Some Reactions of *cis*-Dichlorodiammine Palladium(II) with Nucleosides

GEORGE PNEUMATIKAKIS

University of Athens, Inorganic Chemistry Laboratory, 13A Navarinou Str., Athens, Greece

Received October 16, 1981

The reactions of cis-$Pd(NH_3)_2Cl_2$ with nucleosides have been studied in aqueous and dmso solutions. From aqueous solutions, with the nucleosides Ino, Guo and Cyd (= nucl) the complexes $[Pd(NH_3)_2(nucl)_2]Cl_2$ have been isolated, while adenosine gave the dimeric complex $\{[Pd(NH_3)_2Cl]_2Ado\}Cl_2$. From dmso solutions the mononucleoside complexes $[Pd(NH_3)_2(nucl)(dmso)]Cl_2$ have been isolated. These complexes were stable in neutral aqueous solutions, but in alkaline solutions (pH 9–10) those with ionizable N(1)H imino proton, were deprotonated and complexes of the general formula $Pd(NH_3)_2(nucl\text{-}H^+)Cl$ precipitated. These complexes were further transformed to the mononucleoside complexes $[Pd(NH_3)_2(nucl)Cl]Cl$ in acid solution ($pH \cong 1$), which in aqueous solution ($pH > 5$) deprotonated to the parent compound. The isolated complexes were characterized by elemental analyses, conductivity measurements, IR, ^1H NMR and ^{13}C NMR spectra.

Introduction

The interaction of metals and especially of Pt(II) with nucleic acid constituents has been the subject of extensive investigations in recent years, after Rosenberg's [1–3] discovery of the antitumour properties of *cis*-$Pt(NH_3)_2Cl_2$. There exist numerous reports on such interactions, including crystallographic studies and most of them are described in several review articles [4–10].

Among the studies on interactions of different metals with the nucleic acid bases, reports on similar studies with Pt(II) are quite limited [11–14]. Such studies are of great importance, because Pd(II), as a d^8 system, forms square planar complexes like Pt(II) and could serve as model for the reactions of the latter with the nucleic acid constituents, especially because the Pd(II) reactions are much more fast than the respective reactions of Pt(II) [15]. The Pd(II) complexes are also interesting in biological chemistry. For example Kirschner and collaborators noted that *cis*-dichloropiperidine palladium(II) can induce filamental growth in *E. Coli* [16]. The same effect was also noted by Charlson *et al.* with caesium *cis*-dichloro-L-serinato-palladium(II) [17].

During the past few years we have been studying the interactions of Pt(II), Pd(II), Rh(II) and Au(III) with nucleic acid constituents, in order to investigate the binding sites, the general reactivity behavior of such reactions and correlate the results to the mechanism of the antitumour action of *cis*-$Pt(NH_3)_2Cl_2$ [18–21]. In an attempt to investigate further the general reactivity behavior of Pd(II) towards the nucleic acid constituents, I now report on the interactions of *cis*-$Pd(NH_3)_2Cl_2$ with inosine, guanosine, cytidine and adenosine.

Results and Discussion

cis-$Pd(NH_3)_2Cl_2$ reacts with nucleosides in aqueous solutions at room temperature producing 1:2 complexes as follows:

$$cis\text{-}Pd(NH_3)_2Cl_2 + 2nucl \rightarrow [Pd(NH_3)_2(nucl)_2]Cl_2$$

where nucl is ino, guo, cyd.

The 1:1 complexes were obtained from dmso solutions at room temperature.

$$cis\text{-}Pd(NH_3)_2Cl_2 + nucl \xrightarrow{dmso} [Pd(NH_3)_2(nucl)\text{-}(dmso)]Cl_2$$

The 1:1 complexes are stable in neutral aqueous solutions, but in alkaline (pH ~ 10) solutions they lose dmso with simultaneous deprotonation of the N(1)H imino proton and the formation of complexes of the general formula $Pd(NH_3)_2(nucl\text{-}H^+)Cl$ according to the scheme:

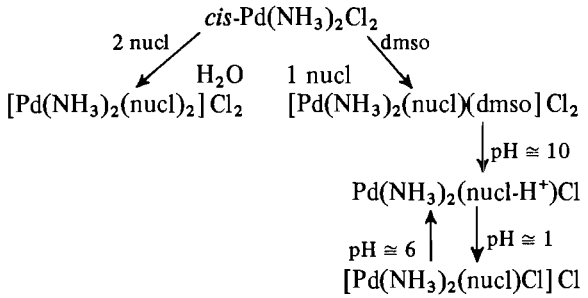
$$[Pd(NH_3)_2(nucl)(dmso)]Cl_2 \xrightarrow{Ph\ 10} Pd(NH_3)_2\cdot(nucl\text{-}H^+)Cl + HCl \quad (nucl = ino, guo)$$

In acid solution the above reaction was reversed and the mononucleoside complexes $[Pd(NH_3)_2(nucl)Cl]Cl$ were obtained. These complexes are very unstable in aqueous solutions, where they lose one HCl molecule producing complexes of the empirical formula $Pd(NH_3)_2(nucl\text{-}H^+)Cl$:

$$[Pd(NH_3)_2(nucl)Cl[Cl \xrightarrow{H_2O} Pd(NH_3)_2(nucl\text{-}H^+)\text{-}Cl + HCl$$

The above reactions may be summarized as follows:

0020-1693/82/0000-0000/$02.75



The reaction with adenosine gave the water insoluble complex $\{[Pd(NH_3)_2Cl]_2ado\}Cl_2$

The analytical and conductivity measurements data are included in Table I. The assigned formulae agree with their elemental analyses.

The complexes $[Pd(NH_3)_2(nucl)_2]Cl_2$, $[Pd(NH_3)_2(nucl)(dmso)]Cl_2$, and $[Pd(NH_3)_2(nucl)Cl]Cl$ (nucl = ino, guo)

The conductivity measurements of the complexes $[Pd(NH_3)_2(nucl)_2]Cl_2$ and $[Pd(NH_3)_2(nucl)(dmso)]Cl_2$ indicate that they behave as 1.2 electrolytes in aqueous solutions [22] in agreement with their four coordination and square geometry. The complexes $[Pd(NH_3)_2(nucl)Cl]Cl$ behave as 1:1 electrolytes in dmf solutions but they attain very high conductivities in aqueous solutions due to the deprotonation of the N(1)H imino proton and the liberation of HCl in the solution.

The binding site of the nucleosides in these complexes was deduced mainly from their NMR spectra. The ^1H NMR spectra show a Pd–N(7) coordination in all the above complexes, because the signal of the H(8) proton is always shifted downfield, as compared to the free ligands, while the signals of the other protons remain essentially unchanged (see Table II).

This shift is about 0.6 ppm and it is comparable to the shift caused by Pd(II), Rh(II), Au(III) and Au(I) in their purine complexes [18–21].

The binding site of the nucleosides in these complexes is further confirmed by their ^{13}C NMR spectra. The ^{13}C NMR assignements are summarized in Table III.

They were identified by reference to nucleoside assignments made by Jones *et al.* [23] and by comparison with the undecoupled spectra. The chemical shift changes in the proton decoupled spectra of the complexes confirm that the nucleoside binding sites were as suggested above. In the case of inosine and guanosine, the downfield shifts observed for the C(5) and C(8) resonances are consistent with the coordination at N(7), since these carbons are adjacent to this nitrogen [24].

TABLE I. Analytical[a] and Conductivity Data of the Complexes

Compound	% C	% H	% N	% Pd	Λ_m, Ω^{-1} cm^2 M^{-1}
$[Pd(NH_3)_2(Guo)_2]Cl_2$	31.05 (30.85)	4 25 (4.15)	21.22 (21 59)	13.80 (13.68)	182 (10^{-3} *M*, H_2O)
$[Pd(NH_3)_2(Guo)(dmso)]Cl_2$	25.38 (25.14)	4.52 (4.40)	17 50 (17.11)	18 80 (18.58)	180 (10^{-3} *M*, H_2O)
$pd(NH_3)_2(Guo\text{-}H^+)Cl$	26.93 (26 77)	4 28 (4.05)	21 60 (21.39)	23.47 (23 74)	
$[Pd(NH_3)_2(Guo)Cl]Cl$	24.40 (24 26)	3.62 (3 87)	19.50 (19.81)	21.85 (21.51)	95 (10^{-3} *M*, dmf)
$[Pd(NH_3)_2(Ino)_2]Cl_2$	32.30 (32.09)	4.25 (4.01)	11.53 (11.23)	14.55 (14.23)	190 (10^{-3} *M*, H_2O)
$[Pd(NH_3)_2(Ino)(dmso)]Cl_2$	25.50 (25.82)	4.05 (4.30)	15.38 (15.06)	19.42 (19.08)	185 (10^{-3} *M*, H_2O)
$Pd(NH_3)_2(Ino\text{-}H^+)Cl$	27.35 (27.08)	3.50 (3.84)	18.50 (18 96)	24.50 (24.01)	
$[Pd(NH_3)_2(Ino)Cl]Cl$	25.41 (25.02)	3.49 (3.75)	17.12 (17.51)	22.50 (22.19)	92 (10^{-3} *M*, dmf)
$[Pd(NH_3)_2(Cyd)_2]Cl_2$	30.62 (30 95)	4.75 (4 59)	16.45 (16 05)	15 55 (15 25)	197 (10^{-3} *M*, H_2O)
$[Pd(NH_3)_2(Cyd)(dmso)]Cl_2$	24 50 (24.78)	4.46 (4.69)	13.45 (13.14)	20.31 (19.98)	188 (10^{-3} *M*, H_2O)
$\{[Pd(NH_3)_2Cl]_2Ado\}Cl_2$	17.59 (17.39)	3.45 (3.62)	17.92 (18.26)	31.22 (30.84)	190 (10^{-3} *M*, dmf)

[a]The numbers in parentheses represent the calculated figures.

TABLE II. ^{1}H NMR Chemical Shifts of the Complexes [a]

Compound	H_2	H_5	H_6	H_8	H_1	Solvent
Guo				7.80	5.74(d) 5.68	dmso-d_6
$[Pd(NH_3)_2(Guo)_2]Cl_2$				8.40	5.87(d) 5.80	D_2O
$[Pd(NH_3)_2(Guo)(dmso)]Cl_2$				8.35	5.85(d) 5.78	D_2O
Ino	8.11			8.22	6.03(d) 5.93	D_2O
$[Pd(NH_3)_2(Ino)_2]Cl_2$	8.16			8.87	5.83(d) 5 72	D_2O
$[Pd(NH_3)_2(Ino)(dmso)]Cl_2$	8.20			8.85	5.85(d) 5.76	D_2O
Cyd		5.75(d) 5.66	7.79(d) 7 78		6.24(d) 6.17	D_2O
$[Pd(NH_3)_2(Cyd)_2]Cl_2$		6.37(d) 6.30	8.20(d) 8.11		6.27(d) 6.26	D_2O
$[Pd(NH_3)_2(Cyd)(dmso)]Cl_2$		6 40(d) 6.37	8 25(d) 8.17		6.26(d) 6.24	D_2O
Ado	8.15			8.36	5.90(d) 5.80	dmso-d_6
$\{[Pd(NH_3)_2Cl]_2Ado\}Cl_2$	8.66			8.90	6.31(d) 6.23	dmso-d_6

[a]d = doublet.

TABLE III. ^{13}C NMR Chemical Shifts of the Complexes.

Compound	C(2)	C(4)	C(5)	C(6)	C(8)
Inosine	159.6	154.5	120.2	157.4	132.2
$[Pd(NH_3)_2(Ino)_2]Cl_2$	160.1	155.1	122.3	159.1	135.6
$[Pd(NH_3)_2(Ino)(dmso)]Cl_2$	160.0	155.0	122 1	158.9	135.4
Guanosine	154.6	152.2	117.5	157.5	136.5
$[Pd(NH_3)_2(Guo)_2]Cl_2$	155.7	153.2	119.6	159.0	139.9
$[Pd(NH_3)_2(Guo)(dmso)]Cl_2$	155.5	153.0	119.5	158.8	139.8
Adenosine	146.3	145.0	111.3	149.5	132.5
$\{[Pd(NH_3)_2Cl]_2Ado\}Cl_2$	149.0	145.3	115.6	153.2	134.8
Cytidine	151.5	162.5	98 5	147.5	
$[Pd(NH_3)_2(Cyd)_2]Cl_2$	155.4	165.2	96.7	146.1	
$[Pd(NH_3)_2(Cyd)(dmso)]Cl_2$	155.0	165.1	97.5	146.2	

The participation of the exocyclic O(6) in coordination was excluded in these complexes, because the ν(C=O) frequency observed at about 1700 cm^{-1} in the uncomplexed nucleosides remains essentially unchanged in the complexes (see Table IV).

The medium band observed at 320 cm^{-1} in the far infrared spectra of the complexes $[Pd(NH_3)_2(nucl)Cl]Cl$ was assigned to the metal–halogen stretching. The IR spectra also indicate sulfur coordination of dmso to palladium [25].

The complexes $\{[Pd(NH_3)_2Cl]_2ado\}Cl_2$, $[Pd(NH_3)_2(cyd)_2]Cl_2$ and $[Pd(NH_3)_2(cyd)(dmso)]Cl_2$

The analytical and conductivity measurements data (see Table I) agree with the proposed formulae.

The nucleoside adenosine behaves as a bidentate ligand in the complex $\{[Pd(NH_3)_2Cl]_2ado\}Cl_2$, bridging two palladium atoms through its N(1) and N(7) atoms. Both ^{1}H and ^{13}C spectra are consistent with this conclusion.

TABLE IV. Characteristic IR Bands of the Complexes (cm^{-1})[a].

Compound	ν C=O skeletal	ν C=C, ν C=N skeletal	ν S=O	ν Pd–Cl
Ino	1690	1584, 1510		
$[Pd(NH_3)_2(Ino)_2]Cl_2$	1680	1590, 1568		
$[Pd(NH_3)_2(Ino)(dmso)]Cl_2$	1685	1597, 1566, 1539	1160	
$Pd(NH_3)_2(Ino\text{-}H^+)Cl$	1630	1610, 1535, 1500		
$[Pd(NH_3)_2(Ino)Cl]Cl$	1683	1595, 1560		330
Guo	1725	1620, 1530		
$[Pd(NH_3)_2(Guo)_2]Cl_2$	1700	1595, 1530		
$[Pd(NH_3)_2(Guo)(dmso)]Cl_2$	1695	1580, 1530	1160	
$Pd(NH_3)_2(Guo\text{-}H^+)Cl$	1630	1600, 1533		
$[Pd(NH_3)_2(Guo)Cl]Cl$	1700	1585, 1535		330

[a]Measured in KBr disks

The down field shift of both H(2) and H(8) signals by about 0.5 ppm in the ^1H NMR spectrum of the complex as compared with the uncomplexed adenosine (Table II) is consistent with the participation of both N(1) and N(7) in coordination [19]. It is also evident from the ^{13}C NMR spectra (Table II) that the signals of all four carbons, C(2) C(6), C(5) and C(8), adjacent to both N(1) and N(7) atoms are donwfield shifted upon coordination, and this further supports the participation of both these nitrogens in coordination [11, 18, 24, 26].

In the complexes $[Pd(NH_3)_2(cyd)_2]Cl_2$ and $[Pd(NH_3)_2(cyd)(dmso)]Cl_2$, cytidine coordinates through its N(3) atom, as was evidenced by both ^1H and ^{13}C NMR spectra. Both H(5) and H(6) doublets shifted downfield, with the larger shift for H(5). This indicates that H(5) is closer to the coordination site on the ligand, probably N(3) [24] and this has been confirmed by the crystallographic investigations of interaction of Pt(II) with the analogous base 1-methylcytosine [27]. Also the downfield shifts observed for the C(2) and C(4) resonances, in contrast to the upfield shifts of the C(5) and C(6) signals, support coordination of the cytidine to palladium through N(3) [24].

The Complexes $Pd(NH_3)_2(nucl\text{-}H^+)Cl$ (nucl = ino, guo)

These complexes are insoluble in all common solvents and the information concerning their structure was deduced only from their chemical behavior and their IR spectra.

The preparation of these complexes from the complexes $[Pd(NH_3)_2(nucl)(dmso)]Cl_2$ and their reversible conversion to the complexes $[Pd(NH_3)_2(nucl)Cl]Cl$, suggested that the Pd–N(7) bonding, present in the former and the latter complexes, exists in these complexes too.

The IR spectra of the complexes give strong indications for the participation or not of the exocyclic oxygen atom of the 6th position in bonding with palladium. The shifting of the ν(C=O) to lower frequencies has been widely used as a criterion for the participation in bonding of this atom, in complexes of the proper nucleosides with Pd(II) and Pt(II) [19, 28]. The ν(C=O) frequency occuring at about 1700 cm^{-1} in the free ligands, is shifted to about 1625–1630 cm^{-1} upon metal complexation (see Table IV). In the complexes with no O(6) involvement in bonding, it remains practically at constant frequency. Thus in the complexes $Pd(NH_3)_2(nucl\text{-}H^+)Cl$ the ionized $O^-(6)$ atoms, following deprotonation of the N(1)–H imino proton seem to participate in bonding with palladium. The observed more pronounced shift (1595 cm^{-1}) [29] of the ν(C=O) stretching mode in the ionic sodium or potassium salts of guanosine, could be explained by the formation of a 100% ionic bond of the type $O(6)^-–Na^+(K^+)$ and it should be less, when the bond is more covalent in character. In view of the above data it is proposed that inosine and guanosine behave as bidentate O(6)N(7) ligands in a polymeric rather structure of the type:

Oxygen involvement in bonding, following deprotonation of the imino protons, has also been found in the crystal structure of *cis*-diammineplatinum a pyridone blue [30], where both O and N atoms bridge two platinum atoms. Kistenmacher *et al.* [31] have also found an O–Ag(I) interaction in the crystal structure of (nitrato) (1-methylcytosine) silver (I). More recently Bau *et al.* [32] unambiguously showed the participation of the exocyclic O(6) in coordination, in the crystal structure of a tetranuclear copper-(II)-inosone monophosphate-O-phenanthroline complex, where inosine acts as an O(6)N(7) bridging ligand with Cu–O(6) distance 1.956 Å [32].

Experimental

Materials

The nucleosides were from Fluka A.G. and used without further purification. *cis*-Dichlorodiammine-palladium(II) was from Johnson Matthey.

Methods

IR spectra were recorded in a JASCO-DS 701 G spectrophotometer. ^{1}H NMR spectra were recorded on a Varian T60 spectrometer. TMS was used as internal reference when dmso-d_6 was used as solvent, while in D_2O, DSS. ^{13}C NMR spectra were obtained on a Varian XL 100 NMR spectrometer operating in Fourier transform mode with proton noise decoupling at frequency 25.2 MHz. Chemical shifts were measured relative to internal dmso-d_6 or dioxane and converted to the TMS scale using $\delta^{\text{dmso-d}_6} = +39.6$ ppm and $\delta^{\text{dioxane}} = 67.4$ ppm. Conductivity measurements were performed using an E365B conductoscope, Metrohm, Herisau, Switzerland.

Microanalyses

These were performed in the Laboratories of the National Research Foundation of Greece in Athens by Dr. Mantzos.

Preparation of the Complexes

I. Complexes $[Pd(NH_3)_2(nucl)_2]Cl_2$ (nucl = ino, guo, cyd)

cis-Dichlorodiammine palladium(II) (*cis*-$Pd(NH_3)_2Cl_2$), 1 mmol, and the respective nucleoside, 2 mmol, were suspended in 50 ml water and stirred at room temperature for 4 h. The resulting yellow solution was filtered and roto evaporated to about 5 ml. The complexes were then precipitated with excess of acetone. ether (1:2). The yield was in the range of 90%.

II. Complexes $[Pd(NH_3)_2(nucl)(dmso)]Cl_2$ (nucl = ino, guo, cyd)

cis-Dichlorodiammine palladium(II) (*cis*-$Pd(NH_3)_2Cl_2$), 1 mmol and the respective nucleoside, 1 mmol, were suspended in 3 ml dmso-d_6 and stirred until complete dissolution. The ^{1}H NMR spectra of the solution indicated the presence of only one species in the solution and the complexes were precipitated with excess isopropanol.ether (1:2). The yield was in the range of 90%.

III. Complexes $Pd(NH_3)_2(nucl\text{-}H^+)Cl$ (nucl = ino, guo)

1 mmol of the respective complexes $[Pd(NH_3)_2(nucl)(dmso)]Cl_2$ was dissolved in 10 ml water and the solution was made alcaline to pH ≅ 10 with KOH 1 *N*. The precipitated complexes were filtered washed with water, ethanol and ether and dried at 75 °C under vacuum. Yield 65%.

IV. Complexes $[Pd(NH_3)_2(nucl)Cl]Cl$ (nucl = ino, guo)

1 mmol of the respective complexes $Pd(NH_3)_2(nucl\text{-}H^+)Cl$ was suspended in 7 ml 0.5 *N* HCl and stirred (at room temperature) until complete dissolution. The solution was filtered from any undissolved material and the complexes were precipitated with excess isopropanol:ether (1:2). Yield 60%.

V. Complex $\{[Pd(NH_3)_2Cl]_2ado\}Cl_2$

1 mmol *cis*-dichlorodiammine palladium(II) (*cis*-$Pd(NH_3)_2Cl_2$) was suspended in 15 ml water and to that was added 0.5 mmol adenosine dissolved in 10 ml water. The mixture was stirred at room temperature for 2 h, and the yellow precipitate formed, filtered, washed with water, ethanol, ether and dried at 65 °C under vacuum. Yield ≅ 70%.

Acknowledgement

I thank the University of Athens for financial support.

References

1 B. Rosenberg, E. Renshaw, L. Van Camp, J. Hardwick and J. Drobnick, *J. Bacteriology, 93*, 716 (1967).
2 B. Rosenberg, L. Van Camp, E. Grimlay and A. J. Thomson, *J. Biol Chem., 242*, 1347 (1967).
3 B. Rosenberg, *Platinum Metals Rev., 15*, 42 (1971)
4 R. M Izatt, J. J. Christensen and J. H. Rytting, *Chem. Rev , 71*, 439 (1971).
5 A. T Tu and M. J. Heller, *Metal ions in Biological Systems, 1*, 1 (1974).
6 L. G Marzilli, *Progress in Inorganic Chemistry, 23*, 256 (1976).
7 R. C. Harrison and C. A. McAuliffe, *Inorg. Persp. Biol Med., 1*, 261 (1978).
8 R. B. Martin, *Metal ions in Biological Systems, 8*, 56 (1979).
9 D. J. Hodgson, *Progress in Inorganic Chemistry, 23*, 211 (1976).
10 R. W. Gellert and R. Bau, *Metal ions in Biological Systems, 8*, 1 (1979).
11 D. J. Nelson, P. I Yeagle, T. I. Miller and R. B. Martin, *Bioinorg Chem , 5*, 353 (1976).
12 (a) M. C. Lim and R. B Martin, *J. Inorg. Nucl. Chem , 38*, 1911 (1976), *ibid., 38*, 1915 (1976)
13 I. Sovago and R. B Martin, *Inorg. Chem., 19*, 2868 (1980).
14 P. I. Vestues and R. B. Martin, *J. Am Chem. Soc., 103*, 806 (1981).
15 M. J. Cleare, *Coord. Chem Rev., 12*, 349 (1974).
16 S. Kirschner, A Maurer and C. Dragulescu, *J Clin Hematol. Oncol., 7*, 293 (1977).
17 A. J. Charlson, N. T. McArdle and E. C. Watton, *Inorg. Chim. Acta, 56*, L35 (1981).
18 N Hadjiliadis and G. Pneumatikakis, *Inorg Chim Acta, 46*, 255 (1980).
19 (a) G. Pneumatikakis, N. Hadjiliadis and T. Theophanides, *Inorg. Chim. Acta, 22*, L1 (1977).
(b) G. Pneumatikakis, N. Hadjiliadis and T. Theophanides, *Inorg. Chem , 17*, 915 (1978).
(c) N. Hadjiliadis and G. Pneumatikakis, *J Chem. Soc., Dalton*, 1691 (1978).
(d) G. Pneumatikakis, *Inorg. Chim Acta, 46*, 243 (1980).

20 G. Pneumatikakis and N. Hadjiliadis, *J. Chem Soc, Dalton,* 596 (1979).
21 N. Hadjiliadis, G. Pneumatikakis and R. Basosi, *Inorg Biochem., 14,* 115 (1981).
22 W. J. Gerry, *Coord Chem. Rev., 7,* 81 (1971)
23 A. J. Jones, D. M. Grant, M. W. Winkley and R. K. Robins, *J Am Chem. Soc, 92,* 4079 (1970).
24 J. Dehand and J. Jordanov, *J Chem. Soc., Dalton,* 1588 (1977).
25 K. Nakamoto, 'Infrared Spectra of Inorganic and Coordination Compounds'. J. Wiley and Sons, 1963.
26 H. Kozłowski and E. Matchzak-Jon, *Inorg. Chim Acta, 32,* 143 (1979)
27 C J. L. Lock, R. A. Speranzini and J. Powell, *Canad. J. Chem., 54,* 53 (1976).
28 N. Hadjiliadis and T Theophanides, *Inorg Chim Acta, 16,* 77 (1976).
29 A. J. Canty and R. S Tobias, *Inorg Chem., 18,* 413 (1979)
30 (a) J K. Barton, H. N. Rabinowitz, D. J. Szalda and S J. Lippard, *J. Am. Chem. Soc, 99,* 2827 (1977)
(b) J K. Barton, D. J Szalda, H. N Rabinowitz, J. V. Waszcazak and S. P. Lippard, *J. Am Chem Soc, 101,* 1434 (1979).
31 (a) L G. Marzilli, T. J Kistenmacher and M. Ross, *J Am. Chem. Soc., 99,* 2797 (1977)
(b) T. J Kistenmacher, M. Rossi and L. G. Marzilli, Inorg. Chem., 18, 240 (1979).
32 R. W. Gellert, B. E. Fischer and R Bau, *J Am Chem. Soc., 102,* 7812 (1980)