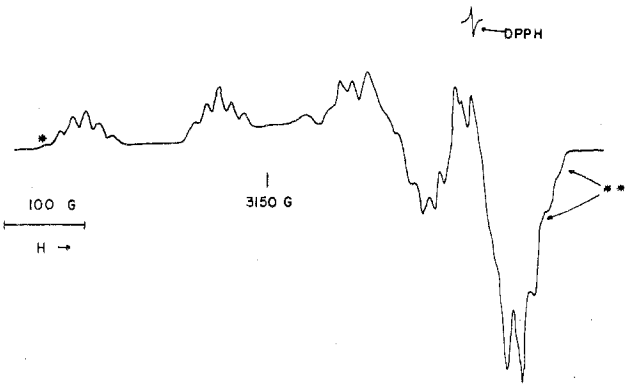
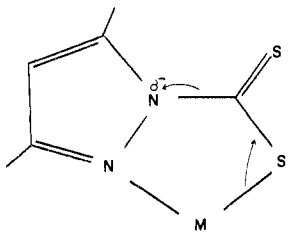


Figure 1. Electron spin resonance spectrum of bis(3,5-dimethylpyrazole-1-carbodithioato)copper(II) in 50:50 $Me_2SO/CHCl_3$ (temperature 100 K; frequency 9.086 GHz). The "extra" (asterisk) weak peak on the low-field side of the $-^3/_2$ parallel line is due to the Cu^{63} isotope effect. The Cu^{63} isotope present also accounts for the two extra peaks on the overshoot line (double asterisk).

constant also support a N_2S_2 environment.[11] The magnitude of the coupling to the nitrogens indicates a very covalent Cu–N bond, something which is quite unusual in the presence of sulfur ligand atoms. For comparison, one can examine the ESR spectra of copper(II) complexes of N_2S_2 Schiff base complexes where the nitrogen constant is significantly less, ranging from 10 to 13 G.[12] The large nitrogen coupling here suggests a particularly important role of the five-member pyrazole ring in the bonding scheme.

The key to unraveling the bonding question lies in the chemistry displayed by the copper(II) complex. We find, as did Trofimenko, that the metal complex of this dithiocarbamate ligand is unstable with respect to loss of CS_2.[7] While the mechanism for this reaction represented below seems logical and as such may be a good indication of the electron density distribution in the complex, it is only speculation on our part; yet it is reasonable that a partial negative charge may reside on the 1-nitrogen.



The result of the extra electron density on the five-membered ring would be to *increase* the donor ability of the nitrogen atom coordinated to the metal atom, thus producing a more covalent metal–nitrogen bond. This effect is most easily seen in the larger unpaired electron density on the nitrogen from the antibonding molecular orbital, which is mainly of copper d character. Since the ligand itself is unstable in the solid state, the decomposition is ligand induced and not metal induced. In some ways, the decomposition in the presence of a metal is the reverse reaction of the well-known CS_2 insertion reaction of metal amides. We investigated the solid-state decomposition of this complex. As CS_2 is lost, the resulting complex is diamagnetic as indicated by the total loss of a detectable ESR signal (in solution), by the decrease in the magnetic moment measured in the solid state, and by the disappearance of C=S (1340 cm^{-1}) and Cu—S (390 cm^{-1}) absorptions in the infrared spectrum. The data we obtained are listed in Table II. We were not able to obtain a compound whose stoichiometry was exactly Cu(pyrazolate)$_2$ by decomposition of the dithiocarbamate. It is possible that a copper(II)–copper(II) dimer or higher aggregate is formed or that a copper(I)–copper(III) complex results. Our data do not allow us to differentiate between these possibilities.

Table II. Magnetic Susceptibility (μ_B)

>1 h	1.85	36 h	1.37
12 h	1.64	2 months	0.79
24 h	1.46		

Acknowledgment. The research was partially supported by Institutional Funds, the Research Foundation of the SUNY System, and the Graduate Student Association of SUNY/Buffalo. R.D.B. gratefully acknowledges receipt of a Camille and Henry Dreyfus Foundation Fellowship.

Registry No. Bis(3,5-dimethylpyrazole-1-carbodithioato)copper(II), 67800-65-1.

References and Notes

(1) D. Coucouvanis, *Prog. Inorg. Chem.*, **11**, 294 (1970).
(2) J. McCleverty, *Prog. Inorg. Chem.*, **10**, 49 (1968).
(3) R. Eisenberg, *Prog. Inorg. Chem.*, **12**, 295 (1970).
(4) G. Thorn and R. Ludwig, "Dithiocarbamates and Related Compounds", Elsevier, New York, N.Y., 1962.
(5) R. D. Bereman and D. Nalewajek, *Inorg. Chem.*, **16**, 2687 (1977).
(6) R. D. Bereman and D. Nalewajek, *Inorg. Chem.*, **17**, 1085 (1978).
(7) S. Trofimenko, *J. Org. Chem.*, **33**, 890 (1968).
(8) S. N. Choi and J. R. Wasson, *Inorg. Chem.*, **14**, 1964 (1975).
(9) L. F. Fieser and K. L. Williamson, "Organic Experiments", 3rd ed., D. C. Heath, Lexington, Mass., 1975.
(10) B. N. Figgis and J. Lewis, "Modern Coordination Chemistry", J. Lewis and R. G. Wilkins, Ed., Interscience, New York, N.Y., 1960, p 403.
(11) J. Peisach and W. E. Blumberg, *Arch. Biochem. Biophys.*, **165**, 691 (1974).
(12) G. D. Shields, S. Christiano, and R. D. Bereman, *J. Inorg. Nucl. Chem.*, in press.

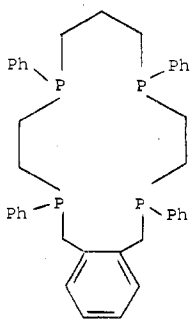
Contribution from the Department of Chemistry, University of Rhode Island, Kingston, Rhode Island 02881

Studies of a 15-Membered Tetraphosphorus Macrocyclic Ligand

T. A. DelDonno and William Rosen*

Received June 26, 1978

Recently, we reported the synthesis of a novel tetraphosphine macrocyclic ligand, 1,4,8,11-tetraphenyl-13,14-benzo-1,4,8,11-tetraphosphacyclopentadecane, Benzo-15-P_4, having a 15-membered core.[1] Others have also prepared similar tetradentate macrocycles having 16[2]- and 14[3]-membered cores, but as yet, no physical information dealing with the coordination properties of these ligands has appeared. In lieu of this, we wish to present some data which tend to support our contention that these ligands are of the strong-field variety, possibly comparable to the phthalocyanines.[4]



Benzo-15-P_4

Experimental Section

All UV–vis spectra were recorded on a Cary 15 spectrophotometer using 10^{-3} M solutions in either water, methanol, or chloroform.

Table I. Physical Data on Ni(Benzo-15-P_4)X_2 Complexes

X^-	λ_{max} (e)[a]	Λ_m[f] H_2O	Λ_m[f] CH_3OH	μ_{eff}[g]
BF_4^-	345 (1200)[b]	210	234	diamag
Cl^-	340 (1100)[b]	198	90[d]	diamag
NCS^-	340 (1000)[b]	197	64[d]	diamag
CN^-	340 + 440[c]		e	

[a] λ in nanometers. [b] Solvents: H_2O, CH_3OH, $CHCl_3$. [c] Solvent: methanol (extinction coefficient not known). [d] These values rise as the 10^{-3} M solutions are aged. [e] Concentration dependent; see Figure 1. [f] In MeOH di-univalent electrolytes have molar conductances near 200 while uni-univalent electrolytes have molar conductances near 100 μmhos. All the complexes were essentially nonconductors in $CHCl_3$ (see ref 6). [g] Diamagnetism determined by the NMR method (see ref 5).

Matched standard 1-cm Beckmann cells were utilized in both the sample and reference beams. Conductivity measurements were recorded at 25 °C in $CHCl_3$, CH_3OH, or H_2O using an Electro Mark Analyzer (Model 4400) from Markson Science Co. The instrument was calibrated using standard solutions of aqueous or methanolic potassium chloride. Nuclear magnetic resonance spectra were recorded on a JEOL C-60 instrument. Magnetic susceptibilities in solution were measured on this instrument by the NMR technique.[5] All elemental analyses were performed by Micro-Analysis, Inc., Wilmington, DE 19808. *All* synthetic manipulations were concluded under nitrogen. Solvents used in synthetic preparations were deoxygenated by purging with nitrogen.

Preparation of Ni(Benzo-15-P_4)Cl_2. In 100 mL of absolute ethanol was dissolved 5.7 g (0.011 mol) of 1,4,8,11-tetraphenyl-1,4,8,11-tetraphosphaundecane.[1] To this mixture was added a solution of 2.6 g (0.011 mol) of $NiCl_2 \cdot 6H_2O$ in 40 mL of absolute ethanol. The solution immediately turned deep red. After being gently refluxed under N_2 for 2 h, this red solution was filtered hot and the solvent removed under reduced pressure to yield 6.8 g (93%) of a reddish brown, glassy solid. Recrystallization from 2-propanol yielded 6.3 g of an orange solid whose analysis is consistent with the formulation $C_{31}H_{36}P_4NiCl_2 \cdot H_2O$. Anal. Calcd for $C_{31}H_{36}P_4NiCl_2 \cdot H_2O$: C, 54.36; H, 5.59. Found: C, 54.21; H, 5.72.

To 100 mL of absolute ethanol was added 1.0 g (1.5 mmol) of the above prepared orange solid. To this solution was added 2.0 g (0.015 mol) of anhydrous K_2CO_3, and this mixture was stirred for 25 min before addition of a solution of 0.4 g (1.5 mmol) of α,α′-dibromo-*o*-xylene in 40 mL of absolute ethanol. The deep orange color of the solution changed to light orange within 1 h, and stirring was continued for an additional 47 h. A solution of excess KCl in ethanol was added, and the entire mixture filtered. The supernatant ethanol solution was evaporated to dryness under reduced pressure to yield a bright orange oil along with some white solid. The oil was dissolved in chloroform, the mixture filtered, and the chloroform removed by evaporation to yield 0.60 g (52%) of an orange solid. Careful recrystallization from 2-propanol afforded 0.45 g of an orange solid whose elemental analysis was satisfactory. Anal. Calcd for $C_{39}H_{42}P_4NiCl_2$: C, 61.29; H, 5.54; Cl, 9.29. Found: C, 61.11; H, 5.67; Cl, 9.57.

Preparation of Ni(Benzo-15-P_4)$(BF_4)_2$. To 0.5 g (0.65 mmol) of Ni(Benzo-15-P_4)Cl_2, dissolved in 25 mL of methanol, was added an excess of $NaBF_4$ (1.5 mmol). This mixture was stirred and gently refluxed for 1 h after which the solution was filtered hot and the solvent removed. The resulting orange-yellow solid was recrystallized from methanol to yield 0.43 g of an orange-yellow solid whose elemental analysis was satisfactory for $C_{39}H_{42}P_4NiB_2F_8$. Anal. Calcd for $C_{39}H_{42}P_4NiB_2F_8$: C, 54.03; H, 4.88; P, 14.29. Found: C, 53.89; H, 4.94; P, 14.83.

Preparation of Ni(Benzo-15-P_4)$(NCS)_2$. This derivative was made in exact analogy to the above BF_4^- salt by substituting 1.5 mmol of NaNCS for $NaBF_4$. A yield of 0.37 g was obtained after recrystallization of the yellow-orange solid from methanol. Elemental analysis was consistent for $C_{41}H_{42}P_4NiN_2S_2$. Anal. Calcd for $C_{41}H_{42}P_4NiN_2S_2$: C, 60.83; H, 5.23; N, 3.46. Found: C, 60.37; H, 5.31; N, 3.22.

Results and Discussion

As part of our study of the nickel(II) complexes of the prepared macrocycle Benzo-15-P_4[1] we chose to study a series of monodentate ligands that span a wide range of spectrochemical values. As can be seen by the data presented in Table I, most of the selected monodentate ligands do not bond to the axial sites of the nickel(II) cation when the macrocycle is in the equatorial plane of the metal. This means that the square-planar Ni^{II}(Benzo-15-P_4)$^{2+}$ complex is the predominant species in aqueous solution when the counterion is BF_4^-, Cl^-, or NCS^-. This is evidenced by the single d–d transition at 340 nm, the diamagnetism of the compounds, and the di-univalent electrolyte behavior of these solutions. In methanol and chloroform solutions, the physical data are very similar, although the conductance behavior of these materials is somewhat different. We believe that since the single d–d transition at 340 nm is unchanged and the solutions remain diamagnetic regardless of the solvent, other interactions between the macrocycle backbone and the counteranions must be contributing to the observed conductance phenomena. This explanation is partially substantiated by the observation that a continually rising molar conductance in methanol has also been previously observed[6] with similarly *o*-xylyl-substituted macrocycles. An exact description of this interaction is not possible at the present time.

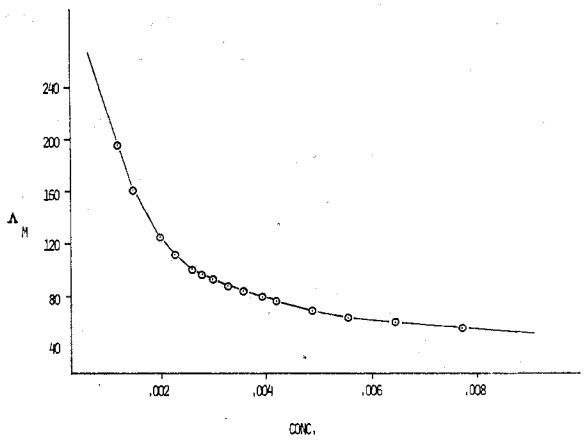


Figure 1. Plot of molar concentration vs. molar conductance during the early stages of the titration of Ni(Benzo-15-P_4)$(BF_4)_2$ with KCN in methanol. The linear data for KBF_4 have been subtracted so that the points are representative of Ni(Benzo-15-P_4)CN·BF_4 in methanol. This plot is, therefore, a combination of the linear strong electrolyte Ni(Benzo-15-P_4)$CN^+ + BF_4^-$ and the nonlinear weak electrolyte described in the text.

The inability of most monodentate anions to substantially interact with the nickel(II) cation is in sharp contrast to the cyanide ion which is capable of completely removing the macrocycle from the metal.[1] Conductometric titration of the BF_4^- complex with potassium cyanide produces data, during the first 10–20% of titration, which are readily rationalized in terms of the formation of a weak electrolyte system superimposed upon the strong electrolyte KBF_4. (After approximately 20% of the titration was completed, irreproducible results were obtained due to the decomposition of the complex in the presence of large quantities of cyanide ion.) If the conductance data for KBF_4 in methanol are taken into account, a curve is generated which is displayed in Figure 1. This type of curve indicates that there is an equilibrium between the four-coordinate, square-planar macrocyclic complex and a five-coordinate complex having one cyanide ligand in an axial site. This interpretation is confirmed by the appearance of a 440-nm band[7] in the visible spectrum as cyanide ion is added under similar conditions to those which existed during the titration. This further means that there is a rapid establishment of the equilibrium between the four- and five-coordinated metal complexes. The equilibrium constant for the process can be calculated if one assumes that during the initial stages of the titration cyanide ion contributes little to the

conductance. Using this assumption and the Ostwald dilution law, we calculate[8] an equilibrium constant of 3.9×10^{-3} for the reaction

$$Ni(Benzo\text{-}15\text{-}P_4)CN^+ \rightleftarrows Ni(Benzo\text{-}15\text{-}P_4)^{2+} + CN^-$$

The fact that only the cyanide ion is capable of entering the axial site of this complex is indicative of the strong ligand field strength of this macrocycle,[9] and thus these macrocycles have some similarity to the phthalocyanines.[4]

The effect of ring size on ligand field strength of macrocyclic ligands has been amply demonstrated.[10] It has been concluded in the case of the nitrogen macrocycles that the 14-membered ring is probably a very tight fit while the 15-membered example may be very close to ideal when high-spin nickel(II) is the encapsulated metal. The same types of arguments can be used in the present situation to conclude that the 15-membered phosphorus macrocycle is a very tight fit for the larger high-spin nickel(II), and thus, when encapsulated by Benzo-15-P_4, the nickel(II) ion prefers to remain in the smaller, low-spin configuration. Whether this explanation or the well-known back-bonding capabilities of ligating phosphine moieties are dominating the coordination chemistry of these macrocyclic phosphines will have to await further studies of variously sized phosphorus macrocycles.[2,3]

Registry No. $Ni(Benzo\text{-}15\text{-}P_4)(BF_4)_2$, 68024-58-8; $Ni(Benzo\text{-}15\text{-}P_4)Cl_2$, 65296-99-3; $Ni(Benzo\text{-}15\text{-}P_4)(NCS)_2$, 68024-59-9; $Ni(Benzo\text{-}15\text{-}P_4)(CN)(BF_4)$, 68024-61-3; 1,4,8,11-tetraphenyl-1,4,8,11-tetraphosphaundecane, 65201-65-2; α,α'-dibromo-*o*-xylene, 91-13-4; $C_{31}H_{36}P_4NiCl_2$, 65296-98-2.

References and Notes

(1) T. A. DelDonno and W. Rosen, *J. Am. Chem. Soc.*, **99**, 8051 (1977).
(2) L. Horner, H. Kunz and P. Walach, *Phosphorus*, **6**, 63 (1975). At the time of our previous endeavors,[1] the elegant studies of Professor Horner and his co-workers were not available to us, and consequently, we were unable to reference their accomplishments. We apologize for our oversight and thank Professor Horner and Professor E. K. Barefield for their correspondence.
(3) E. P. Kyba, C. W. Hudson, M. J. McPhaul, and A. M. John, *J. Am. Chem. Soc.*, **99**, 8053 (1977); R. E. Davis, C. W. Hudson, and E. P. Kyba, *ibid.*, **100**, 3642 (1978).
(4) A. B. P. Lever, *Adv. Inorg. Chem. Radiochem.*, **7**, 27 (1965).
(5) D. F. Evans, *J. Chem. Soc.*, 2003 (1959).
(6) M. J. Thompson and D. H. Busch, *J. Am. Chem. Soc.*, **86**, 3651 (1964).
(7) L. Hertli and T. A. Kaden, *Chimia*, **29**, 304 (1975).
(8) W. Rosen and D. H. Busch, *Chem. Commun.*, 148 (1969).
(9) L. Y. Martin, C. R. Sperati, and D. H. Busch, *J. Am. Chem. Soc.*, **99**, 2968 (1977).
(10) Y. Hung, L. Y. Martin, S. C. Jackels, A. M. Tait, and D. H. Busch, *J. Am. Chem. Soc.*, **99**, 4029 (1977).

Contribution from the Department of Chemistry, College of General Education, Hirosaki University, Bunkyo, Hirosaki 036, Japan, and the Institute of Pharmaceutical Sciences, Hiroshima University School of Medicine, Kasumi, Hiroshima 734, Japan

Kinetics of Macrocyclic Tetraamine Reactions with Copper(II) Triglycine

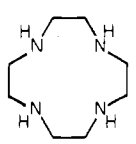
Mutsuo Kodama[1a] and Eiichi Kimura*[1b]

Received June 21, 1978

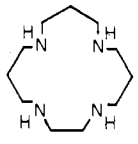
In order to explore the biological application of macrocyclic tetraamines, we have investigated kinetics of the replacement of triglycine by L^1 and L^2 on copper(II) ions, as shown by (1)

$$Cu(H_{-2}trigly)^- + L \rightarrow (CuL)^{2+} + trigly \qquad (1)$$

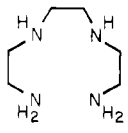
which represents the most fundamental reaction of copper transfer from copper-binding peptides. Reaction 1 is thermodynamically and kinetically very favorable with a linear tetraamine homologue L^3 (ref 2) which is used as a therapeutic agent to remove excess copper from the body in the treatment of Wilson's disease. Our previous studies showed the copper complexes of L^1 (ref 3) and L^2 (ref 4) to be far more stable than that of L^3, suggesting equilibrium 1 to be shifted more in favor of the copper transfer with the macrocycles. The kinetic aspects of reaction 1 thus drew our attention.



L^1
1,4,7,10-tetraazacyclododecane



L^2
1,4,8,12-tetraazacyclopentadecane



L^3
3,6-diazaoctane-1,8-diamine

Reaction 1 is also of interest from a mechanistic point of view. The replacement by L^3 occurs almost via a nucleophilic mechanism, wherein dissociation of triglycine in the rate-determining step is caused by the direct attack of the nitrogens of L^3. The restricted flexibility and steric hindrance of macrocycles might render the nucleophilic pathway unfeasible. The use of the two extreme macrocyclic tetraamines, the most rigid L^1 and the least rigid L^2 among the well-investigated 12- and 15-membered tetraamines,[3-6] may help identifying the reaction mechanism. This work constitutes a series of the investigations of macrocyclic polyamine replacement reactions.[7,8]

Experimental Section

The macrocyclic tetraamines L^1 and L^2 were prepared as described before.[3,4] The mixed protonation constants used, log K_1 and log K_2, respectively, were 10.70 and 9.70 for L_1 and 11.20 and 10.10 for L^2.[3,4] The values of log K_3 and log K_4 are less than 2 for both, and the kinetic contributions of the tri- and tetraprotonated species were negligible in the borate buffer conditions used. Triglycine was obtained commercially. Copper–triglycine solution was prepared by mixing a stock solution of copper nitrate (standardized against EDTA) and triglycine (2% molar excess) in borate buffers (sodium borate–boric acid). Constant ionic strength was maintained at 0.2 M by adjusting with $NaClO_4$. All the work was at 25.0 ± 0.1 °C. The data associated with protonation constants are based on pH readings.

Kinetic runs were followed spectrophotometrically by measuring the increase in absorbance at the wavelengths sensitive to the formation of CuL, 630 nm for L^1 and 645 nm for L^2, on a Union Giken stopped-flow instrument with a 2-cm cell path. The second-order (unequal concentrations) plots and the initial-slope method gave practically the same observed rate constants k_{obsd}. Typical data by the second-order plots are shown in Table I.

Results and Discussion

In the pH range of 8.2–9.6 used,[9] the copper–triglycine complex exists mostly in the form of $Cu(H_{-2}trigly)^-$,[10] the macrocyclic tetraamines in diprotonated form $(H_2L)^{2+}$, and the macrocyclic complexes in $(CuL)^{2+}$.[3,4] The log of the conditional equilibrium constants for (1) at pH 9 are estimated at 11 and 9.8, respectively, for L^1 and L^2 from the available constants.[3,4,10] Experimentally, the spectra of the product solutions corresponded to those of $(CuL)^{2+}$ and showed no evidence of mixed complexes.

The transfer of Cu^{II} from triglycine to the macrocyclic tetraamines by the reaction 1 is much slower than to the linear homologue L^3: the half-lives are ca. 1 s (L^1) and 2 s (L^2) as against 0.1 ms (calculated value for L^3 using the data in ref 2) at the concentrations given in the caption to Figure 1 and pH 9. The exchange reactions were first order in $[Cu(H_{-2}trigly)]$ and first order in $[L]_{tot}$. The small pH dependence of the k_{obsd} indicates that the reactive forms of L are mainly

0020-1669/78/1317-3716$01.00/0