomycins: Possibility of Coordination of the Carboxamide Group of the β-Aminoalaninamide Moiety of Bleomycin to Copper in Copper(II) Bleomycin at Physiological pH

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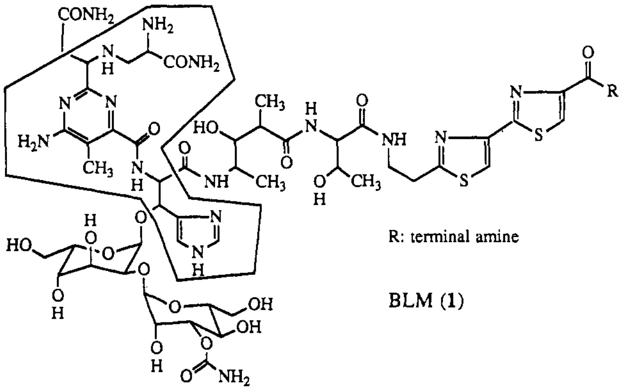
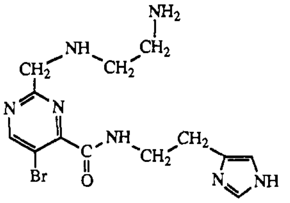
Introduction

The antineoplastic action of the bleomycin (BLM, **1**) family of antibiotics is attributed to the oxidative damage of cellular DNA by the metal chelates (metallobleomycins, M-BLMs) of the drugs.[1]

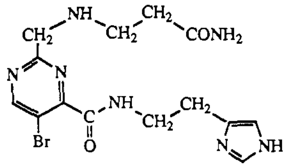


R: terminal amine

BLM (**1**)



PMAH (**2**)



PMBH (**3**)

Elucidation of the exact mechanism of the O_2-activation and concomitant DNA strand scission by M-BLMs therefore requires precise structural data on the metallated drugs. It is quite unfortunate that, to date, no M-BLM has been characterized by crystallography. The coordination structures of M-BLMs have been predicted primarily on the basis of spectroscopic data. Reports on the synthetic analogues of M-BLMs[2-4] are also no exception.

As part of our systematic analogue approach to M-BLMs, we have recently reported the structures and properties of the Cu(II) and Co(III) complexes of the designed ligand PMAH (**2**; the dissociable H is the amide H), which mimics a major portion of the metal-chelating locus of BLM.[5-7] The spectral parameters[5] as well as the characteristics of the DNA cleavage reaction[6] by [Cu(II)-PMA]X (X = ClO_4^-, BF_4^-) have established the architecture of the coordination sphere of copper in Cu(II)-BLM. Comparison of PMAH (**2**) with the metal-chelating portion of BLM (boxed area in **1**) reveals that the amide group of the β-aminoalaninamide part of BLM is not modeled in this designed ligand. In order to check the possibility (and the consequence(s)) of coordination of this primary amide group to metals in M-BLMs, we have completed the synthesis of a second designed ligand PMBH (**3**; the dissociable H is the secondary amide H, i.e. the

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Table I. Summary of Crystal Data, Intensity Collection, and Structure Refinement Parameters for [Cu(II)-PMB]BF_4 (**4**)

formula (mol wt)	$CuC_{14}H_{17}N_7O_2BrBF_4$ (545.6)	transm coeff range	0.37–0.58
T, K	130	2θ range, deg	0–55
cryst color, form	purple dichroic prisms	scan type	ω
		no. of data collcd	4949
cryst size, mm	0.20 × 0.34 × 0.60	no. of data used ($I > 4\sigma(I)$)	3774
cryst syst	monoclinic		
space group	$P2_1/n$	no. of variables	266
a, Å	7.793 (2)	R^a	0.052
b, Å	18.574 (6)	$R_w{}^b$	0.061
c, Å	13.696 (4)	gof	1.17
β, deg	99.16	largest Δ/σ	0.125
V, Å^3	1957.1 (10)	largest diff peak, e Å^{-3}	1.20
Z	4		
d_{calcd}, g cm^{-3}	1.852		
abs coeff (μ), cm^{-1}	32.03		

$^a R = (\sum||F_o - F_c||)/\sum|F_o|$. $^b R_w = [[\sum w(|F_o| - |F_c|)^2/\sum wF_o{}^2]^{1/2}$.

amide group attached to the pyrimidine ring). Included in this report are the syntheses of PMBH and the copper complex [Cu(II)-PMB]BF_4 (**4**). Spectral parameters of **4** suggest that coordination of the amide group of the β-aminoalaninamide moiety of BLM to copper in Cu(II)-BLM is quite unlikely at physiological pH.

Experimental Section

Preparation of Compounds. PMBH (3). This ligand was synthesized by following a procedure identical with that for PMAH (**2**)[5] except for the last step, where 4 equiv of β-alaninamide[8] was used instead of ethylenediamine. The NMR spectrum[9] of the cream-colored foam indicated that the product also contained ~2 equiv of β-alaninamide.[10] However, very different solubilities of the copper(II) complexes of PMBH and β-alaninamide allowed isolation of pure **4** without any complication.

[Cu(II)-PMB]BF_4 (4). A solution of 0.76 g of $Cu(NO_3)_2 \cdot 6H_2O$ in 15 mL of methanol was slowly added with stirring to a solution of 1.3 g of the mixture of PMBH and β-alaninamide (1:2 ratio) in 15 mL of methanol. The small amount of a green precipitate that formed during addition was filtered off, and the greenish blue filtrate was stored at 0 °C for 12 h. A blue precipitate was obtained in 30% yield (based on total copper).[11,12] Next, a batch of 0.30 g of the blue powder was dissolved in 25 mL of water and the pH was adjusted to 7 with LiOH when the initial blue color changed to deep purple. After 9 h of stirring with occasional pH adjustment (pH 7), 3 equiv of $NaBF_4$ was added to the

Table II. Atomic Coordinates (×10^4) and Equivalent Isotropic Displacement Coefficients (Å^2 × 10^3) for [Cu(II)-PMB]BF_4 (**4**)

	x	y	z	U(eq)^a
Cu	1760 (1)	1333 (1)	2378 (1)	21 (1)
Br	2014 (1)	169 (1)	6238 (1)	30 (1)
O(1)	53 (5)	1448 (2)	5018 (2)	31 (1)
O(2)	4324 (5)	2108 (2)	2930 (2)	28 (1)
N(1)	673 (5)	1991 (2)	1369 (2)	23 (1)
N(2)	−529 (6)	2510 (2)	−8 (3)	29 (1)
N(3)	623 (5)	1720 (2)	3450 (2)	22 (1)
N(4)	3538 (5)	−563 (2)	3695 (3)	31 (1)
N(5)	2363 (5)	575 (2)	3336 (3)	21 (1)
N(6)	3375 (5)	726 (2)	1627 (3)	24 (1)
N(7)	4848 (7)	3049 (2)	1952 (3)	35 (1)
C(1)	377 (7)	1915 (3)	401 (3)	30 (1)
C(2)	−750 (7)	2961 (3)	762 (3)	29 (1)
C(3)	−45 (6)	2639 (2)	1613 (3)	24 (1)
C(4)	108 (6)	2904 (2)	2646 (3)	25 (1)
C(5)	−447 (7)	2357 (3)	3382 (3)	31 (1)
C(6)	751 (6)	1333 (2)	4279 (3)	21 (1)
C(7)	1863 (5)	663 (2)	4222 (3)	21 (1)
C(8)	2356 (6)	117 (2)	4903 (3)	23 (1)
C(9)	3146 (6)	−493 (3)	4584 (4)	30 (1)
C(10)	3145 (6)	−6 (3)	3089 (3)	23 (1)
C(11)	3517 (6)	−13 (3)	2040 (3)	25 (1)
C(12	5131 (6)	1051 (3)	1651 (4)	28 (1)
C(13)	5094 (7)	1828 (3)	1336 (3)	30 (1)
C(14)	4707 (6)	2350 (3)	2141 (3)	24 (1)
F(1)	−11 (4)	889 (2)	−1437 (2)	44 (1)
F(2A)	693 (8)	−273 (3)	−1673 (5)	40 (2)
F(2B)	981 (24)	−195 (9)	−1823 (13)	36 (4)
F(3A)	2677 (7)	631 (3)	−1678 (4)	49 (1)
F(3B)	2908 (37)	574 (17)	−1097 (21)	106 (8)
F(4A)	1892 (9)	288 (4)	−267 (5)	53 (2)
F(4B)	1391 (21)	211 (8)	−204 (10)	31 (3)
B	1306 (7)	373 (3)	−1251 (4)	28 (1)

^{a} Equivalent isotropic U defined as one-third of the trace of the orthogonalized $\mathbf{U}_{ij}$ tensor.

Table III. Selected Bond Lengths (Å) and Angles (deg) for [Cu(II)-PMB]BF_4 (**4**)

Bond Lengths			
Cu–N(1)	1.937 (3)	Cu–N(3)	1.968 (4)
Cu–N(5)	1.931 (4)	Cu–N(6)	2.079 (4)
Cu–O(2)	2.481 (4)	O(1)–C(6)	1.241 (6)
O(2)–C(14)	1.249 (6)	N(1)–C(1)	1.317 (6)
N(1)–C(3)	1.389 (6)	N(2)–C(1)	1.381 (6)
N(2)–C(2)	1.378 (6)	N(3)–C(5)	1.442 (6)
N(3)–C(6)	1.333 (5)	N(4)–C(9)	1.308 (7)
N(4)–C(10)	1.331 (6)	N(5)–C(7)	1.342 (6)
N(5)–C(10	1.310 (6)	N(6)–C(11)	1.483 (6)
N(6)–C(12)	1.491 (6)	N(7)–C(14)	1.332 (6)
Bond Angles			
N(1)–Cu–N(3)	96.0 (2)	N(1)–Cu–N(5)	167.6 (2)
N(3)–Cu–N(5)	81.3 (2)	N(1)–Cu–N(6)	102.7 (2)
N(3)–Cu–N(6)	161.3 (1)	N(5)–Cu–N(6)	80.8 (2)
Cu–N(3)–C(5)	125.2 (3)	Cu–N(3)–C(6)	117.2 (3)
Cu–N(6)–C(12)	113.3 (3)	C(11)–N(6)–C(12)	110.7 (3)
O(1)–C(6)–N(3)	128.2 (4)	O(1)–C(6)–C(7)	120.5 (4)
N(6)–C(11)–C(10)	109.9 (4)	N(6)–C(12)–C(13)	114.0 (4)
C(12)–C(13)–C(14)	113.4 (4)	O(2)–C(14)–N(7)	123.9 (4)
O(2)–C(14)–C(13)	119.7 (4)	N(7)–C(14)–C(13)	116.4 (4)

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(1) (a) Stubbe, J.; Kozarich, J. W. *Chem. Rev.* **1987**, *87*, 1107. (b) Hecht, S. M. *Acc. Chem. Res.* **1986**, *19*, 383. (c) Sugiura, Y.; Takita, T.; Umezawa, H. *Met. Ions Biol. Syst.* **1985**, *19*, 81. (d) Dabrowiak, J. C. *Adv. Inorg. Biochem.* **1983**, *4*, 69. (e) Povrick, L. F. In *Molecular Aspects of Anticancer Drug Action*; Neidle, S., Waring, M. J., Eds.; Macmillan: London, 1983; p 157. (f) Dabrowiak, J. C. *Met. Ions Biol. Syst.* **1980**, *11*, 305. (g) Umezawa, H.; Takita, T. *Struct. Bonding (Berlin)* **1980**, *40*, 73.

(2) (a) Umezawa, H.; Takita, T.; Sugiura, Y.; Otsuka, M.; Kobayashi, S.; Ohno, M. *Tetrahedron* **1984**, *40*, 501. (b) Sugiura, Y.; Suzuki, T.; Otsuka, M.; Kobayashi, S.; Ohno, M.; Takita, T.; Umezawa, H. *J. Biol. Chem.* **1983**, *258*, 1328.

(3) (a) Kittaka, A.; Sugano, Y.; Otsuka, M.; Ohno, M. *Tetrahedron* **1988**, *44*, 2811, 2821. (b) Kurosaki, H.; Hideki, A.; Kimura, E. *J. Chem. Soc. Jpn.* **1988**, *4*, 691. (c) Kittaka, A.; Sugano, Y.; Otsuka, M.; Ohno, M.; Sugiura, Y.; Umezawa, H. *Tetrahedron Lett.* **1986**, *27*, 3631, 3635.

(4) (a) Kenani, A.; Lohez, M.; Houssin, R.; Helbecque, N.; Bernier, J. L.; Lemay, P.; Henichart, J. P. *Anti-Cancer Drug Des.* **1987**, *2*, 47. (b) Henichart, J. P.; Bernier, J. L.; Houssin, R.; Lohez, M.; Kenani, A.; Catteau, J. P. *Biochem. Biophys. Res. Commun.* **1985**, *126*, 1036. (c) Henichart, J. P.; Houssin, R.; Bernier, J. L.; Catteau, J. P. *J. Chem. Soc., Chem. Commun.* **1982**, 1295.

(5) (a) Brown, S. J.; Hudson, S. E.; Stephan, D. W.; Mascharak, P. K. *Inorg. Chem.* **1989**, *28*, 468. (b) Brown, S. J.; Stephan, D. W.; Mascharak, P. K. *J. Am. Chem. Soc.* **1988**, *110*, 1996.

(6) Hudson, S. E.; Mascharak, P. K. *Chem. Res. Toxicol.* **1989**, *2*, 411.

(7) Brown, S. J.; Hudson, S. E.; Olmstead, M. M.; Mascharak, P. K. *J. Am. Chem. Soc.* **1989**, *111*, 6446.

(8) Franchimont, A. P. N.; Friedmann, H. *Recl. Trav. Chim. Pays-Bas.* **1906**, *25*, 75.

(9) PMBH (**3**) is sensitive to both moisture and oxygen. When kept at −20 °C under dry N_2, the compound is stable for weeks. ^{13}C NMR ($(CD_3)_2SO$, 298 K, 300 MHz, ppm from TMS): δ 26.77, 39.21, (36.65, 37.26), 40.62, 45.04, 54.20, 114.40, 116.80, 134.41, 134.88, 158.41, 160.82, 163.63, 167.15, (173.40), 174.03 (values within parentheses are due to excess β-alaninamide).

(10) Excess β-alaninamide is needed to avoid the formation of a tertiary amine.

(11) The blue compound, like free PMBH, exhibits a broad ν_{CO} around 1660 cm^{-1}. This suggests that both amide groups of PMBH exist in the protonated form in this compound. It is quite likely that this blue material is $[Cu(PMBH)](NO_3)_2$.[5]

(12) The copper(II) complex of β-alaninamide (L), $[CuL_2](NO_3)_2$, remains soluble in methanol under this condition.

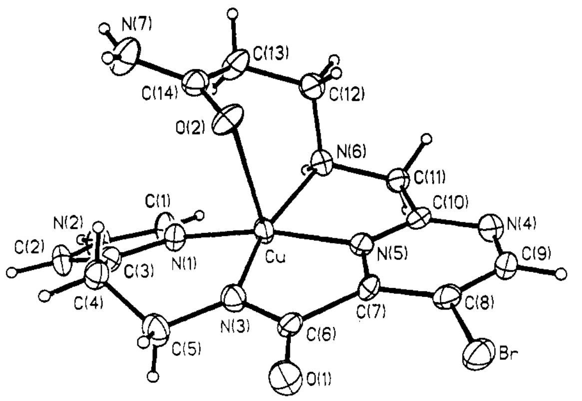

Figure 1. Computer-generated thermal ellipsoid (probability level 50%) plot of [Cu(II)-PMB]$^+$ (cation of **4**) with the atom-labeling scheme. Hydrogen atoms are shown at arbitrary sizes.

purple solution and the pH was reset to 7. Following 12 h of stirring, the solvent was removed and the purple solid thus obtained was dissolved in 20 mL of acetonitrile. This solution was then filtered to remove a gray precipitate. Once again, the solvent was removed and the purple residue was dissolved in 10 mL of methanol. Slow evaporation of this dark purple solution afforded purple blocks. Anal. Calcd for $CuC_{14}H_{17}N_7O_2BrBF_4$: C, 30.80; H, 3.14; N, 17.98. Found: C, 31.04; H, 3.16; N, 17.68. Selected IR bands (KBr pellet, cm^{-1}): 3423 (m), 3299 (s), 3187 (s), 2922 (m), 1665 (s), 1600 (s), 1550 (s), 1429 (m), 1345 (m), 1220 (m), 1080 (s, br), 620 (m).

Physical Measurements. Absorption spectra were obtained with a Perkin-Elmer Lambda9 spectrophotometer. Infrared spectra were measured with a Perkin-Elmer 1600 FTIR spectrometer. NMR spectra were recorded on a General Electric 300-MHz GN-300 instrument. EPR spectra were monitored at X-band frequencies by using a Bruker ESP-300 spectrometer. Elemental analyses were performed by Atlantic Microlab Inc., Atlanta, GA.

X-ray Data Collection and Structure Solution and Refinement. Purple prisms were obtained by slow evaporation of a methanolic solution of **4** over glycerol. Diffraction experiments were performed on a Siemens R3m/V diffractometer equipped with graphite monochromator and modified LT-1 low-temperature apparatus. Mo Kα radiation was employed. Only random fluctuations of less than 2% in the intensities of two standard reflections were observed during the course of data collection. The structure was solved by direct methods (SHELXTL-PLUS (VMS)). Non-hydrogen atoms were refined anisotropically. Hydrogen atoms were included at calculated positions by using a riding model. A total 3774 reflections with $F > 4.0\sigma(F)$ were used in the refinement (full-matrix least-squares), and the data were corrected for absorption effects by the use of the program XABS.[13]

Machine parameters, crystal data, and data collection parameters are summarized in Table I. Positional coordinates are given in Table II, while selected bond distances and angles are included in Table III. The rest of the crystallographic data have been submitted as supplementary material.

Results and Discussion

The ligand PMBH (**3**) resembles a major portion of the metal-binding domain of BLM and is designed specifically to examine the effect of coordination of the amide group of the β-aminoalaninamide moiety of BLM to copper at neutral pH. Therefore, the synthesis of **4**, in most part, has been carried out at pH 7 and the spectral parameters have been collected and compared with those of Cu(II)-BLM at the same pH.

Structure of [Cu(II)-PMB]BF$_4$ (4). The crystal structure consists of discrete cations and anions. The metric parameters of the anion are unexceptional and have been deposited in the supplementary material. A computer-generated drawing of the cation is shown in Figure 1, and selected bond distances and angles are collected in Table III.

The coordination geometry around copper in [Cu(II)-PMB]$^+$ (cation of **4**) is distorted square pyramidal (Figure 1). Four nitrogens from the pyrimidine, imidazole, secondary amine, and the deprotonated secondary amide group form the basal plane of coordination, while the oxygen atom of the primary amide group occupies the axial position. This difference in the mode of coordination of the secondary and primary amide group of PMBH to copper at neutral pH namely, *deprotonated amido N vs O ligation*, is worthy of notice and presumably arises from the different inherent basicities of the two amide groups (vide infra). Coordination of the primary amide group through the oxygen atom results in shorter C(14)-N(7) (1.332 (6) Å) and longer C(14)-O(2) (1.249 (6) Å) bond distances.[14] The Cu(II)-N distances range from 1.931 (4) to 2.079 (4) Å and compare well with those found in related compounds.[5]

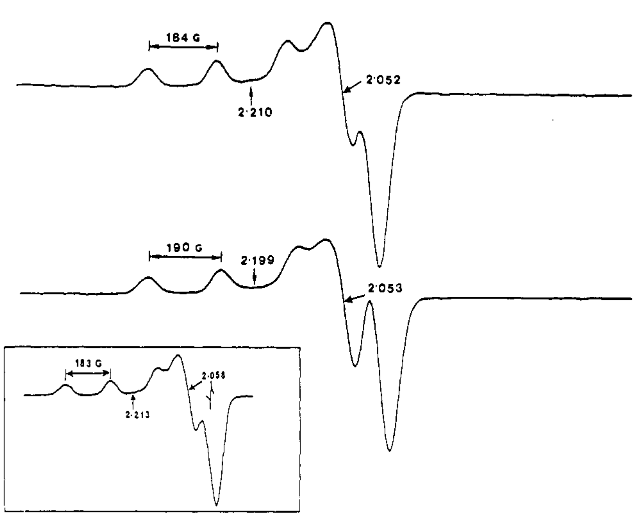

Figure 2. X-Band EPR spectra of [Cu(II)-PMA]$^+$ (top) and [Cu(II)-PMB]$^+$ (bottom) in a 7:3 v/v mixture of aqueous phosphate buffer and glycerol (pH 7.2) at 100 K. Inset: X-Band EPR spectrum of Cu(II)-BLM in the same medium. Selected g and $A_{\parallel}$ values are indicated. Spectrometer settings: microwave frequency, 9.43 GHz; microwave power, 10 mW; modulation frequency, 100 kHz; modulation amplitude, 2 G.

In [Cu(II)-PMB]$^+$, the copper atom is displaced only 0.07 Å from the mean basal plane in the direction of the oxygen atom. The longer primary amide tether of PMBH (compare **2** and **3**) allows formation of a six-membered chelate ring and consequently a more regular square-pyramidal geometry.[15] The long Cu(II)-O bond (2.481 (4) Å) reflects weak axial interaction typical for Jahn-Teller-sensitive copper(II) complexes.[16]

Properties. The modes of coordination of the two amide groups of PMBH to copper in **4** are evident in the IR spectrum of the complex, which exhibits two ν_{CO}'s at 1665 cm^{-1} (primary amide, coordinated through O[17]) and 1600 cm^{-1} (secondary amide, deprotonated and bonded to copper through N[5,14]). That the situation remains the same in an aqueous solution of **4** has also been confirmed by infrared spectroscopy.[18]

In the visible region, **4** exhibits one absorption band with λ_{max} at 580 nm (water, pH 7.2, ϵ = 140 M^{-1} cm^{-1}),[19] which is blue-shifted compared to the analogous band for Cu(II)-BLM (595 nm, ϵ = 120).[2] Since the visible band maximum remains unchanged in different solvents (water, methanol, DMF), it is evident that, like the metal center [Cu(II)-PMA]$^+$, the metal center in **4** also remains pentacoordinated both in solid state and in solu-

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(13) Moezzi, B. Ph.D. Dissertation, University of California, Davis, 1987. The program obtains an absorption tensor from $F_o - F_c$ differences.

(14) Sigel, H.; Martin, R. B. *Chem. Rev.* **1982**, *82*, 385.

(15) In [Cu(II)-PMA]$^+$, the copper atom is displaced 0.23 Å from the mean basal plane in the direction of the apical nitrogen.[5] This strain arises due to formation of a five-membered chelate ring.

(16) Brown, S. J.; Tao, X.; Stephan, D. W.; Mascharak, P. K. *Inorg. Chem.* **1986**, *25*, 3377 and references cited therein.

(17) Karczynski, F.; Lapkowska, H.; Ratajczyk, H.; Klinert, K. *Stud. Univ. Babes-Bolyai, Chem.* **1977**, *22*, 60.

(18) The IR spectrum of the aqueous solution of **4** (20 mM, pH 7) was obtained with a Nicolet 800 FTIR spectrometer. An attenuated total reflection (ATR) cell was used.

(19) Electronic spectrum of [Cu(II)-PMB]BF$_4$, aqueous phosphate buffer, pH 7.2 [λ_{max}, nm (ϵ, M^{-1} cm^{-1})]: 580 (140), 320 sh (3700), 290 sh (5000). The same spectrum is recorded in a glycerol/water (3:7) mixture.

tion.[20] Taken together, these spectroscopic data verify that the structure of [Cu(II)-PMB]$^+$, as shown in Figure 1, remains intact in solution.

The X-band EPR spectrum of **4** has been run in glycerol/water glass (3:7)[19] at 100 K. The spectrum, shown in Figure 2, is distinctly different from that of Cu(II)-BLM. Noteworthy are the feature around the $g = 2$ region and the A value (190 G vs 183 G for Cu(II)-BLM[2]). It is clear from Figure 2 that the coordination structure of copper in Cu(II)-BLM is better represented by [Cu(II)-PMA]$^+$ (square-pyramidal N$_5$ chromophore), and this in turn indicates that the amide function of the β-aminoalaninamide moiety of BLM is not bonded to copper through the oxygen atom in Cu(II)-BLM. Since coordination of the deprotonated primary amido nitrogen of β-aminoalaninamide to copper(II) is only reported at pH 9 or above,[14,21–23] the present work suggests that the amide group of the β-aminoalaninamide moiety of BLM does not at all participate in coordination to copper in Cu(II)-BLM at physiological pH.

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Supplementary Material Available: Tables of selected bond distances and bond angles, anisotropic displacement coefficients, and H atom coordinates for **4** (2 pages); a table of observed and calculated structure factors (16 pages). Ordering information is given on any current masthead page.

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(20) Belford, R. L.; Calvin, M.; Belford, G. *J. Chem. Phys.* **1957**, *26*, 1165.

(21) (a) Sigel, H.; Prijs, B.; Martin, R. B. *Inorg. Chim. Acta* **1981**, *56*, 45. (b) Kroneck, P. M. H.; Vortisch, V.; Hemmerich, P. *Eur. J. Biochem.* **1980**, *109*, 603.

(22) Spectral parameters of **4** in aqueous phosphate buffer do not change in the pH range 7–9.

(23) One of the reviewers has suggested a reason for deprotonation of only one amide group of PMBH. The deprotonation is driven by the increase in CFSE that occurs when the Cu atom is coordinated by N instead of O in the basal (xy) plane. Since the CFSE effect of the more distant donor in the axial z direction is much smaller, the N–H bond presumably remains intact.

Additions and Corrections

1990, Volume 29

Linqing Ma, Scott R. Wilson, and John R. Shapley*: Synthesis and Characterization of Heptarhenium Carbido Clusters with (η^2-Olefin)iridium Capping Moieties.

Page 5134. In Table I, the chemical formula is missing Ir. Also in Table I, footnote *a*, the expression for *w* contains an *R* instead of an *F*. In the first paragraph following the heading Crystallographic Study, the end of the 10th line should read as follows: ...were collected by scanning $\pm h$, $\pm k$, $+l$.... In footnote 13, the asterisks should be deleted from the cell parameters, since they are expressed in real space.

Pages 5135–5136. In the section following the heading Solid-State Structure of $[PPN]_2[Re_7C(CO)_{21}Ir(C_2H_4)(CO)]$, replace sentences 3 and 4 with the following sentences: Since the 1,4-bicapped octahedral anion (vide infra) is not centrosymmetric, an inversion disorder problem was encountered in the structural determination, which caused the apparent superposition of the Re(CO)$_3$ and Ir(C$_2$H$_4$)(CO) capping moieties. The positions of rhenium and iridium capping moieties were successfully separated and refined; however, only three octahedron skeletal rhenium atom positions were resolved, since positions of their center of symmetry disordered counterparts (Re2′, Re3′, Re4′) were crystallographically indistinguishable.

This revision removes the previous use of the term "2-fold" disorder and replaces it with the more accurate term "inversion" disorder. We thank Professor Richard E. Marsh for discussions that indicated the need for clarifying this point.—Scott R. Wilson and John R. Shapley