Reactivity of Metal Chelates of Sulphur Containing Ligands Towards Lewis Bases. Part III. Reaction of Bis(1,2-dimethyl- and 1-phenyl-1,2-ethanediylidene)bis-(S-methylhydrazinecarbodithioate)NN'SS'(−2)dizinc(II) with Pyridines

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Received January 31, 1985

Abstract

The reaction of the dimeric zinc(II) chelates of the type I ($R_1 = R_2 = CH_3$, $R_1 = H$, $R_2 = Ph$) with pyridine, 2-methylpyridine, 3-methylpyridine and 4-methylpyridine afforded the monomeric monobase adducts. The isolated adducts were characterized by their electronic and ^1H NMR spectra, and a five coordinate square pyramidal structure was tentatively assigned for these adducts.

The adduct formation reaction was followed spectrophotometrically and the reaction kinetics were studied using a stopped flow technique. From the available kinetic data, as well as the measured activated parameters ($\Delta H^{\#}$, $\Delta S^{\#}$), a mechanism for the adduct formation reaction is proposed.

Introduction

The ligation properties of bishydrazone Schiff bases of α-diketones and α-ketoaldehydes derived from thiosemicarbazide and S-methylhydrazinecarbodithioate have been studied and a series of metal(II) chelates of these types of ligands were synthesized and characterized [1–9]. The copper(II) and zinc(II) chelates of 3-ethoxy-2-oxobutyraldehyde bis(thiosemicarbazone) were found to possess antineoplastic activity and their interactions with biological systems have been studied [10–15].

In a continuation of our studies on the reactivity of metal chelates of sulphur-containing ligands towards Lewis bases as a possible model for their mode of action within biological systems [16, 17], the reaction of zinc(II) chelates of both (1,2-dimethyl-1,2-ethanediylidene) and (1-phenyl-1,2-ethanediylidene)bis(S-methylhydrazinecarbodithioate) (I, $R_1 = R_2 = Me$, $M = Zn(II)$ and $R_1 = Ph$, $R_2 = H$, $M = Zn(II)$), hereafter abbreviated as Zn(Da2SMe)
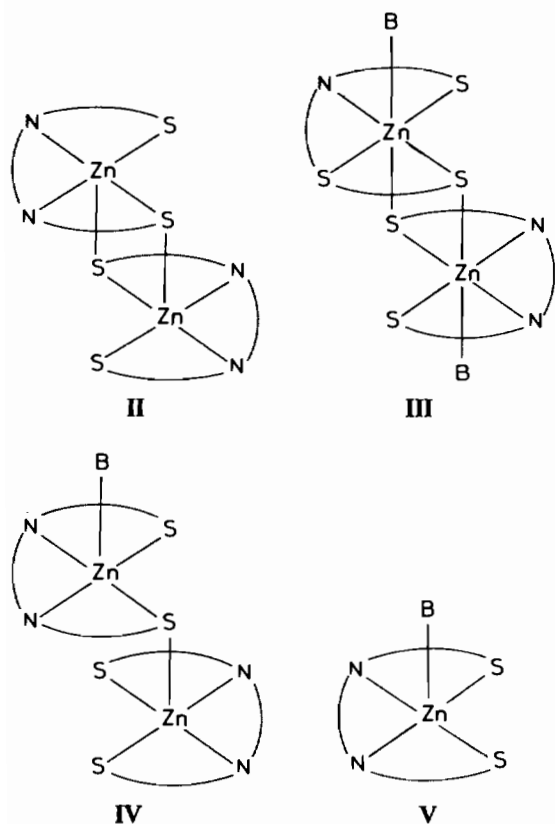

I
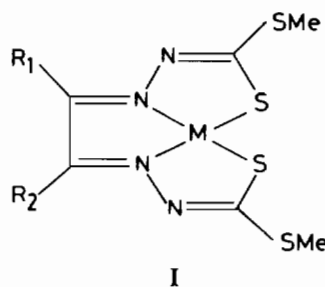
and Zn(Phg2SMe) respectively, with pyridines are discussed in the present work. A series of Zn(Da2SMe) and Zn(Phg2SMe) monobase adducts have been isolated and characterized. The kinetics of the reaction between Zn(Da2SMe) and pyridine, 3-methyl- and 4-methylpyridine in benzene solutions are also studied and a mechanism for monoadduct formation reaction is proposed.

Results and Discussion

The electronic absorption spectra of both Zn(Da2SMe) and Zn(Phg2SMe) chelates suggest that the two hydrazone units are highly conjugated and the dinegative NNSS ligand forms with the zinc(II) a coplanar tricyclic structure (I) [9]. Due to the square planar arrangement imposed by these ligands around zinc(II), a dimeric five-coordinate square pyramidal structure (II) has been assigned for these chelates [9]. Their limited solubility in most of non-coordinated solvents makes molecular weight determination impossible. However, the field desorption mass spectra of Zn(Da2SMe) and Zn(Phg2SMe) in $CHCl_3$ solutions show peaks at m/e (RA), 714 (20) and 810 (25) respectively due to the dimeric $Zn_2(Da2SMe)_2$ and $Zn_2(Phg2SMe)_2$ molecular ions, besides peaks at 357 (100) and 405 (100) corresponding to the monomeric units. This is in agreement with the proposed five-coordinate structure (II).

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II   III

IV   V

TABLE I. Elemental Analyses of Monobase Adducts.

Compound	Found (Calcd.) %		
	N	S	Zn
Zn(Da2SMe)Py	16.03	30.30	15.32
	(16.00)	(29.30)	(14.96)
Zn(Da2SMe)2MePy	15.50	29.03	14.67
	(15.53)	(28.44)	(14.49)
Zn(Da2SMe)3MePy	14.70	28.53	14.48
	(15.53)	(28.44)	(14.49)
Zn(Da2SMe)4MePy	15.00	29.09	14.54
	(15.53)	(28.44)	(14.49)
Zn(Phg2SMe)Py	13.70	25.82	13.69
	(14.44)	(26.45)	(13.48)
Zn(Phg2SMe)3MePy	13.60	26.32	13.15
	(14.03)	(25.70)	(13.00)
Zn(Phg2SMe)4MePy	13.25	26.43	13.25
	(13.10)	(25.70)	(13.10)

The reaction of both $Zn_2(Da2SMe)_2$ and Zn_2-(Phg2SMe)$_2$ chelates with heterocyclic bases (pyridine, 2-methyl-, 3-methyl- and 4-methylpyridine) in benzene using 1:2 molar ratio gives the monomeric monoadducts (V). The isolated monoadducts together with their elemental analyses are listed in Table I.

The isolation of these monoadducts demonstrates the Lewis acidic property of these dimeric Zn(II) chelates. A large number of Lewis base monoadducts of Zn(II) chelates with sulphur containing ligands

such as dithiocarbamates [18, 19], dithiophosphates [20] and xanthates [21, 22] have been isolated and characterized. A distorted trigonal bipyramidal structure had been assigned for these monoadducts [22, 23]. In some cases octahedral bisadducts have been either identified in solution or isolated as solid products [20]. Attempts to prepare Lewis base bis-adducts of either $Zn_2(Da2SMe)_2$ or $Zn_2(Phg2SMe)_2$ by using large excess of the heterocyclic base were unsuccessful and only the monoadducts were isolated. This is in agreement with the preferential stability of the five-coordinated zinc(II).

An inspection of the ^1H NMR spectra of the isolated monoadducts, Table II, reveals that both β and γ-protons of the coordinated base exhibit a downfield shift by ca. 0.200–0.25 ppm as compared to the free uncoordinated base. This can be related to a decrease in C–H electron density resulting

TABLE II. ^1H NMR Spectra of Monobase Adducts in CDCl$_3$.

Compound	δ (ppm)						
	C–Me	S–Me	Me–Py	=CH	α-H	β-H	γ-H
Zn(Da2SMe)Py	2.41	2.60	–	–	8.44	7.40	7.80
Zn(Da2SMe)2MePy	2.60	2.63	2.40	–	8.47	7.20	7.57
Zn(Da2SMe)3MePy	2.37	2.63	2.30	–	8.20	7.27	7.60
Zn(Da2SMe)4MePy	2.37	2.60	2.37	–	8.28	7.27	–
Zn(Phg2SMe)Py	–	2.57	–	8.30	8.48	7.32	7.90
		2.63					
Zn(Phg2SMe)3MePy	–	2.57	2.37	8.30	8.27	7.43	7.92
		2.63					
Zn(Phg2SMe)4MePy	–	2.57	2.37	8.30	8.27	7.33	7.90
		2.63					

from the coordination of the azanitrogen to zinc-(II). The α-protons, however, show an upfield shift (*ca.* 0.08–0.20 ppm) due to the shielding effect of the delocalized π-current above the pseudoaromatic ZnN_2S_2 rings which overcome the electronic effects. This is in agreement with a distorted square pyramidal structure (**II**) similar to that reported for aquo(3-ethoxy-2-oxobutyraldehyde)bis(thiosemicarbazonato)zinc(II) [24].

The ^{1}H NMR spectra of Zn(Da2SMe)B adducts, Table II, display signals at 2.37 and 2.60 ppm, attributed respectively to the two magnetically equivalent C–Me and S–Me groups of the equatorial bishydrazone dinegative anion. The two S–Me in Zn(Phg2-SMe)B adducts however are magnetically not equivalent due to the presence of different substituents (R_1 = Ph and R_2 = H) and they appear as two signals at 2.57 and 2.63 ppm.

The electronic spectra of the isolated monoadducts, Table III, are more or less similar and show a red shift as compared to the corresponding zinc(II) dimers. The observed red shift can be related to the rupture of the two Zn–S bridges, which makes the sulphur orbitals more available to contribute in an extended π-bonding in the equatorial ZnN_2S_2 plane of the monomeric monoadduct.

TABLE III. Electronic Spectra of Monobase Adducts in $CHCl_3$.

Compound	Band max. (nm) log ϵ (dm^{-3} mol^{-1} cm^{-1})		
Zn(Da2SMe)Py	255sh, 345, 450b, 485sh (4.21) (3.81)		
Zn(Da2SMe)2MePy	265, 340, 420sh, 480sh (4.00) (4.16)		
Zn(Da2SMe)3MePy	260sh, 340, 450, 490sh (4.12) (3.85)		
Zn(Da2SMe)4MePy	255sh, 340, 450b, 485sh (4.28) (4.01)		
Zn(Phg2SMe)Py[a]	260sh, 280, 310, 360, 480, 510sh		
Zn(Phg2SMe)3MePy[a]	270sh, 310, 360, 460sh, 490		
Zn(Phg2SMe)4MePy	262sh, 280, 305, 365, 470sh, 490b (4.07) (4.08) (4.15) (3.88)		

[a]Saturated solution.

The reactions of $Zn_2(Da2SMe)_2$ with pyridine, 3-methyl- and 4-methylpyridine were followed spectrophotometrically. Figure 1 shows the spectral variation of $Zn_2(Da2SMe)_2$ (2.0 × 10^{-5} mol dm⁻³) in the presence of pyridine (8.0 × 10^{-4} mol dm⁻³) as a function of time. The recorded spectrum after complete reaction is identical to the solution of the solid monopyridine adduct in benzene. Similar spectral behaviour was also observed on using 3-methyl- and 4-methylpyridine.
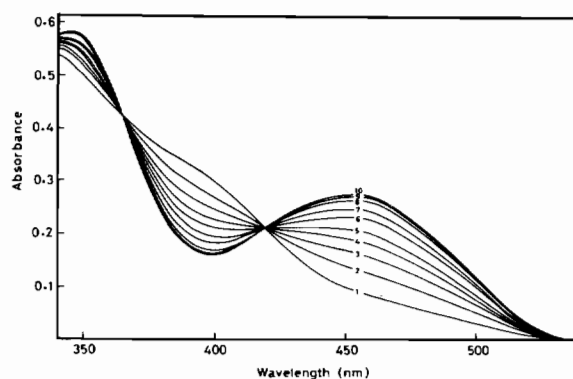

Fig. 1. Variation of the electronic spectra of $Zn_2(Da2SMe)_2$ (2 × 10^{-5} mol dm⁻³) in presence of pyridine (8 × 10^{-4} mol dm⁻³), as a function of time (seconds): (1) 60, (2) 240, (3) 420, (4) 600, (5) 780, (6) 1080, (7) 1380, (8) 1980, (9) 2580 and (10) 3180.

Spectrophotometric titration of $Zn_2(Da2SMe)_2$ with pyridine 3-methyl and 4-methylpyridine in benzene at 460 nm after complete reaction reveals that two equivalents of the base are required to react with the dimeric $Zn_2(Da2SMe)_2$, as shown by the stoichiometric eqn.:

$$Zn_2(Da2SMe)_2 + 2B \longrightarrow 2Zn(Da2SMe)B$$
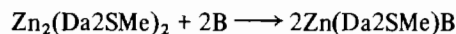
These results show that the reaction of $Zn_2(Da2-SMe)_2$ with the Lewis base molecule proceeds irreversibly and quantitatively to yield the monomeric Zn(Da2SMe)B.

The kinetics of the monoadduct formation, from the reaction of $Zn_2(Da2SMe)_2$ with different pyridines, were also studied spectrophotometrically by following the increase in absorbance measured at λ = 460 nm as a function of time. The order of the reaction was determined using the initial rate method [25] and was found to be first order in each of the reactants. The rate eqn. can be expressed by:
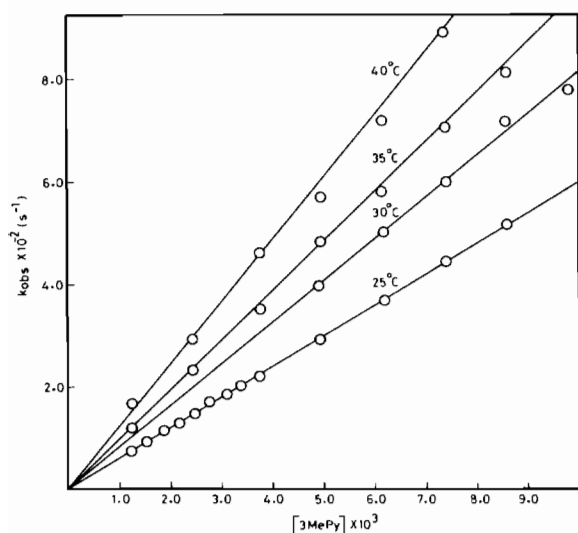
$$Rate = k[Zn_2(Da2SMe)_2][B] \qquad (1)$$

where k (dm^3 mol^{-1} s^{-1}) is the second order reaction rate constant.

The reaction rate constants k_{obs} (s^{-1}) were measured under pseudo first order conditions at different large excesses of the base concentration (1.00–10.00 × 10^{-3}) and plots of k_{obs} *vs.* [B], Fig. 2, give straight lines passing through the origin. From the gradient of the best fitting lines, the second order rate constants k were calculated. The values of k at different temperatures for pyridine, 3-methyl- and 4-methylpyridine monoadduct formation reactions are listed in Table IV. The activation parameters $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ were calculated using the Eyring equation and are also listed in Table IV.

TABLE IV. Rates and Activation Parameters for the Reaction of $Zn_2(Da2SMe)_2$ with Different Lewis Bases.

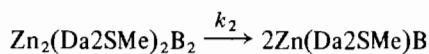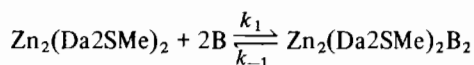| Base	Temp. (°C)	$10^3 \times [B]$ (mol dm^{-3})	No. of solns.	k (dm^3 mol^{-1} s^{-1})	$\Delta H^{\ddagger}$ (KJ mol^{-1})	$-\Delta S^{\ddagger}$ (J mol^{-1} K^{-1})
Py	20.5	1.20–7.20	8	1.702 ± 0.106	506 ± 5.6	67.8 ± 19.0
	25.5	2.00–6.00	8	2.588 ± 0.118		
	30.8	2.00–6.00	6	3.690 ± 0.339		
	35.2	1.20–6.00	6	4.201 ± 0.342		
3MePy	25.0	3.00–9.00	12	5.023 ± 0.102	34.5 ± 3.6	115.6 ± 12.0
	30.0	1.20–9.80	5	6.791 ± 0.132		
	35.0	1.20–9.80	7	8.010 ± 0.149		
	40.0	1.20–7.30	6	10.220 ± 0.616		
4MePy	20.0	0.80–4.00	9	5.705 ± 0.274	30.1 ± 3.9	127.9 ± 12.9
	25.0	0.75–5.00	8	7.703 ± 0.269		
	30.0	0.75–5.00	6	9.909 ± 0.322		
	35.0	0.60–4.80	6	10.727 ± 0.179		
	40.0	0.50–5.00	6	15.769 ± 0.424		

Fig. 2. Variation of k_{obs} (s^{-1}) as a function of [3MePy] (mol dm^{-3}) at different temperatures.

It is apparent from the data cited in Table IV that the measured k values are too small to account for a direct reaction between the base and the monomeric Zn(Da2SMe) species (*i.e.* a simple Lewis acid-base equilibria). Such small k values, however, suggest a reaction between the dimeric Zn_2-(Da2SMe)$_2$ with a base where a rupture of two Zn–S bridges is required to give the monomeric monoadduct (**V**). Accordingly, a possible dimer—monomer equilibrium can be ruled out and the Zn(II) chelate exists in benzene solution as stable $Zn_2(Da2SMe)_2$ dimer.

The kinetic data, Table IV, also show that the values of k are dependent on the nature of the base

used and increase as the basicity increases. It is also observed that both enthalpy $\Delta H^{\ddagger}$ and entropy $\Delta S^{\ddagger}$ of the activation decrease with increasing basicity. This kinetic behaviour suggests an associative mechanism where the base reacts with $Zn_2(Da2-SMe)_2$ to form a dimeric intermediate adduct. The direct dissociation of this adduct intermediate or further reaction with the base accompanied by simultaneous dissociation yields the monomeric monoadduct.

The reaction may proceed initially by the reversible addition of two base molecules to form an unstable octahedral bisadduct (**III**) which dissociates to yield the monomeric monoadduct (**V**) as follows:

$$Zn_2(Da2SMe)_2 + 2B \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} Zn_2(Da2SMe)_2B_2$$

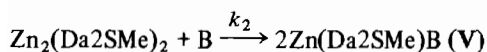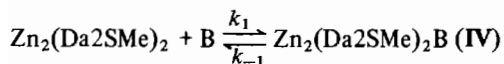$$Zn_2(Da2SMe)_2B_2 \overset{k_2}{\longrightarrow} 2Zn(Da2SMe)B$$

Applying a steady state approximation on the concentration of the octahedral intermediate (**III**) gives the following rate eqn.:

$$k_{obs} = [k_1 k_2/(k_{-1} + k_2)] [B]^2$$

Whether the formation of the dimeric octahedral base adduct (**III**) or its dissociation to (**V**) is the rate controlling step, the obtained rate eqn. shows second order dependence on the base concentration and cannot account for the observed first order dependence eqn. (1).

The striking first order dependence, however, can be rationalized by assuming the initial reversible addition of one Lewis base molecule to (**II**) with

simultaneous rupture of one Zn—S bridge forming the unstable five-coordinate intermediate (**IV**). The reaction of another base molecule with (**IV**) results in the formation of the monoadduct (**V**). The reaction mechanism can be represented by:

$$Zn_2(Da2SMe)_2 + B \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} Zn_2(Da2SMe)_2B \; (\textbf{IV})$$

$$Zn_2(Da2SMe)_2 + B \overset{k_2}{\longrightarrow} 2Zn(Da2SMe)B \; (\textbf{V})$$

Assuming a steady state approximation for the concentration of the intermediate (**IV**) gives:

$$k_{obs} = k_1 k_2 [B]^2/(k_{-1} + k_2[B]) \tag{3}$$

It can be assumed that the reversible formation of the five-coordinate monoadduct is the rate determining step and accordingly $k_2[B] \gg k_{-1}$ and eqn. (3) thus reduces to:

$$k_{obs} = k_1[B] \tag{4}$$

which is in agreement with the observed rate eqn.

The present kinetic study confirms the five-coordinate dimeric structure (**II**) previously suggested spectroscopically [9]. The kinetic data also indicate that the formation of the dimeric five-coordinate monoadduct (**IV**), rather than the six-coordinate bisadduct (**III**), intermediate is the rate controlling step. It seems that the initial coordination of one Lewis base molecule in (**IV**) modifies the remaining Zn—S bridge, rendering it more susceptible to bond rupture on the attack of the second base molecule.

Experimental

Preparation of Zinc(II) Complexes: Zn₂(Da2SMe)₂ and Zn₂(Phg2SMe)₂

These dimeric complexes were prepared as previously described [9] and were recrystallized from chloroform. Zn(Da2SMe)B and Zn(Phg2SMe)B, B = Py, 2MePy, 3MePy or 4MePy.

A hot solution of $Zn_2(Da2SMe)_2$ or $Zn_2(Phg2-SMe)_2$ (0.01 mol) in benzene (50 cm³) was treated with a solution of the base (0.02 mol) in benzene (10 cm³). The reaction mixture was then refluxed for 2 h and the resulting solution was concentrated by evaporation to half its original volume and left to cool. The crystals which separated out were filtered, washed with Et₂O and dried *in vacuo*. In the case of Zn(Phg2SMe)B, however, petroleum ether (40—60 °C) was added to affect precipitation.

Physical Measurements

The ¹H NMR spectra were recorded on a Varian T90 spectrometer. The electronic spectra were recorded on a Pye Unicam SP-1800 recording spectrophotometer equipped with a thermostatted cell holder. The actual temperature of the solution was measured by a calibrated thermocouple.

The kinetic measurements were made by using a Durrum D-101 stopped flow spectrophotometer. A Shimatzu recorder was used to record the variation of absorbance as a function of time.

References

1 G. Bähr, *Z. Anorg. Allg. Chem.*, 268, 351 (1952); 273, 325 (1953); 278, 136 (1955).
2 B. A. Gingras, T. Suprunchuk and C. H. Bayley, *Can. J. Chem.*, 40, 1053 (1962).
3 M. R. Taylor, E. J. Gabe, J. P. Glusker, J. M. Minkin and A. L. Patterson, *J. Am. Chem. Soc.*, 88, 1845 (1966).
4 C. J. Jones and J. A. McCleverty, *J. Chem. Soc. A:*, 2829 (1970).
5 L. E. Warren, S. M. Horner and W. E. Hatfield, *J. Am. Chem. Soc.*, 94, 6392 (1972).
6 M. J. M. Campball, A. J. Collis and R. Crzeshawiak, *J. Inorg. Nucl. Chem.*, 38, 173 (1976).
7 K. Balschmiter, H. Greber and H. G. Steinhauser, *J. Inorg. Nucl. Chem.*, 40, 631 (1978).
8 G. W. Bushnell and A. Y. M. Tsang, *Can. J. Chem.*, 57, 603 (1979).
9 A. El-Toukhy, M. El-Essawi, M. Tawfik, L. El-Sayed and M. F. Iskander, *Transition Met. Chem.*, 8, 116 (1983).
10 D. A. Winkelmann, Y. Bermke and D. H. Petering, *Bioinorg. Chem.*, 3, 261 (1974).
11 D. H. Petering, *Biochem. Pharmacol.*, 23, 567 (1974).
12 C. H. Chan Stier, D. T. Minkel and D. H. Petering, *Bioinorg. Chem.*, 6, 203 (1976).
13 D. T. Minkel, C. H. Chan Stier and D. H. Petering, *Mol. Pharmacol.*, 12, 1036 (1976).
14 D. T. Minkel, A. L. Saryan and D. H. Petering, *Cancer Res.*, 38, 124 (1978).
15 D. T. Minkel and D. H. Petering, *Cancer Res.*, 38, 117 (1978).
16 M. F. Iskander, L. El-Sayed, M. Khalil and A. El-Toukhy, *Inorg. Chim. Acta*, 86, 191 (1984).
17 M. F. Iskander, L. El-Sayed, L. Labib and A. El-Toukhy, *Inorg. Chim. Acta*, 86, 197 (1984).
18 G. M. C. Higgins and B. Saville, *J. Chem. Soc.*, 2812 (1963).
19 B. B. Mohapatra, B. K. Mohapatra and S. Guru, *J. Inorg. Nucl. Chem.*, 39, 1577 (1977).
20 D. R. Dakternicks and D. P. Graddon, *Aust. J. Chem.*, 23, 1989 (1970); 24, 2077 (1971).
21 H. R. Hunt, A. G. Kruger, L. Smith and G. Winter, *Aust. J. Chem.*, 24, 53 (1971).
22 C. L. Raston, A. H. White and G. Winter, *Aust. J. Chem.*, 29, 731 (1976).
23 K. A. Fraser and M. M. Harding, *Acta Crystallogr.*, 22, 75 (1967).
24 P. E. Bourne and M. R. Tayler, *Acta Crystallogr., Sect. B:*, 36, 2143 (1980).
25 K. J. Laidler, 'Chemical Kinetics', McGraw Hill, New York, 1965.