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Seven Membered Chelate Rings in Copper(II) Complexes with Spermidine

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Cu(spermidine)X_2 complexes (spermidine = $NH_2(CH_2)_3NH(CH_2)_4NH_2$, X = I, Br, Cl) have been prepared and studied by I.R. and U.V. spectroscopy and the single crystal analysis of the bromine derivative has been carried out. Spermidine chelates to copper atom forming a seven-membered ring fused with a six-membered one; the complexes are five coordinate with a square-pyramidal geometry.

Introduction

Coordination properties of polyamines present in biological materials are important factors for the role they play in various cell processes [1]. The antitumor activity in the presence of plasma amine oxidase, for example, requires a terminal NH_2–$(CH_2)_3$–NH group and at least three carbon atoms between the primary and secondary amino groups [2], while the antimicrobial action is based on the ability to serve as effective chelating agents [3].

Recently the coordinating capability of spermidine ($NH_2(CH_2)_3NH(CH_2)_4NH_2$) towards copper(II) cation has been studied in aqueous solution; thermodynamic data suggested the bonding of all the nitrogen atoms to the metal ion, with the formation of a seven-membered chelate ring fused with a six-membered one [4].

To deepen the understanding of the coordinating properties of these polyamines we have examined the complexes Cu(spermidine)X_2 (X = Cl, Br, I). Electronic spectra, both in the solid state and in ethanol solution, are reported in Table I together with conductivity data. The I.R. and U.V. spectra of the three compounds are very similar; in the solid state the U.V. maximum shifts to higher frequencies passing from Cl to Br to I, as already observed in other five coordinate copper(II) complexes [5], and its frequency is close to that previously observed in CudptBr_2 [6] and in Cudpt$(NCS)_2$ [7], where dpt = $NH_2(CH_2)_3NH(CH_2)_3NH_2$. These compounds were assumed to have a square pyramidal coordination polyhedron and, for the last one, this geometry has been confirmed by an X-ray structural analysis [8]. In ethanolic solution the three Cu(spermidine)X_2 complexes practically behave as no electrolytes and the absorption spectra are essentially identical, suggesting the preservation of a square pyramidal geometry; the ϵ value decreases in the order I > Br > Cl indicating some contributions from the polarizable halogens.

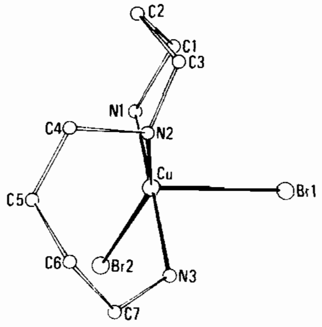
In order to get detailed structural information an X-ray single-crystal analysis was carried out on the bromide derivative, which gave suitable crystals. The structure consists of discrete molecules; three of them are crystallographically independent and are slightly

TABLE I. Electronic Spectra.

	Solid (kK)	Ethanol Solution	A cm^2 Ω^{-1} mol^{-1} in Ethanol
Cu(spermidine)Cl_2	15.0	15.9(195)	17.0
Cu(spermidine)Br_2	15.4; 28.6	15.7(295)	18.5
Cu(spermidine)I_2	15.6; 26.7	15.6(310)	20.0

TABLE II. Bond Distances and Angles. J = 1, 2, 3 refer to the three independent molecules.

	J = 1	J = 2	J = 3
Br(J1)–Cu(J)	2.65(1)	2.62(1)	2.70(1)
Br(J2)–Cu(J)	2.52(1)	2.51(1)	2.48(1)
Cu(J)–N(J1)	1.95(2)	1.94(2)	2.01(2)
Cu(J)–N(J2)	2.03(4)	2.06(3)	2.04(2)
Cu(J)–N(J3)	1.96(2)	2.05(2)	1.99(2)
N(J1)–C(J1)	1.52(3)	1.50(3)	1.44(4)
N(J2)–C(J3)	1.62(4)	1.44(4)	1.51(3)
N(J2)–C(J4)	1.41(5)	1.54(5)	1.41(4)
N(J3)–C(J7)	1.55(5)	1.48(4)	1.47(4)
C(J1)–C(J2)	1.44(6)	1.56(6)	1.57(4)
C(J2)–C(J3)	1.38(4)	1.54(4)	1.52(5)
C(J4)–C(J5)	1.60(4)	1.51(4)	1.65(4)
C(J5)–C(J6)	1.47(4)	1.50(3)	1.53(5)
C(J6)–C(J7)	1.60(6)	1.57(5)	1.51(4)
Br(J2)–Cu(J)–Br(J1)	105.8(5)	99.7(4)	104.7(5)
Br(J2)–Cu(J)–N(J1)	88.1(6)	89.5(6)	88.9(6)
Br(J2)–Cu(J)–N(J2)	151.2(8)	152.5(7)	153.7(8)
Br(J2)–Cu(J)–N(J3)	87.2(8)	89.1(6)	89.5(7)
Br(J1)–Cu(J)–N(J1)	93.7(7)	93.1(8)	93.7(6)
Br(J1)–Cu(J)–N(J2)	103.0(9)	107.6(7)	101.5(9)
Br(J1)–Cu(J)–N(J3)	86.4(8)	88.3(8)	87.8(8)
Cu(J)–N(J1)–C(J1)	117.8(15)	116.6(15)	121.3(21)
Cu(J)–N(J2)–C(J3)	117.0(25)	118.3(24)	114.9(15)
Cu(J)–N(J2)–C(J4)	112.6(20)	108.0(17)	116.0(21)
Cu(J)–N(J3)–C(J7)	121.3(17)	119.4(13)	122.6(22)
N(J1)–Cu(J)–N(J2)	89.4(10)	93.0(9)	92.1(9)
N(J1)–Cu(J)–N(J3)	175.2(10)	178.2(7)	178.0(11)
N(J1)–C(J1)–C(J2)	114.0(30)	111.4(27)	109.7(21)
N(J2)–Cu(J)–N(J3)	95.3(12)	87.8(9)	88.8(9)
N(J2)–C(J3)–C(J2)	115.6(24)	115.1(22)	116.0(29)
N(J2)–C(J4)–C(J5)	109.5(29)	112.0(28)	112.5(21)
N(J3)–C(J7)–C(J6)	106.5(24)	110.9(21)	111.8(22)
C(J1)–C(J2)–C(J3)	113.3(32)	109.1(26)	111.0(23)
C(J3)–N(J2)–C(J4)	110.7(27)	110.6(24)	109.3(20)
C(J4)–C(J5)–C(J6)	120.4(22)	118.1(20)	108.0(31)
C(J5)–C(J6)–C(J7)	110.3(30)	113.2(29)	114.5(27)



different both in bonding parameters and in the conformation of chelate rings. A representative view of the molecule with atoms labelling is given in Fig. 1; values of bond distances and angles are given in Table II. The coordination polyhedron is close to square pyramidal with Br(2) and nitrogen atoms on the basal plane and Br(1) in apical position; accordingly Cu–Br(1) bond lengths are significantly longer than Cu–Br(2) ones; the values of Cu–N distances fall in the expected range 1.95–2.05 Å; the differences observed among the values of some C–N and C–C bonds are hardly significant because of the high thermal motion of these atoms; the widening of bond angles at C(5) and C(6) atoms is remarkable and is the probable consequence of ring strains.

The six-membered rings adopt a chair conformation; the seven membered rings have the N–C amine bonds almost coplanar but divergent; copper atoms are displaced about 1.1–1.4 Å from this plane and the values of the torsion angles at Cu–N(2) and Cu–N(3) bonds are around 80°; the torsion angles at C(5)–C(6) are much higher (105–109°) than those at the other carbon–carbon single bonds (60–71°); this peculiarity was also present in the seven-membered chelate ring of copper(II) spermine perchlorate (spermine = $NH_2(CH_2)_3NH(CH_2)_4NH(CH_2)_3NH_2$) [9].

Since putrescine does not chelate to copper(II) to give stable complexes both in solution and solid state [10], the presence of the seven-membered chelate ring in the complexes with spermine and spermidine suggest that its stability is enhanced by the presence of fused rings. Further investigations on the derivatives of omospermidine and of N-3-aminopropyl-1,5-diaminopentane are in progress to better elucidate this problem.

Experimental

The amine spermidine was obtained commercially. The solid compound Cu(spermidine)Cl_2 was prepared by adding an alcoholic solution of $CuCl_2$ to a methanolic solution of amine in a 1/1 molar ratio. After the solution had been concentrated a small amount of isopropanol was added and the solution was then cooled. The product was recrystallised from ethanol. The compounds Cu(spermidine)Br_2 and Cu(spermidine)I_2 were obtained from an alcoholic solution of Cu(spermidine)Cl_2 by adding a hot solution of either KBr or KI. The complexes crystallised on cooling and were recrystallised from ethanol. All the compounds gave satisfactory C, H, N, Cu analyses.

Electronic and I.R. Spectra

Absorption spectra were recorded at room temperature with a Beckmann DK-2A spectrophotometer using 1 cm silica cells. Reflectance spectra were obtained by a method analogous to that reported by Venanzi *et al.* [11].

The I.R. spectra were recorded on a Perkin-Elmer 457 spectrophotometer, the solids being examined as Nujol mulls between potassium bromide plates.

Conductivity Measurements

Conductivity data were obtained by use of a WTW LBR conductometer, the cell being thermostatted at 25 ± 0.1 °C. Solutions were *ca.* 10^{-3} *M*.

X-ray Analysis

Crystal data: $C_7H_{19}Br_2CuN_3$, M = 368.8. Monoclinic: a = 11.73(2); b = 15.39(2); c = 24.33(3) Å; β = 120.6(4)°; U = 3781 Å^3; D_m (flotation) 1.92 cm^{-3}; Z = 12; D_c = 1.94 cm^{-3}; space group $P2_1/c$ from systematic absences. MoKα radiation λ = 0.7107 Å, μ(MoKα) = 67.0. Unit cell parameters and their estimated standard deviations were determined by a least-squares fit to 23 values of θ, χ, ϕ accurately measured by use. of a narrow counter aperture. A prysmatic crystal of dimensions 0.35 × 0.28 × 0.25 mm was mounted on a Siemens AED automatic single crystal diffractometer with the c axis nearly coincident with the polar ϕ axis of the goniostat. A total of 4735 independent intensities up to $2\theta \leqslant 45°$ was recorded, by a procedure similar to that previously described [12], using the θ–2θ scan technique. The value of I and $\sigma(I)$ (from counting statistics) were corrected for Lorentz-polarization effects but not for absorption or extinction. The reflections which had a negative net intensity count were reset to zero; 2888 obey the condition $F_0 \gg 2\sigma(F_0)$ and were used in subsequent calculations.

The position of the bromine and copper atoms were obtained by an E map calculated with the 282 reflections with highest E s, using the Multan set of programs [13].

A successive three-dimensional Fourier map gave the positions of all the remaining non hydrogen atoms. The R factor, obtained by use of the overall temperature and scale factors derived from a Wilson plot was 0.24 for 2888 observed reflections. Refinement of the structure was carried out by block diagonal least-squares method. Throughout the refinement the quantity minimized was $\Sigma w(\Delta F)^2$, where $w = 1/(320 + F_0 + 0.0022\, F_0^2)$.

Atomic scattering factors were taken from Cromer and Waber [14].

Seven cycles of isotropic refinement reduced R to 0.15; refinement was terminated after five cycles using anisotropic parameters for bromine and copper atoms. The final R factor is 0.087 for 2888 refined reflections.

Final structural parameters are given in Table III; observed and calculated structure factors are listed in a Table available from the Editor.

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TABLE III. Final Structural Parameters.

	X/*a*	Y/*b*	Z/*c*	B11	B22	B33	B12	B13	B23
BR11	4635(2)	2658(2)	814(1)	2.60(10)	8.32(16)	3.81(12)	1.77(21)	3.82(18)	−1.53(22)
BR12	1428(3)	4082(2)	−507(1)	4.74(12)	4.35(11)	4.31(13)	1.87(19)	4.63(20)	1.24(19)
BR21	8122(2)	3221(2)	3969(1)	2.99(10)	8.18(16)	3.53(12)	1.94(21)	4.05(18)	2.48(22)
BR22	5650(2)	4598(2)	2472(1)	2.77(9)	4.17(10)	4.67(12)	1.66(17)	3.77(17)	0.59(18)
BR31	2041(2)	3680(2)	3725(1)	2.71(10)	6.48(14)	5.94(15)	2.08(20)	4.95(20)	2.62(23)
BR32	3374(3)	2379(2)	2686(1)	7.07(16)	6.67(15)	3.71(12)	−4.52(26)	5.41(24)	−2.19(22)
CU1	2186(2)	3126(2)	460(1)	2.02(10)	4.40(13)	3.35(13)	0.36(20)	3.09(19)	0.06(21)
CU2	7483(2)	3513(2)	2784(1)	2.41(11)	3.31(11)	3.24(12)	0.57(18)	3.55(19)	0.57(19)
CU3	4139(2)	2843(2)	3798(1)	2.26(11)	3.67(12)	3.31(12)	−0.61(19)	2.92(19)	0.38(20)

	X/*a*	Y/*b*	Z/*c*	B
N11	1390(18)	2142(11)	−120(9)	3.69(35)
N12	1855(28)	2514(17)	1105(13)	7.99(61)
N13	2970(22)	4168(14)	980(11)	5.38(48)
N21	6179(17)	2585(11)	2454(9)	3.50(34)
N22	8794(21)	2830(14)	2620(10)	5.09(45)
N23	8820(19)	4518(11)	3110(9)	3.93(37)
N31	4888(18)	3925(11)	3640(9)	3.78(37)
N32	5463(21)	2887(14)	4755(10)	4.92(44)
N33	3413(21)	1750(13)	3934(10)	4.95(45)
C11	1807(31)	1236(19)	154(15)	6.31(66)
C12	1415(33)	1007(20)	609(16)	7.51(72)
C13	2077(30)	1473(19)	1173(15)	6.89(64)
C14	617(31)	2734(19)	1035(15)	6.63(68)
C15	386(31)	3760(19)	926(15)	6.28(67)
C16	1384(30)	4374(19)	1380(15)	7.03(64)
C17	2103(31)	4857(20)	1057(15)	6.60(70)
C21	6692(29)	1681(18)	2650(14)	5.74(62)
C22	7580(31)	1405(19)	2374(15)	6.01(66)
C23	8902(29)	1909(18)	2726(14)	5.51(62)
C24	8482(32)	3041(20)	1938(15)	6.72(70)
C25	8134(25)	3986(16)	1772(12)	4.63(51)
C26	9151(28)	4656(17)	2173(14)	5.25(59)
C27	8832(25)	5136(16)	2647(12)	4.50(52)
C31	5216(27)	4673(17)	4049(13)	5.17(59)
C32	6310(28)	4426(18)	4746(14)	5.39(58)
C33	5777(28)	3789(18)	5040(13)	5.43(59)
C34	6651(29)	2425(19)	4966(14)	5.82(64)
C35	6436(29)	1531(18)	4549(14)	5.71(62)
C36	5474(29)	943(18)	4626(14)	5.86(62)
C37	4094(29)	911(18)	4050(14)	5.93(61)

[a] The anisotropic temperature factor is of the form: $\exp[-(1/4)(B_{11}h^2a^{*2} + B_{22}k^2b^{*2} + B_{33}l^2c^{*2} + B_{12}hka^*b^* + B_{13}hla^*c^* + B_{23}klb^*c^*)]$.

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