^{1}H Nuclear Magnetic Resonance of Zinc(II) Compounds Containing 1-Amino-2-propanol Isomers as Ligands

G. NIEUWPOORT, J. BRUSSEE and J. REEDIJK

Department of Chemistry, Gorlaeus Laboratories, State University of Leiden, P. O. Box 9502, 2300 RA Leiden, The Netherlands

Received May 6, 1982

Coordination compounds of general formula $[Zn(apH)_3]X_2$ with X = I, NO_3, $\frac{1}{2}SO_4$ and apH = R,S-1-amino-2-propanol, S(+)-1-amino-2-propanol, R(−)-1-amino-2-propanol have been studied with the aid of proton NMR in CD_3OD. The effect of the counter ion upon the conformational parameter, n_{eq}, has been determined and is discussed in relation with the distance between the Lewis base sites of the counter ion and the tendency for ion-pair formation. A temperature-dependent study of the conformation of $[Zn(RS\text{-}apH)_3]I_2$ indicates an increase of the torsion angle, ω, with decreasing temperatures (+58 to −63 °C). In addition, the detailed analysis of the proton NMR spectrum of S(+)-1-amino-2-propanol in various solvents is discussed. During this work an improved synthesis for the resolution of R,S-1-amino-2-propanol has been developed.

Introduction

Differences in the coordination chemistry of racemic and optically-active ligands have been reported in the literature, although satisfactory explanations are not always available. As an example the differences in stoichiometry between compounds with racemic and optically active 1,2-propanediol can be mentioned [1]. Another example is the formation of crystals with ethylenediamine, in which the conformation of the two ligands is δλ rather than δδ (or λλ), which is calculated to be more favourable in energy [2]. For a basic understanding it is interesting to compare the coordination properties of optically-active and racemic ligands. The alcohol amines were selected as an extension of earlier studies involving ethylenediamine and 1,2-propanediamine [2]. Moreover, the alcohol amines play important roles in nature, *e.g.* in the hormones adrenaline and noradrenaline and in the amino polysaccharides [3]. Differences in coordination chemistry between compounds with *R,S*-1-amino-2-propanol (RS-apH) and *S*(+)-1-amino-2-propanol (S-apH) have been discussed [4]. The circular dichroism study of compounds with S-apH [4b] shows the occurrence of a δ–λ equilibrium in solution of $[Cu(S\text{-}apH)_3](NO_3)_2$, in which the CH_3 group alternately is in an equatorial or axial substituent position.

To obtain more knowledge about the equilibrium, a study of the proton NMR spectra was thought useful.

The proton NMR spectra of amino-alcohol coordination compounds have not been extensively studied. Evilia and Reilley [5] studied nickel(II) compounds and Hawkins and Palmer [3] used proton NMR to investigate Co(III) compounds. In the latter study proton coupling constants were used to determine quantitatively the conformational preference of diamagnetic five-membered Co(III) amino-alcohol compounds. In the present study the proton NMR of S-apH and the proton NMR of some Zn(II) compounds with 1-amino-2-propanol isomers will be discussed. Proton coupling constants are used to investigate the conformational preference of the free ligand and the Zn(II) compounds, as well as the influence of temperature on the conformational preference of one of the Zn(II) isomers.

Experimental

Starting Materials

The anhydrous metal salts and racemic 1-amino-2-propanol were used as commercially available. The preparation of the optically-active 1-amino-2-propanol isomers is given below.

The Resolution of R,S-*1-amino-2-propanol*

The first report about the resolution of *R,S*-1-amino-2-propanol (RS-apH) was described by Clark *et al.* [6]. Later, the resolution as described in detail by Sullivan and Woodbary [7], appeared to be much simpler. We describe here that this last method can be significantly improved. In 80 g water, 3 g of RS-apH and 60 g of *R*(+)-tartaric acid were dissolved. The solution was concentrated and *S*(+)-1-amino-2-propanol hydrogen *R*(+)-tartrate dihydrate

0020-1693/83/0000-0000/$03.00

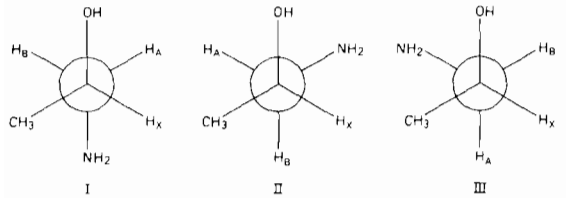

Fig. 1. The three possible rotamers of *S*(+)-1-amino-2-propanol and the used proton labeling.

(*I*) crystallized on standing. After recrystallisation of (*I*) from ethanol (96%), 25 g NaOH in 400 ml ethanol (96%) was added in portions to a solution of 80 g (*I*) in 100 ml ethanol (96%), which was stirred at 60–70 °C. After cooling to room temperature the resulting sodium tartrate was removed by filtration and washed with absolute ethanol (3 × 100 ml) and sodium-dried diethyl ether (1 × 100 ml). The excess of water was removed by distillation of ethanol under normal pressure. S-apH was then distilled under nitrogen and at low pressure (b.p. 65–70 °C at 2.6 kPa). After the distillation S-apH crystallizes at room temperature ($[\alpha]_D^{23}$ = +18.1 °C (c = 0.1 *M*; H_2O)). The melting point is 30 °C. The filtrate obtained after the crystallisation of (*I*) was used to prepare *R*(−)-1-amino-2-propanol (R-apH). This filtrate was concentrated and treated in the above way to give a product with $[\alpha]_D^{23}$ = −8 (C = 0.1 *M*; H_2O). This product is used for a completely new cycle (with S(−)-tartaric acid) and yielded R-apH with $[\alpha]_D^{23}$ = −18.0 (C = 0.1 *M*; H_2O). The melting point is 30 °C. The optical purity of S-apH was determined by means of gas chromatography with a SE-30, 1%, 25 m capillary column.

According to the literature [8], S-apH was treated with N-trifluoroacetyl(trifluoroacetamide)-L-alanine, which acts as a chiral reagent for optically-active compounds with hydroxy and amino functions. For the necessary silylation N-methyl-bis(trimethylsilyl)-trifluoroacetamide was used. This resulted in, at most, 3% impurity of the optical antipode in S-apH. The two peaks in the gas chromatogram were, under the present conditions (not exactly the same as in the literature [8]), not completely base-separated. It is possible that the 3% impurity partly originates from the tail of the most abundant enantiomer. Based on a maximum impurity of 3% we now propose $[\alpha]_D^{23}$ = +19.2° for S-apH. The great discrepancy between this value and values reported earlier [7, 9] can probably be explained by the hygroscopic properties and the concentration dependence of S-apH.

Synthesis of the Coordination Compounds

The anhydrous metal salts and the ligands are dissolved in methanol in the molar ratio 1:3. After concentrating the solutions and the addition of sodium-dried diethyl ether a viscous phase separated, which solidified after stirring with sodium-dried diethyl ether. All metal salts yielded tris-chelate compounds, in agreement with the zinc, carbon, hydrogen and nitrogen analyses.

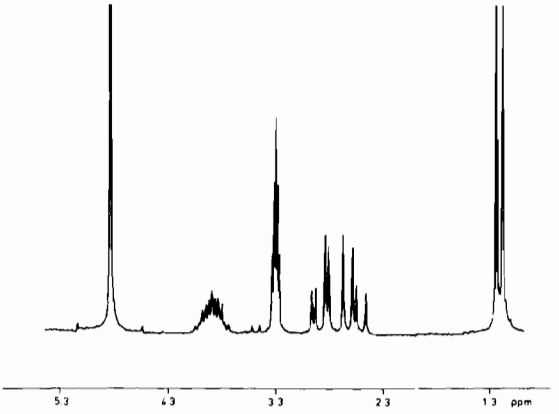

Fig. 2. ^1H NMR spectrum of $[Zn(R\text{-}apH)_3]I_2$ in CD_3OD.

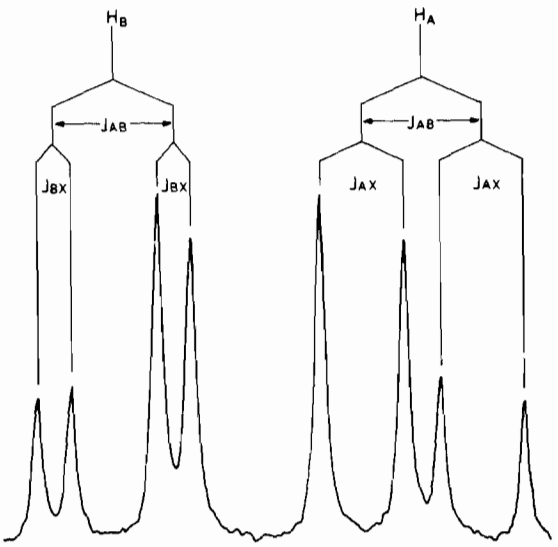

Fig. 3. Indication of $\bar{J}_{AB}$, $\bar{J}_{AX}$ and $\bar{J}_{BX}$ as determined by first-order methods.

Analyses and Physical Measurements

Metal analyses were carried out complexometrically [10]. Carbon, hydrogen and nitrogen analyses were performed by Dr. F. Pascher (Mikroanalytisches Laboratorium, Buschstrasse 54, D-5500 Bonn 1, BRD). The ^1H NMR spectra were recorded with a JEOL PS-100 spectrometer in the Fourier transform mode with 100 MHz (120–160 scans), using CD_3OD as a solvent. The concentrations of the solutions of the Zn(II) compounds were about 0.015 *M*. The spectra of S(+)-apH and its Zn(II) compounds are

TABLE I. Chemical Shifts (ppm relative to TMS), Proton Coupling Constants (Hz) and Rotamer Population of *S*(+)-1-amino-2-propanol (0.08 *M*).

Compound	Solvent	H_A	H_B	J_{AB}	J_{AX}	J_{BX}	CH_3	J_{CH_3X}	P_I	P_{II}	P_{III}
S-apH	$CDCl_3$	2.50	2.78	−12.6	8.1	3.5	1.15	6.2	8	67	25
S-apH	CD_3OD	2.50	2.59	−13.0	6.9	4.6	1.13	6.4	20	50	30
S-apH	D_2O/NaOD pH = 12	2.56	2.61	−13.6	6.5	5.0	1.15	6.3	25	44	31
S-apH	D_2O/DCl pH = 1	2.90	3.12	−13.1	8.8	3.5	1.25	6.6	9	74	17
(S-apH)(HCl)	CD_3OD	2.73	2.98	−12.7	8.9	3.4	1.22	6.4	9	75	17

TABLE II. Chemical Shifts (ppm relative to TMS) and Proton Coupling Constants (Hz) of the Zn(II) Compounds in CD_3OD; (about 0.015 *M*).

Compound	H_A	H_B	J_{AB}	J_{AX}	J_{BX}	CH_3	J_{CH_3X}	$\bar{n}^a_{eq}$
$ZnSO_4(S\text{-apH})_3$	2.59	2.82	−12.7	8.8	3.7	1.18	6.2	77
$ZnSO_4(R\text{-apH})_3$	2.61	2.84	−12.7	8.7	3.7	1.18	6.4	76
$ZnSO_4(RS\text{-apH})_3$	2.63	2.84	−12.8	8.6	3.8	1.18	6.4	75
$ZnI_2(S\text{-apH})_3$	2.57	2.87	−12.6	8.8	3.6	1.20	6.1	77
$ZnI_2(R\text{-apH})_3$	2.57	2.87	−12.6	8.8	3.5	1.20	6.2	77
$ZnI_2(RS\text{-apH})_3$	2.58	2.88	−12.6	8.9	3.6	1.20	6.1	78
$Zn(NO_3)_2(S\text{-apH})_3$	2.52	2.91	−12.5	9.4	3.3	1.20	6.2	83
$Zn(NO_3)_2(R\text{-apH})_3$	2.52	2.88	−12.5	9.2	3.5	1.20	6.2	81
$Zn(NO_3)_2(RS\text{-apH})_3$	2.52	2.91	−12.5	9.3	3.4	1.20	6.2	82

[a]The conformational parameter n_{eq} (eq = equatorial) is expressed in % ($n_{eq} + n_{ax} = 100\%$); estimatd deviation about 3%.

very similar and show a doublet at about 1.2 ppm (assigned to the methyl group), an octet at 2.7 ppm (assigned to H_A and H_B (see Fig. 1)) and a multiplet at about 3.9 ppm (assigned to H_X). The spectrum of $[Zn(RS\text{-apH})_3]I_2$ is shown in Fig.2 and the results of the first order measurement of $\bar{J}_{AB}$, $\bar{J}_{AX}$ and $\bar{J}_{BX}$ from the spectra is shown in Fig. 3.

Results and Discussion

The ^1H NMR of S(+)-1-amino-2-propanol

The observed chemical shifts and proton coupling constants of *S*(+)-1-amino-2-propanol (S-apH) are listed in Table I. The three possible rotamers are drawn in Fig. 1, together with the proton labeling system. Expressions for the average $\bar{J}_{AX}$ and $\bar{J}_{BX}$ values may be written in terms of the J_{AX} and J_{BX} values for the three rotamers and the population weighting factors (P) by reference to Fig. 1; thus yielding:

$\bar{J}_{AX} = P_I \cdot J_{AX}(I) + P_{II} \cdot J_{AX}(II) + P_{III} \cdot J_{AX}(III)$ and $\bar{J}_{BX} = P_I \cdot J_{BX}(I) + P_{II} \cdot J_{BX}(II) + P_{III} \cdot J_{BX}(III)$, in which $P_I + P_{II} + P_{III} = 1$. According to Haasnoot *et al.* [11], the J_{AX} and J_{BX} values for the three rotamers are: $J_{AX}(I) = 4.5$; $J_{BX}(I) = 11.0$; $J_{AX}(II) = 11.0$; $J_{BX}(II) = 2.6$; $J_{AX}(III) = 1.6$ and $J_{BX}(III) = 3.5$ Hz. The population distributions calculated with these values for S-apH in various solvents are listed in Table I.

It is clear that in an aprotic solvent (such as $CDCl_3$) rotamer II is preferred, because of the relatively strong *intra*molecular hydrogen bonding and the smaller steric repulsion between the methyl and the amine group, rotamer III is preferred to rotamer I because of the strong *intra*molecular hydrogen bond. In a protic solvent, such as CD_3OD, the preference of rotamer II decreases and that of rotamer I increases, because of the *inter*molecular hydrogen bonding with the solvent, which is not possible in $CDCl_3$. Also the preference of rotamer III shows a small increase in $CDCl_3$. These effects are even more prominent in D_2O/NaOD and the population ratios

approach a random distribution. In D_2O/DCl and the HCl salt of S-apH in CD_3OD, when the amine group is protonated, rotamer II is again the most stable rotamer, because of the smaller steric repulsion between the methyl and the protonated amine group and the charge-charge interaction between the positive amine group and the negative hydroxy group. A comparison of the population distributions of S-apH in $CDCl_3$ and D_2O/DCl shows that the steric effect is more dominant in D_2O/DCl compared to $CDCl_3$, as can be expected from the protonation of the amine group.

The ^1H NMR Spectra of the Zn(II) Compounds

The chemical shift and proton coupling constants of the Zn(II) compounds with RS-apH, S-apH and R-apH are listed in Table II. As has been shown for aminopropanol compounds both RS-apH and S-apH coordinate bidentately in methanolic solutions [4]. The bidentate coordination in solution is favoured because of the chelate effect [12]. Based on this observation, the effects of dissociation of the chelates can be ignored.

For a distribution of chelate rings, *e.g.* Δ or Λ, the δ and λ conformations are not equally populated. The observed proton coupling constants are averaged with respect to the abundance of the δ and the λ conformations. Possible Δ–Λ inversions as a result of metal–ligand dissociation/association can be neglected, because this is known to be slow on the NMR time scale [13]. As expected, the spectra of the Zn(II) compounds are very similar to the spectrum of S-apH in CD_3OD. The larger splitting between H_A and H_B in the Zn(II) compounds compared to S-apH can be explained by the fact that H_A will be axial in the most abundant conformation, having the methyl group equatorial. H_B on the other hand, is equatorial in the most abundant conformation.

In agreement with the observed torsion angles in free and coordinated aminopropanol [4c, 14, 15, 16], coordinated 1,2-propanediol [17] and 1,2-propanediamine [2, 18], the most stable conformation of these ligands will have a torsion angle of about 55°. Therefore it is assumed that $\omega_{eq} = 55°$. For chiral ligands ω_{ax} does not necessarily have to be equal to ω_{eq}. The unfavourable interactions are minimized by the ring, which flattens to minimize the non-bonded interactions [13, 18]. In agreement with propanediamine compounds [18], it is assumed that $\omega_{ax} = 49°$. A deviation from this angle, up to 55°, does not significantly influence the calculations.

According to Haasnoot *et al.* [11], the following parameters for the equatorial conformation are predicted: $J_{AX} = 11.2$ and $J_{BX} = 3.2$; for the axial conformation the values are $J_{AX} = 1.0$ and $J_{BX} = 5.0$ Hz. The conformational equilibrium is monitored well by the values of J_{AX} and the conformational parameter n_{eq} can now be calculated with the formula: $J_{AX}(obs) - 1.0/11.2 - 1.0 = n_{eq}$. The results of the calculation of n_{eq} are listed in Table II. The averaged values of the conformational parameter n_{eq} for $[Zn(apH)_3]SO_4$, $[Zn(apH)_3]I_2$ and $[Zn(apH)_3](NO_3)_2$ turn out to 0.76, 0.77 and 0.82 respectively (see Table II). The anion dependence of n_{eq} can be explained as follows. Chemical shift changes of hydrogen can be brought about by ion-associations with anions *via* hydrogen bonding [19]. As shown by Cramer and Huneke [20], small anions like NO_3^-, SO_4^{2-} and I^- have a preference for association with the $\Delta(\lambda\lambda\lambda)$ [or $\Lambda(\delta\delta\delta)$] conformation, which are the most stable conformations, as they have all equatorial methyl groups. This is so, because maximum hydrogen bonding to all of the available anion sites is achieved only when the amine and hydroxy protons are close together and point in a common direction. In the NO_3^- ion the separation between the Lewis base sites is 2.20 Å compared to 2.49 Å in SO_4^{2-} [20]. Thus the preference for $\Delta(\lambda\lambda\lambda)$ [or $\Lambda(\delta\delta\delta)$] is stronger for NO_3^- compared with SO_4^{2-}. Another argument is the tendency for ion-pair formation [21] in protic solvents, such as CD_3OD, which is $I^- > NO_3^- > SO_4^{2-}$, and the hydrogen-bonding ability which has a reverse order. The similar n_{eq} values found for the I^- and SO_4^{2-} compounds can be explained by the much stronger tendency for ion-pair formation in protic solvents for I^- compared with SO_4^{2-} together with the much stronger hydrogen bonding ability for SO_4^{2-} compared with I^-, which apparently results in nearly equal n_{eq} values.

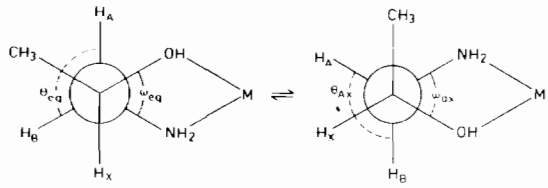

Fig. 4. The conformational equilibrium of the Zn(II) compounds.

The Temperature Dependence of the Conformations of [Zn(RS-apH)] I_2

The chemical shift and proton coupling constants of $[Zn(RS\text{-}apH)]I_2$ at varying temperatures are listed in Table III, together with the results of the calculation of the conformational parameter n_{eq}.

As can be seen from the change in n_{eq}, the equilibrium shifts into the direction of the most stable conformation with decreasing temperatures. At −63 °C the equilibrium is almost completely at the side of the equatorial conformation.

The experimental J_{BX} value measured at low temperatures is about 1 Hz smaller than the value of

TABLE III. Chemical Shifts (ppm relative to TMS), Proton Coupling Constants (Hz), and the Conformational Parameter n_{eq} of $ZnI_2(RS\text{-}apH)_3$ in CD_3OD (0.008 *M*) at Varying Temperatures.

Temp. (°C)	H_A	H_B	J_{AB}	J_{AX}	J_{BX}	CH_3	J_{CH_3X}	n_{eq}[a]
+58	2.58	2.86	−12.7	8.4	3.6	1.20	6.2	73
+28	2.57	2.87	−12.6	8.8	3.5	1.20	6.2	76
+1	2.55	2.87	−12.6	9.0	3.4	1.20	6.1	78
−10	2.55	2.88	−12.5	9.3	3.3	1.21	6.1	81
−21	2.53	2.88	−12.5	9.6	3.2	1.20	6.1	84
−28	2.53	2.88	−12.5	9.8	3.1	1.20	6.1	86
−37	2.52	2.89	−12.5	10.0	2.9	1.20	6.0	88
−52	2.50	2.89	−12.5	10.4	2.3	1.20	6.1	92
−63	2.50	2.89	−12.2	10.9	2.2	1.20	6.0	97

[a]The conformational parameter n_{eq} (eq = equatorial) is expressed in % ($n_{eq} + n_{ax} = 100\%$); estimated deviation about 3%.

3.2 Hz, as calculated by the Karplus equations from Hasnoot *et al.* [11]. This together with the fact that there is no linear relation between J_{AX} and J_{BX}, most likely indicates an increase in torsion angles with decreasing temperatures. Because J_{AX} is hardly affected by changes of ω, this will not significantly influence the calculated conformational parameter. Table III shows that the largest change in J_{BX} value (*i.e.* in torsion angle) appears between −37 and −52 °C.

The increase in torsion angle causes the axial protons to be more susceptible to the diamagnetic shielding arising from the metal ion and as a result the chemical shift difference between H_A and H_B increases (see Table III) with decreasing temperatures [22].

Concluding Remarks

The conformation equilibrium in 1-amino-2-propanol is influenced by the effect of the solvent upon the intramolecular hydrogen bond. Especially in protic solvents, intermolecular hydrogen bonding appears to be important. In Zn(II) coordination compounds with 1-amino-2-propanol, dissolved in CD_3OD, the size of the anion and the tendency for ion-pair formation determine the conformation equilibrium. A temperature dependence study shows an increase in the torsion angle of the ligand with decreasing temperatures.

Acknowledgements

The authors are indebted to Dr. C. Altona for helpful suggestions concerning the conformational analysis.

References

1 D. Knetsch, 'Diols as Ligands', *Thesis*, Leiden (1976).
2 Y. Saito, 'Inorganic Molecular Dissymmetry', Springer Verlag (1979).
3 C. J. Hawkins and J. A. Palmer, *Austr. J. Chem., 31*, 1689 (1978).
4 a) G. Nieuwpoort and W. L. Groeneveld, *Recl. Trav. Chim. Pays-Bas, 99*, 394 (1980).
b) G. Nieuwpoort and J. Reedijk, *ibid., 100*, 378 (1981).
c) G. Nieuwpoort and G. C. Verschoor, *Inorg. Chem., 20*, 4079 (1981).
5 R. F. Evila and C. N. Reilley, *J. Coord. Chem., 3*, 7 (1973).
6 R. L. Clark, W. H. Jones, W. J. Raich and K. Folkers, *J. Am. Chem. Soc., 76*, 3995 (1954).
7 R. H. Sullivan and N. J. Woodbury, United States Patent Office 3,116, 332, Dec. 31, 1963.
8 K. Kruse, W. Francke and W. A. König, *J. Chrom., 170*, 423 (1979).
9 P. Karrer and W. Klarer, *Helv. Chim. Acta, 8*, 393 (1925).
10 A. I. Vogel, 'A Textbook of Quantitative Inorganic Analysis', Longmans, London (1964).
11 C. A. G. Haasnoot, F. A. A. M. de Leeuw and C. Altona, *Tetrahedron, 36*, 2783 (1980).
12 R. D. Hancock, *Inorg. Chim. Acta, 49*, 145 (1981).
13 C. J. Hawkins and R. M. Peachey, *Acta Chem. Scand., A32*, 815 (1978).
14 G. Nieuwpoort, A. J. de Kok and C. Romers, *Recl. Trav. Chim. Pays-Bas, 100*, 177 (1981).
15 a) K. M. Marstok and H. Møllendal, *J. Mol. Struct., 35*, 57 (1976).
b) B. H. Ellingsen, K. M. Marstok and H. Møllendal, *ibid., 48*, 9 (1978).
16 G. Nieuwpoort, G. C. Verschoor and J. Reedijk, *J. Chem. Soc. (Dalton)*, in press.
17 B. M. Antti, B. K. S. Lundberg and N. Ingri, *Acta Chem. Scand., 26*, 3984 (1972).
18 L. J. DeHayes and D. H. Busch, *Inorg. Chem., 12*, 1505 (1973).
19 H. Nakazawa, U. Sakaguchi, H. Yoneda and Yu. Morinoto, *Inorg. Chem., 20*, 973 (1980).
20 R. E. Cramer and J. T. Huneke, *Inorg. Chem., 17*, 365 (1978).
21 a) D. W. James and R. F. Armishaw, *Austr. J. Chem., 28*, 1179 (1975).
b) D. W. James and R. L. Frost, *Discuss. Faraday Soc., 64*, 48 (1977).
22 a) J. R. Gollogly, C. J. Hawkins and J. K. Beattie, *Inorg. Chem., 10*, 317 (1971).
b) J. K. Beattie and L. H. Novak, *J. Am. Chem. Soc., 93*, 620 (1971).