parison with **4** and **5**, both **14** and **15** reacted either with base or $NaBH_4$ to regenerate the alkoxide complexes **7** and **10**, respectively. Quite unlike their hydride analogues, however, **14** and **15** can undergo rapid isomerization. Thus the solution infrared spectrum of **14** shows ν(CO) and ν(NO) at 2009 and 1776 cm^{-1}, respectively, and isolating a solid from these solutions results in a mixture containing **14** and a (dominant) new complex with ν(CO) and ν(NO) at 2007 and 1782 cm^{-1}, which also appears to possess an associated perchlorate group. The ^1H NMR spectrum of **14** is also quite unlike that of **4** in that a signal attributable to the OH--O proton is not observed. Instead, only an OCH_3 singlet is observed at 3.36 ppm, exactly coincident with the singlet arising it free methanol is added to the solution. Extracting the NMR solution with D_2O results in the complete disappearance of the signal at 3.36 ppm, implying that it is indeed due to free methanol. Exactly the same behavior was exhibited by solutions made essentially from the isomer of **14**. Although we cannot be sure of the nature of the isomers of **14** and **15**, one possibility admitted by the above evidence consists of a relatively rapid loss of alcohol (possibly reversible) from the initially formed complexes in favor of a coordinated perchlorate complex solvated with the appropriate alcohol.

$$ReCl(ROH{\cdot}OClO_3)(CO)(NO)(PPh_3)_2 \rightleftarrows ReCl(OClO_3)(CO)(NO)(PPh_3)_2{\cdot}ROH$$

This particular behavior is not seen in **4** presumably because the hydride ligand renders the metal more class "b" in character, thereby favoring the alcohol complex over the isomer with the presumably harder perchlorate ligand.[13] If this argument has some validity it can probably also be used to explain why compound **6**, derived from **4** via dihydrogen elimination, appears to exist as a genuine perchlorate complex rather than as an alcohol cation with a hydrogen-bound perchlorate group. Despite the uncertainty in the solution structures of **14** and **15**, it seems from our preliminary observations that both can be used to generate further examples of the series $ReXY(CO)(NO)(PPh_3)_2$ via reaction in dichloromethane with crown ether solubilized salts, MY.[14]

Acknowledgment. The authors acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada.

Registry No. **1**, 98481-35-7; **2**, 98481-36-8; **3**, 98481-38-0; **4**, 98481-40-4; **5**, 98481-42-6; **6**, 98481-43-7; **7**, 98481-44-8; **8**, 98481-45-9; **9**, 98481-46-0; **10**, 98481-47-1; **11**, 98481-48-2; **12**, 98481-49-3; **13**, 98481-50-6; **14**, 98481-52-8; **15**, 98481-54-0; $ReH_2(NO)(PPh_3)_3$, 58694-74-9; D_2, 7782-39-0.

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Ruthenium(II)-6-Mercaptopurine Complex Synthesis and Solution Properties. Molecular and Crystal Structure of Bis(6-mercaptopurine)bis(triphenylphosphine)ruthenium(II) Chloride

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Received January 25, 1985

The preparations of the complexes $[Ru^{II}(6\text{-MP})_2(P(C_6H_5)_3)_2]Cl_2{\cdot}2C_2H_5OH{\cdot}2H_2O$ (**1**) (6-MP = 6-mercaptopurine), $[Ru^{II}(6\text{-MP-9-Me})_2(P(C_6H_5)_3)_2]Cl_2{\cdot}1.5H_2O$ (**2**) (6-MP-9-Me = 6-mercapto-9-methylpurine), $[Ru^{II}(6\text{-MP})(6\text{-MP-H})(P(C_6H_5)_3)_2]Cl$ (**3**) (6-MP-H = N(9)-deprotonated 6-mercaptopurine), and $[Ru^{II}(6\text{-MP-1-Me-9-Me})_2(P(C_6H_5)_3)_2]Cl_2{\cdot}H_2O$ (**4**) (6-MP-1-Me-9-Me = 1,9-dimethyl-6-mercaptopurine), together with the molecular and crystal structure of **1**, are reported. Complexes **1** and **2** were prepared from ethanol solution under nitrogen by treating $[Ru^{II}Cl_2(P(C_6H_5)_3)_3]$ with the stoichiometric amount of the mercapto ligand. Compound **1** crystallizes in the monoclinic system, space group $P2_1/a$ with a = 29.504 (4) Å, b = 16.848 (3) Å, c = 10.542 (2) Å, β = 97.78 (3)°, V = 5192 Å^3 (at 22 °C), Z = 4, D_{calcd} = 1.45 g cm^{-3}, and μ(Mo Kα) = 5.47 cm^{-1}. Intensities for 2991 reflections were collected by using the θ-2θ scan technique employing graphite-monochromatized Mo Kα radiation. The structure was solved by the Patterson method. Full-matrix least-squares refinement has led to final R and R_w values of 0.056 and 0.054, respectively. The structure contains $[Ru^{II}(6\text{-MP})_2(P(C_6H_5)_3)_2]^{2+}$ cations, chloride anions, and free water and ethanol molecules. The coordination sphere about the ruthenium(II) center is approximately octahedral. The two 6-MP molecules act as bidentate ligands via the S(6) and N(7) atoms and are protonated at N(1) and N(9). The two sulfur atoms are in trans positions. The Ru-S distances are 2.417 (4) and 2.447 (4) Å, respectively, and the Ru-N bond lengths average 2.156 (14) Å. The double-bond character of the C-S group is not significantly altered by coordination, and the purine system is essentially planar. The "bite" distance S--N(7) (average value 3.10 Å in the complex) is significantly shorter than in the free ligand (3.352 Å). Strong intermolecular and intramolecular stacking interactions occur between purine systems and between purine and phenyl rings. Water, ethanol molecules, chloride ions, and H-N(1) and H-N(9) are involved in a network of hydrogen bonds. The title complex in Me_2SO-d_6 was studied by ^1H and ^{31}P NMR spectroscopy. The H(2) and H(8) signals of **1** and **3** were assigned by selective deuteration. The ^1H NMR spectrum was monitored as a function of added base and/or added CH_3I. On addition of base to solutions of **1**, the H(8) signal was most affected, consistent with H-N(9) deprotonation. A complex series of reactions occurs on addition of CH_3I under strongly basic conditions, and **2** was not identified as one of the products. However, when mild basic conditions were used, a simpler process was observed on addition of CH_3I. When a slight excess of CH_3I was added to a mixture containing **1** and $NaHCO_3$, the methylation occurred at N(1) and N(9) and complex **4** was isolated in 50% yield. We speculate that the N(1) proton becomes sufficiently acidic on N(9)-alkylation for additional alkylation to proceed at N(1).

Introduction

The direct alkylation of 6-oxopurine leads to a mixture of products.[1] Acyclovir, an important drug that is an antiviral compound useful in the treatment of herpes, is a 9-alkylated 6-oxopurine.[1] We previously exploited the concept that a metal complex could act both as a protecting group and as an activator of purine alkylation by stabilizing the deprotonated form of the purine.[2] However, because of the essential impossibility of a 6-oxo

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0020-1669/85/1324-3903$01.50/0

group of purines forming strong bonds to metal centers, such molecules prefer to bind via N(9).[3] N(9) is sterically accessible and is the most nucleophilic site on deprotonated 6-oxopurines.[3] Thus the desired site for alkylation is typically blocked by metal coordination.

Nevertheless, 6-oxopurines are easily accessible via H_2O_2 oxidation of 6-thiopurines,[4] which in turn are easily prepared from 6-oxopurine precursors via treatment with P_2S_5.[5] It occurred to us that an inert complex of a 6-mercaptopurine could afford a route to 9-alkylated 6-oxopurines, if the ligand coordinated via N(7) and S(6). N(9) could be deprotonated and be available for reaction whereas N(7) would be protected.

Substituted purines like 6-mercaptopurine (6-MP) and 6-mercaptoguanine are also of interest because they are antitumor agents, particularly against leukemia.[6-9] In some cases metal complexes of these bases show higher anticancer activity than the free ligands.[10] Some authors have speculated that the anticarcinogenic activity of 6-MP may be related to its metal-binding properties.[11]

The X-ray structures of relevant metal complexes show that 6-MP or its derivatives act as bidentate ligands via the S(6) and N(7) donors or as a monodentate ligand via the S(6) atom. In spite of the large interest in 6-MP complexes, only four species have been investigated by X-ray analysis.[12] Furthermore, only two of these complexes have the purine moiety with the N(9) nitrogen atom (usually a powerful donor in metal–purine complexes) unsubstituted. Continuing our earlier interest in the alkylation of coordinated purines and in 6-MP complexes,[13] we have now extended our studies to Ru(II) complexes. This study has allowed us to evaluate the structural features and geometry of this new class of Ru(II) complexes and to assess the synthetic value of using Ru(II)–6-mercaptopurine compounds.

Experimental Section

Materials. Ruthenium(III) chloride trihydrate and triphenylphosphine (Aldrich) were used as received. 6-Mercaptopurine (6-MP) (Sigma) was recrystallized from ethanol before use. All other chemicals were reagent grade. ^1H and ^{31}P NMR spectra of samples in Me_2SO-d_6 were recorded on a Nicolet 360 NB spectrometer (360 MHz, ^1H) and on an IBM WP-200SY spectrometer (81.01 MHz, ^{31}P). The IR spectra, as Nujol mulls between CsI plates, were measured on a Perkin-Elmer Model 597 spectrometer.

Dichlorotris(triphenylphosphine)ruthenium(II) was obtained as described in ref 14. 6-Mercapto-9-methylpurine (6-MP-9-Me) was prepared by the methods of Robins and Lin[5] using 9-methylhypoxanthine as starting material.

Preparation of $[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]Cl_2\cdot 2C_2H_5OH\cdot 2H_2O$ (1) and $[Ru(6\text{-}MP\text{-}9\text{-}Me)_2(P(C_6H_5)_3)_2]Cl_2\cdot 1.5H_2O$ (2). 6-MP (or 6-MP-9-Me) (2 mmol) was mixed with ethanol (30 mL). The suspension was flushed with dry nitrogen for 30 min, and then $[RuCl_2(P(C_6H_5)_3)_3]$ (1 mmol) was added. The mixture was refluxed and stirred for 1 h under dry nitrogen. During the addition of the Ru component, the mixture started to become yellow. On heating, the solution became clear and golden yellow in color. On cooling to room temperature, the solution formed a yellow crystalline precipitate, which was separated from the mother liquor and washed twice with cold ethanol. The crude product, which is stable in alcoholic solution even in aerobic conditions, was recrystallized twice from ethanol. The solid was washed twice with cold ethanol and twice with ether and dried for 8 h under vacuum. The yield of the purified complex was ca. 70%. Anal. Calcd for **1** ($C_{50}H_{54}Cl_2N_8O_4P_2RuS_2$): C, 53.16; H, 4.82; N, 9.91. Found: C, 52.94; H, 4.95; N, 10.18. Anal. Calcd for **2** ($C_{48}H_{45}Cl_2N_8O_{1.5}P_2RuS_2$): C, 54.59; H, 4.30; N, 10.61. Found: C, 54.46; H, 4.26; N, 10.45. Conductivity measurements for Me_2SO solutions of **1** were in agreement with a 1:2 electrolyte. Crystals of **1** suitable for X-ray diffraction measurements were obtained by slow cooling of a hot ethanol solution of the purified complex.

Table I. Experimental Details of the X-ray Diffraction Study of $[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]Cl_2\cdot 2C_2H_5OH\cdot 2H_2O$

Crystal Data	
formula	$C_{50}H_{54}N_8O_4P_2S_2Cl_2Ru$
fw	1129.7
cryst system	monoclinic
space group	$P2_1/a$
a, Å	29.504 (4)
b, Å	16.848 (3)
c, Å	10.542 (2)
β, deg	97.78 (3)
Z	4
D_{calcd}, g cm^{-3}	1.45
color	yellow
habit	needle
dimens, mm	0.05 × 0.05 × 0.15
Measurement of Intensity Data and Structure Refinement	
radiation	Mo Kα (λ = 0.7107 Å)
monochromator	graphite cryst
method	θ–2θ
2θ limits, deg	$5 < 2\theta < 40$
data collcd	$\pm h,k,l$
linear abs coeff, cm^{-1}	5.47
no. of measd reflcns	2991
no. of obsd reflcns ($F > 3\sigma(F)$) used in the refinement	2215
R ($=\sum(\|F_o\| - \|F_c\|)/\sum\|F_o\|$)	0.056
R_w ($=[\sum w(\|F_o\| - \|F_c\|)^2/\sum wF_o^2]^{1/2}$)	0.054

Preparation of $[Ru(6\text{-}MP)(6\text{-}MP\text{-}H)(P(C_6H_5)_3)_2]Cl$ (3) (6-MP-H = N(9)-Deprotonated 6-Mercaptopurine). $[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]Cl_2\cdot 2C_2H_5OH\cdot 2H_2O$ (ca. 0.2 mmol) was suspended in water (20 mL). After addition of NaOH (ca. 0.4 mmol), the mixture was stirred overnight. The deprotonated complex was extracted by shaking the yellow suspension with chloroform in a separatory funnel. The yellow solution was brought to dryness, and the crystalline solid collected was dried under vacuum for some hours. Alternatively, the same complex was obtained by adding NaOH to a methanolic solution of the starting complex. The solution was stirred for 1 h before the solvent was completely removed. The solid was dried under vacuum, and then 30 mL of $CHCl_3$ was added. The suspension was refluxed with stirring and then filtered. The filtrate was brought to dryness in order to collect the complex. The crude $[Ru(6\text{-}MP)(6\text{-}MP\text{-}H)(P(C_6H_5)_3)_2]Cl$ complex was recrystallized from chloroform (yield 40%). Anal. Calcd for $C_{46}H_{37}ClN_8P_2RuS_2$: C, 57.3; H, 3.9; N, 11.6. Found: C, 57.3; H, 4.2; N, 11.6.

Preparation of $[Ru(6\text{-}MP\text{-}1\text{-}Me\text{-}9\text{-}Me)_2(P(C_6H_5)_3)_2]Cl_2\cdot H_2O$ (4) (6-MP-1-Me-9-Me = 1,9-Dimethyl-6-mercaptopurine). Method 1. A mixture of $[RuCl_2(P(C_6H_5)_3)_3]$ (0.2 mmol) and 6-MP-1-Me-9-Me[15] (0.4 mmol) in deaerated ethanol (10 mL) was maintained at reflux under nitrogen for 2 h. The resulting yellow solution was allowed to cool, and acetone (30 mL) was added. The solid formed was collected and recrystallized from ethanol/acetone (yield 70%). Anal. Calcd for $C_{48}H_{48}Cl_2N_8OP_2RuS_2$: C, 54.85; H, 4.60; N, 10.66. Found: C, 54.60; H, 4.75; N, 10.52.

Method 2. $[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]Cl_2$ (110 mg) was dissolved in Me_2SO (4 mL), and then $NaHCO_3$ (80 mg) and CH_3I (70 mg) were added. The mixture was stirred in the dark for 12 h at room temperature. The resulting mixture was then stirred under vacuum to remove unreacted CH_3I. Benzene (50 mL) was then added, and the white precipitate formed was removed by filtration. The volume of the solution was reduced under vacuum with gentle warming. When the solution was cooled to room temperature, a yellow solid separated. The product was collected, washed with acetone, and recrystallized twice from an ethanol/acetone mixture (yield 50%). Anal. Found: C, 54.28; H, 4.80; N, 10.41. The product has a ^1H NMR spectrum identical with that of the

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Table II. Final Non-Hydrogen Atomic Coordinates ($\times 10^4$) for $[Ru^{II}(6\text{-MP})_2(P(C_6H_5)_3)_2]Cl_2 \cdot 2C_2H_5OH \cdot 2H_2O$

atom	x/a	y/b	z/c	atom	x/a	y/b	z/c
Ru	1281 (0)	1640 (1)	1279 (1)	C(1B2)	2152 (3)	3198 (5)	1733 (9)
Cl(1)	4126 (2)	4805 (3)	4197 (5)	C(2B2)	2303 (3)	2829 (5)	2897 (9)
Cl(2)	4471 (2)	1721 (4)	6990 (5)	C(3B2)	2666 (3)	3152 (5)	3720 (9)
S(A)	1311 (1)	982 (2)	−746 (4)	C(4B2)	2878 (3)	3845 (5)	3378 (9)
S(B)	1115 (1)	2275 (3)	3252 (4)	C(5B2)	2727 (3)	4214 (5)	2214 (9)
P(1)	1644 (1)	2811 (3)	725 (4)	C(6B2)	2364 (3)	3891 (5)	1391 (9)
P(2)	1894 (1)	838 (3)	2188 (4)	C(1B3)	1270 (3)	3698 (6)	804 (9)
O(W1)	238 (4)	1159 (6)	−3313 (10)	C(2B3)	1301 (3)	4117 (6)	1953 (9)
O(W2)	−196 (4)	1607 (9)	4237 (14)	C(3B3)	1017 (3)	4770 (6)	2059 (9)
O(E1)	4240 (5)	2118 (12)	4258 (16)	C(4B3)	703 (3)	5003 (6)	1015 (9)
O(E2)	333 (6)	3613 (11)	5738 (15)	C(5B3)	673 (3)	4583 (6)	−134 (9)
N(1A)	773 (6)	−352 (11)	−1380 (13)	C(6B3)	957 (3)	3931 (6)	−240 (9)
N(3A)	307 (4)	−1008 (8)	−22 (16)	C(1B4)	1773 (3)	−231 (6)	2073 (8)
N(7A)	832 (4)	688 (8)	1659 (15)	C(2B4)	1526 (3)	−615 (6)	3017 (8)
N(9A)	349 (4)	−308 (9)	2046 (15)	C(3B4)	1360 (3)	−1386 (6)	2814 (8)
N(1B)	319 (5)	3164 (9)	3193 (14)	C(4B4)	1402 (3)	−1774 (6)	1666 (8)
N(3B)	−222 (15)	3432 (10)	1405 (18)	C(5B4)	1609 (3)	−1391 (6)	722 (8)
N(7B)	650 (4)	2195 (7)	443 (15)	C(6B4)	1774 (3)	−620 (6)	925 (8)
N(9B)	17 (5)	2755 (9)	−475 (16)	C(1B5)	2107 (3)	949 (6)	3913 (11)
C(2A)	478 (6)	−942 (10)	−1097 (20)	C(2B5)	1779 (3)	921 (6)	4747 (11)
C(4A)	462 (6)	−421 (11)	816 (19)	C(3B5)	1911 (3)	996 (6)	6063 (11)
C(5A)	752 (5)	191 (11)	617 (18)	C(4B5)	2371 (3)	1099 (6)	6545 (11)
C(6A)	939 (5)	263 (9)	−554 (19)	C(5B5)	2700 (3)	1127 (6)	5710 (11)
C(8A)	582 (6)	364 (12)	2490 (16)	C(6B5)	2568 (3)	1052 (6)	4394 (11)
C(2B)	−79 (6)	3503 (12)	2627 (24)	C(1B6)	2425 (3)	795 (5)	1458 (9)
C(4B)	55 (7)	2950 (11)	792 (19)	C(B6)	2750 (3)	216 (5)	1870 (9)
C(5B)	450 (6)	2597 (9)	1357 (19)	C(3B6)	3157 (3)	178 (5)	1337 (9)
C(6B)	617 (6)	2676 (10)	2615 (19)	C(4B6)	3240 (3)	719 (5)	393 (9)
C(8B)	378 (6)	2294 (11)	−616 (17)	C(5B6)	2915 (3)	1298 (5)	−19 (9)
C(1B1)	1783 (2)	2846 (5)	−950 (10)	C(6B6)	2508 (3)	1336 (5)	514 (9)
C(2B1)	1421 (2)	2721 (5)	−1926 (10)	C(1E1)	3773 (9)	2092 (16)	3725 (27)
C(3B1)	1490 (2)	2793 (5)	−3203 (10)	C(2E1)	3694 (8)	2462 (15)	2422 (27)
C(4B1)	1922 (2)	2990 (5)	−3505 (10)	C(1E2)	491 (11)	4343 (21)	6122 (36)
C(5B1)	2285 (2)	3115 (5)	−2529 (10)	C(2E2)	817 (12)	4791 (21)	5584 (32)
C(6B1)	2215 (2)	3043 (5)	−1252 (10)				

complex prepared by the superior method 1.

Collection of X-ray Diffraction Data. A well-shaped yellow prism measuring ca. 0.05 × 0.05 × 0.15 mm was selected and used for data collection on a Philips PW1100 automatic diffractometer. Lattice parameters were determined by the least-squares technique applied to the setting angles of 25 reflections. Unit cell constants and other crystal data are reported in Table I. Intensity data were collected at 22 ± 1 °C in the range $5° < 2\theta < 40°$ by using Mo Kα radiation monochromatized with a graphite crystal (λ = 0.71069 Å). The standard deviation of an intensity was calculated as follows: $\sigma(I) = [P + B_1 + B_2 + (0.01I)^2]^{1/2}$ where P is the total integrated peak count, B_1 and B_2 are the background counts, $I = P - (B_1 + B_2)$, and $0.01I$ is an empirical correction for unrealistically small standard deviations in strong reflections. Intensities were corrected for Lorentz–polarization effects. Three control reflections, monitored every 100 reflections, exhibited no significant deviations in intensity. No absorption correction was applied because of the small size of the crystal and the low value of the linear absorption coefficient. No extinction correction was made.

Structure Solution and Refinement. The systematic absences indicated the space group $P2_1/a$. The structure was solved by the Patterson method, and the positions of all the non-hydrogen atoms were determined by a series of three-dimensional Fourier and difference Fourier maps. Three cycles of full-matrix least-squares computations with isotropic thermal parameters for all the atoms lowered the R index to 0.082. The phenyl hydrogens were assigned a group isotropic temperature factor and allowed to ride on the corresponding carbon atoms with d(C–H) = 1.08 Å and equal H–C–C angles. The phenyl C–C bond distances were fixed at 1.395 Å and the C–C–C angles at 120°. A difference Fourier map calculated at this stage showed five of the eight purine hydrogen atoms. A series of least-squares cycles with anisotropic thermal parameters for Ru, Cl, N, O, and P atoms and the carbon atoms of 6-MP reduced the indexes R and R_w to 0.056 and 0.054, respectively. The five purine hydrogen atoms with thermal parameter fixed at U = 0.06 Å^2 were included in the refinement. The methyl and methylene protons of the alcohol molecules were allowed to ride on the corresponding carbon atom. The function minimized was $\sum w(|F_o| - |F_c|)^2$ with weights $w = 1.1217/(\sigma^2(F) + aF^2)$ where a was refined to 0.000692. Computations were performed with SHELX76.[16] The atomic scattering factors of C, H, N, O, P, S, and Cl were taken from ref 16; those of Ru were taken from ref 17. Both the $\Delta f'$ and $\Delta f''$ components of the anomalous dispersion correction were included for all the non-hydrogen atoms.[17] Final atomic coordinates with estimated standard deviations are reported in Table II. The structure factors as well as the thermal parameters are available as supplementary material.

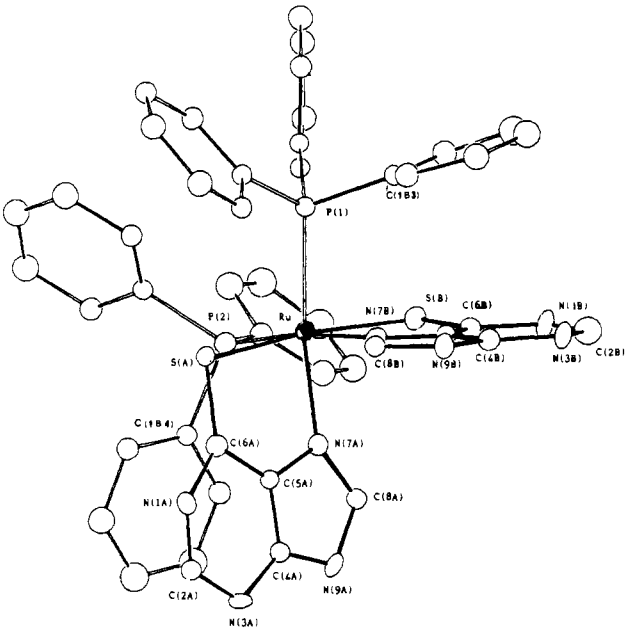

Figure 1. ORTEP drawing of the $[Ru^{II}(6\text{-MP})_2(P(C_6H_5)_3)_2]^{2+}$ cation in the structure of $[Ru^{II}(6\text{-MP})_2(P(C_6H_5)_3)_2]Cl_2 \cdot 2C_2H_5OH \cdot 2H_2O$ showing a partial atom-numbering scheme. The ellipsoids enclose 25% probability.

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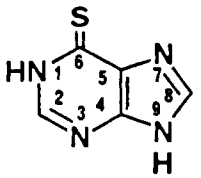
Table III. Selected Bond Distances (Å) and Angles (deg) for $[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]Cl_2 \cdot 2C_2H_5OH \cdot 2H_2O$

Ru–S(A)	2.417 (4)	Ru–P(2)	2.355 (4)
Ru–S(B)	2.447 (4)	Ru–N(7A)	2.15 (1)
Ru–P(1)	2.355 (4)	Ru–N(7B)	2.16 (1)
S(A)–Ru–S(B)	170.6 (1)	S(B)–Ru–P(2)	97.8 (2)
S(A)–Ru–N(7A)	85.3 (4)	N(7A)–Ru–N(7B)	83.1 (4)
S(A)–Ru–N(7B)	88.3 (4)	N(7A)–Ru–P(1)	169.2 (3)
S(A)–Ru–P(1)	95.4 (1)	N(7A)–Ru–P(2)	87.4 (3)
S(A)–Ru–P(2)	88.8 (1)	N(7B)–Ru–P(1)	86.1 (3)
S(B)–Ru–N(7A)	88.2 (4)	N(7B)–Ru–P(2)	170.3 (3)
S(B)–Ru–N(7B)	84.1 (4)	P(1)–Ru–P(2)	103.4 (2)
S(B)–Ru–P(1)	89.7 (2)		

	purine A	purine B
S–C(6)	1.672 (16)	1.674 (16)
N(1)–C(2)	1.38 (2)	1.37 (2)
C(2)–N(3)	1.30 (2)	1.31 (2)
N(3)–C(4)	1.36 (2)	1.37 (2)
C(4)–C(5)	1.37 (2)	1.37 (2)
C(4)–N(9)	1.39 (2)	1.36 (2)
C(5)–C(6)	1.40 (2)	1.36 (2)
C(5)–N(7)	1.37 (2)	1.37 (2)
N(7)–C(8)	1.34 (2)	1.30 (2)
C(8)–N(9)	1.37 (2)	1.34 (2)

Results and Discussion

Description of the Structure. The crystal structure of **1** contains $[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]^{2+}$ cations, chloride anions, and ethanol and water molecules. The structure of the complex cation is shown in Figure 1. (See supplementary material for the complete atom-labeling scheme). The metal center has a pseudooctahedral coordination geometry (see Table III). The two 6-MP molecules in each complex are chemically equivalent but crystallographically independent. These bidentate ligands bind via the S(6) and N(7) donor atoms with the S(6A) and S(6B) atoms trans to each other. No interaction exists between the metal atom and the N(1), N(3), or N(9) atoms. In fact the X-ray analysis shows one of the 6-MP molecules is still protonated at N(9) while no peak attributable to a hydrogen atom linked to N(9) atoms of the other ligand was found in the difference Fourier map. However, the values of the angles N(9)–C(4)–C(5) and C(4)–C(5)–N(7) are sensitive to protonation.[18] They are ~105.9 and ~110.7° for N(9)-protonated purines and ~110.8 and ~105.6° for N(7)-protonated purines, respectively. In the present structure, the mean value of the N(9)–C(4)–C(5) angle is 105.8 (17)° while the C(4)–C(5)–N(7) angles average 111.0 (16)°. Thus, it appears reasonable that both purine ligands are N(9)-protonated, but the significance of this conclusion is limited by the high esd. The C–S bond distances of 1.672 (16) and 1.674 (16) Å in the complex are close to the value of 1.679 (1) Å in the free ligand, and therefore the double-bond character is probably not altered much by coordination. On the basis of the values of the C(2)–N(1)–C(6) angles (127.0 (15) and 127.9 (16)°) in the complex and the Singh rule,[19] it is probable that both coordinated purines are protonated at N(1). These data and the coplanarity of all the atoms of each 6-MP molecule indicate that the coordinated purine systems can be formulated by the following canonical structure:



The "bite" distances S···N(7) in coordinated 6-MP (average value of 3.10 Å) are shorter than in the free base (3.352 Å), as has been observed in complexes of analogous ligands.[20] As a consequence, the Ru–N(7)–C(5) angle (average 110.7 (12)°) is large enough to allow extensive overlap of a ruthenium orbital with the N(7) orbitals.

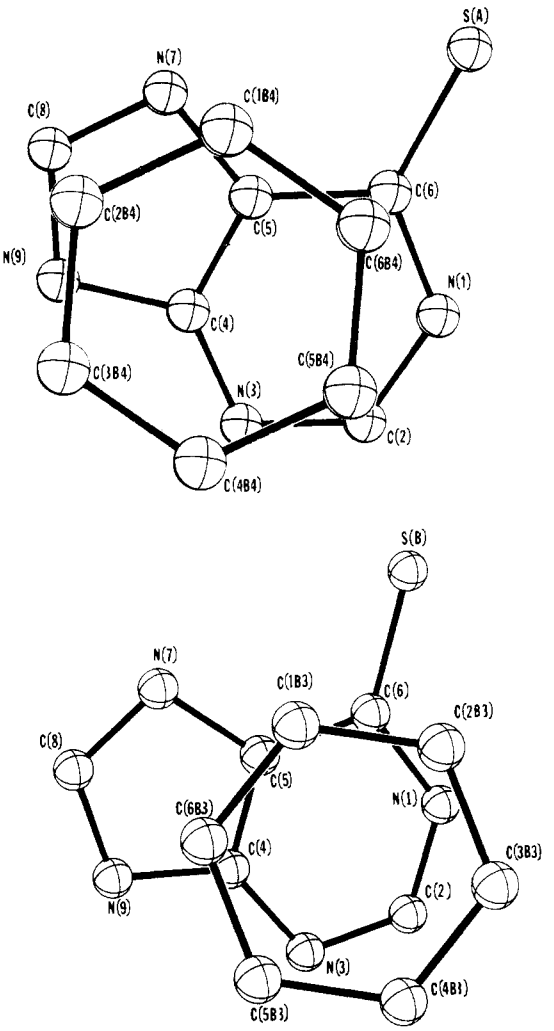


Figure 2. Perspective views of the intramolecular stacking interactions between the purines and the phenyl groups.

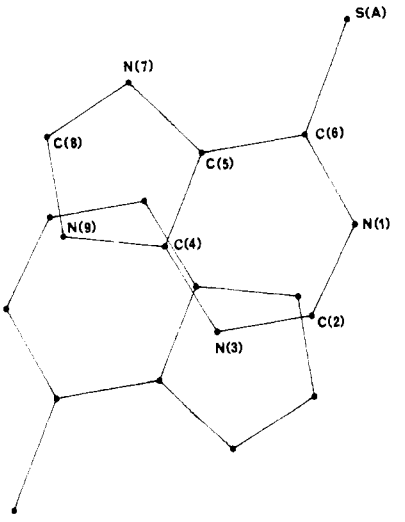


Figure 3. View of the intermolecular stacking interactions between the two centrosymmetric purines.

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Table IV. ^{1}H NMR Shift Data[a]

compd	H(8)[b]	H(2)[b]	triphenylphosphine o-H	triphenylphosphine m-H	triphenylphosphine p-H	9-Me	1-Me
$[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]^{2+}$	8.65	8.42	7.26	7.26	7.11		
$[Ru(6\text{-}MP)(6\text{-}MP\text{-}H)(P(C_6H_5)_3)_2]^{+}$	8.08	8.10	7.23	7.18	6.99		
$[Ru(6\text{-}MP\text{-}H)_2(P(C_6H_5)_3)_2]^{0}$	7.72	7.99	7.18	7.11	6.93		
6-MP, $P(C_6H_5)_3$	8.37	8.18	7.39	7.39	7.24		
$[Ru(6\text{-}MP\text{-}9\text{-}Me)_2(P(C_6H_5)_3)_2]^{2+}$	8.65	8.47	7.26	7.26	7.10	3.56	
$[Ru(6\text{-}MP\text{-}1\text{-}Me\text{-}9\text{-}Me)_2(P(C_6H_5)_3)_2]^{2+}$	8.88	8.84	7.26	7.23	7.14	3.60	4.02

[a] All shifts in ppm, spectra run in Me_2SO-d_6, Me_4Si internal standard. [b] Assigned by selective D exchange. A suspension of 6-MP in D_2O was refluxed for 5 h under nitrogen. After cooling, the solid was filtered, dried under vacuum, and stored under nitrogen. Deuterated 6-MP was used to prepare the Ru(II) complexes.

Strong intermolecular and intramolecular stacking interactions stabilize the crystal structure (see supplementary material for a crystal packing stereoview, the least-squares planes, and the dihedral angles between the planes). There are phenyl–purine intramolecular and purine–purine intermolecular interactions (Figures 2 and 3). The Ru–P–C angles for the phenyl rings involved in the intramolecular interactions (111.7 (4)° and 110.7 (3)° for Ru–P(1)–C(1B3) and Ru–P(2)–C(1B4), respectively) are clearly smaller than the remaining four relevant angles (average 118.8°). The intermolecular interaction between A purines involves two centrosymmetric systems and it is of the 6 to 5, 5 to 6, bottom to bottom type.[21]

Water and ethanol molecules and chloride ions present in the structure are not directly linked to the metal center but are involved in the network of hydrogen bonds (see supplementary material). Significant hydrogen-bonding interactions occur between the N(1A) atom and the $Cl(1)^-$ anion and between the N(1B) atom and one ethanol oxygen atom. Other hydrogen bonds involve the N(9) nitrogen atoms and the water or alcohol molecules.

IR Spectra. The infrared absorption at 1615 cm^{-1} in the spectrum of the free 6-MP ligand attributable to a ring mode[22] shifts to 1635 cm^{-1} in the spectrum of the complex. This value is in agreement with N(1) retaining its proton since otherwise a shift to low frequency would have been observed. Furthermore, similar shifts towards high energy are observed upon complexation in platinum(II)–6-mercaptopurine riboside complexes. Due to the M–S bond formation, the lone pair of electrons on the sulfur atom does not participate in the ring resonance.[23]

^{1}H and ^{31}P NMR Spectra. ^{1}H NMR spectrum of a 10^{-2} M solution of **1** in Me_2SO-d_6 (internal reference, Me_4Si) has two singlets at 8.65 (H(8)) and 8.42 (H(2)) ppm and two multiplets at ca. 7.26 and 7.11 ppm (phenyl protons) (Table IV). In the spectrum of a solution 2×10^{-2} M in 6-MP and in $P(C_6H_5)_3$, two singlets at 8.37 (H(8)) and 8.18 (H(2)) ppm and two multiplets at ca. 7.39 and 7.24 ppm were observed.

The ^{31}P NMR spectrum of **1** has a signal at 42.44 ppm downfield from the trimethylphosphate internal reference. The solution of the 6-MP and $P(C_6H_5)_3$ ligands gave a spectrum with one upfield signal at −9.22 ppm.

The ^{1}H NMR spectrum of a 2×10^{-2} M solution of the deprotonated complex **3** in Me_2SO-d_6 has two closely spaced singlets at about 8.10 ppm and multiplets at ca. 7.23 and 6.99 ppm.

On addition of dry ethanolamine or sodium ethoxide to a Me_2SO solution of **1**, the H(8) and H(2) resonances shifted upfield (see Figure 4). This effect is larger for the H(8) than for the H(2) signal, and the H(8) signal is upfield in respect to H(2) for an ethanolamine/complex molar ratio greater than 1. Above a titrant/complex molar ratio of 2, the resonances of both the H(2) and H(8) protons undergo very small shifts.

Solution NMR studies clearly show that **1** is inert to substitution by either 6-MP or $P(C_6H_5)_3$. There is no evidence for any uncoordinated $P(C_6H_5)_3$ in solutions of **1**. On addition of a base ($NH_2CH_2CH_2OH$ or sodium ethoxide), upfield shifts of the ^{1}H NMR resonances of the purine at ca. 8.5 ppm and smaller upfield shifts of the $P(C_6H_5)_3$ ^{1}H NMR resonances were observed. These results are consistent with the removal of just two protons from the complex. These protons very probably are the N(9) protons since at the beginning of the titration H(8) (identified by selective deuteration at C(8), (see supplementary material) is downfield to H(2) but is upfield to H(2) in the dideprotonated complex. Up to a titrant/complex molar ratio of 20, no further deprotonation could be detected, indicating a very high value of the $pK_{N(1)}$ constant for the coordinated 6-MP-H in Me_2SO.

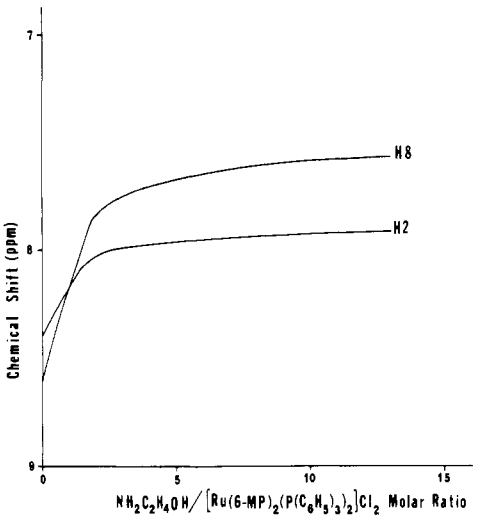

Figure 4. Dependence of the H(8) and H(2) resonances of $[Ru(6\text{-}MP)_2(P(C_6H_5)_3)_2]Cl_2 \cdot 2C_2H_5OH \cdot 2H_2O$ (in Me_2SO-d_6) on added ethanolamine.

Thus, complex **1** satisfied the criteria of containing 6-MP bound by N(7) and S(6) (X-ray results), of being inert to substitution, and of being susceptible to deprotonation. Treatment of **1** or **2** in Me_2SO with CH_3I, in the absence of added base, did not give evidence of any substantial reaction. In the presence of a strong base, such as $CH_3CH_2O^-$, multiple products were formed from **1** as evidenced by a very complex pattern in the ^{1}H NMR spectra region 8.7–8.9 ppm. Cleaner reactions appeared to occur if $NaHCO_3$ was used as the base. However, with this weak base, we still obtained a mixture of products unless the CH_3I/**1** ratio was at least ca. 4. In this case, **4** was formed in good yield (see Experimental Section). Since compound **2** is also alkylated under basic conditions, we suspected that N(1)H of coordinated 6-MP-9-Me is sufficiently acidic to be deprotonated and alkylated under the reaction conditions. Indeed, $NaHCO_3$ induces pronounced changes in the 7–9 ppm region of the spectrum, similar to those observed in the quantitative study of the influence of base on the ^{1}H NMR spectrum of **1** described above.

Thus, although we were able to avoid N(7) and S(6) alkylation by coordination of these sites to Ru(II), the metal center probably increases the acidity of N(1)H sufficiently to make N(1)-alkylation competitive with N(9)-alkylation. Our results suggest that this approach may be successful if bulkier ligands are coordinated to the Ru(II) center, especially if larger alkylating agents are employed. Thus, the results reported here are encouraging.

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Acknowledgment. This work was supported by NIH Grant GM 29222 (to L.G.M.). R.C. thanks the NATO Science Fellowships Program for a grant. We also thank the NSF for a departmental grant to Emory toward the purchase of the 360-MHz NMR spectrometer.

Registry No. **1**, 98218-98-5; **2**, 98218-99-6; **3**, 98301-50-9; **4**, 98219-00-2; 6-MP, 50-66-8; $[Ru(6\text{-MP-H})_2(P(C_6H_5)_3)_2]$, 98219-01-3; $[RuCl_2(P(C_6H_5)_3)_3]$, 15529-49-4.

Supplementary Material Available: Tables of bond lengths, bond angles, parameters for the hydrogen atoms, thermal temperature factors for the nonhydrogen atoms, observed and calculated structure factors, stacking distances, least-squares planes and dihedral angles between the planes, and hydrogen bonds. Figures of ^1H NMR spectra (downfield region) of $[Ru^{II}(6\text{-MP})_2(P(C_6H_5)_3)_2]^{2+}$, $[Ru^{II}(6\text{-MPD})_2(P(C_6H_5)_3)_2]^{2+}$ (6-MPD = 8-deuterated 6-mercaptopurine), and $[Ru^{II}(6\text{-MP-H-8D})_2(P(C_6H_5)_3)_2]$ (6-MP-H-8D = N(9)-deprotonated 8-deuterated 6-mercaptopurine) complexes, the complete atom-labeling scheme for **1**, and the stereoview of the unit cell packing for $[Ru^{II}(6\text{-MP})_2(P(C_6H_5)_3)_2]Cl_2\cdot 2C_2H_5OH\cdot 2H_2O$ (25 pages). Ordering information is given on any current masthead page.

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Comparative Structural and Ligand-Exchange Properties of Organocobalt B_{12} Models. Improved Synthetic Procedures for Costa Models and the Structures of Two Pyridine Complexes with Methyl and Neopentyl Ligands

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Received March 12, 1985

Several organocobalt complexes containing the uninegative equatorial ligand $N^2,N^{2\prime}$-propanediylbis(2,3-butanedione 2-imine 3-oxime) ((DO)(DOH)pn) have been prepared. These complexes of the type [LCo((DO)(DOH)pn)R]X (where X = ClO_4, PF_6 and L = H_2O, py) contain several R ligands (*i*-C_3H_7, *neo*-C_5H_{11}, $CH_2CO_2CH_3$, CH_2CF_3, CH_2Br, and $CH_2Si(CH_3)_3$) which were previously unknown in (DO)(DOH)pn complexes although complexes with *i*-C_3H_7 and *neo*-C_5H_{11} are known with a related equatorial ligand. The py ligands in [pyCo((DO)(DOH)pn)R]ClO_4 complexes dissociate at rates slightly greater than in the comparable cobaloxime complexes in CH_2Cl_2 at 25 °C. The relative dependences on R are almost identical in the two series with identical R but with 4-CN-py as the leaving ligand for the cobaloxime series. The dissociation rate increases by 10^5 across the series $CH_2CO_2CH_3$, CH_2CF_3, CH_2Br, CH_3, $CH_2Si(CH_3)_3$, $CH_2C_6H_5$, CH_2CH_3, *neo*-C_5H_{11}, and *i*-C_3H_7. The three-dimensional structures of [pyCo((DO)(DOH)pn)R]PF_6, R = CH_3 (I) and R = *neo*-C_5H_{11} (II), were determined. Crystallographic details follow. I: $C_{17}H_{27}CoF_6N_5O_2P\cdot C_3H_6O$, $P2_1/c$, a = 7.182 (3) Å, b = 12.557 (3) Å, c = 29.848 (6) Å, β = 99.62 (3)°, D(calcd) = 1.49 g cm^{-3}, Z = 4, R = 0.048 for 3670 independent reflections. II: $C_{21}H_{35}CoF_6N_5O_2P$, $P2_12_12_1$, a = 17.154 (3) Å, b = 8.011 (2) Å, c = 19.726 (3) Å, D(calcd) = 1.45 g cm^{-3}, Z = 4, R = 0.050 for 2863 independent reflections. The most unusual feature of the structures is that the py ligand α-H atoms lie over the five-membered Co–N–C–C–N chelate rings. The py ligand probably adopts this orientation to minimize steric interactions with the puckered Co–N–C–C–C–N ring. In I, the central C of the ring is above the plane toward the alkyl group whereas in II it is toward the py ligand. This difference may also arise from a steric effect. Additionally, the Co–N(py) bond distances are slightly longer (0.04 Å) in I and II than in the analogous cobaloximes but the Co–C bond distances appear insensitive to the nature of the equatorial ligand. Finally, the (DO)(DOH)pn ligand deviates from planarity to a much greater extent than cobaloximes and this feature, along with the longer Co–N bonds, makes [pyCo((DO)(DOH)pn)R]X complexes somewhat better than cobaloximes as structural models for coenzyme B_{12}.

Introduction

Recent advances in our understanding of the role of Co–C bond homolysis and of the radicals formed in coenzyme B_{12} dependent processes have been reviewed.[1-6] The B_{12} system itself (i.e. the cobalamins) is comprised of complex molecules with a pseudooctahedral geometry at Co. The equatorial coordination plane is occupied by four corrin N atoms, and the axial positions are occupied by an alkyl group (5′-deoxyadenosyl in coenzyme B_{12}[7] and methyl in the other enzyme cofactor methyl B_{12}[8]). Small organocobalt complexes have played an important role in giving insight into the more complex chemistry of B_{12}.[1-5] Extensive background information is available on the influence of the axial ligands in only one class of B_{12} models, namely cobaloximes where the equatorial ligand system contains two dioximato ligands, such as dimethylglyoximato (DH). We have recently reviewed the extensive solution and structural chemistry of complexes of the type $LCo(DH)_2X$.[3]

However, attempts at obtaining as detailed information on other, perhaps more realistic models, have not been so successful. For example, although information[9] is available on Co–C bond energies on the system pyCo(saloph)R (where saloph = dianion of bis(salicylidene)-*o*-phenylenediamine and py = pyridine), only three such compounds have been structurally characterized.[10,11] There appears to be a clear relationship between the length of the Co–N bond, the Co–C bond energy, and the L ligand dissociation rate.[9,10] Again, the saloph complexes are not particularly tractable because six-coordinate species are difficult to obtain as pure crystalline materials and, furthermore, ligand dissociation is facile and proceeds at rates often too rapid even for evaluation by dynamic NMR methods. Ligand dissociation rates for $LCo(saloph)CH_3$ exceed those for $LCo(DH)_2CH_3$ by a factor of ca. 10^{11} (see ref 11). In contrast, although exact comparisons are not possible,

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