In all cases protonation and "metalation" cause downfield shifts of each ring proton as would be expected. The 2,6 protons are further downfield than the 3,4 protons. Greater differences in the chemical shifts of H_a and H_b occur upon protonation than upon metalation because of stronger bonding between oxygen and proton than between oxygen and platinum.

Experimental

The preparation and properties of the olefin complexes[1,11] and of the uncomplexed 4-substituted pyridine N-oxides[12] have been reported previously.

N.m.r. Spectra.—Spectra of solutions containing an internal standard were obtained on a Varian Associates A-60 spectrometer at 34–35°. The audiooscillation side-band technique was used for calibration. In addition, spectra of the olefin complexes were obtained in the absence of internal standard because prolonged contact with the standard caused decomposition of the complexes.

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[11] L. Garcia, S. I. Shupack, and M. Orchin, *Inorg. Chem.*, **1**, 893 (1962).
[12] E. Ochai, *J. Org. Chem.*, **18**, 534 (1953).

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Stereochemistry of Complexes of Multidentate Ligands. I. Isomers of the Dichloro-2,9-diamino-4,7-diazadecanecobalt(III) Ion

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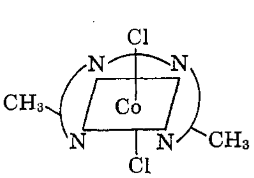
The preparation of the ligand 2,9-diamino-4,7-diazadecane (to be referred to as *l,l*-α,α'-dimethyltriethylenetetramine) is reported. The cobalt(III) complex ion dichloro-*l,l*-α,α'-dimethyltriethylenetetraminecobalt(III) can exist in three possible geometric isomers. All three were prepared. The configurations of these isomers were assigned on the basis of n.m.r. data.

Introduction

A cobalt(III) complex of triethylenetetramine was first prepared by Basolo.[1] The stereochemistry of the dichlorotriethylenetetraminecobalt(III) ion has been further studied by other investigators.[2] Most recently Sargeson and Searle[3] reported the separation of the two *cis* isomers of the dichlorotriethylenetetraminecobalt(III) ion. No complexes of other straight-chain tetramines have been reported in the literature. The present investigation is concerned with the cobalt(III) complex of an analogous ligand, *l,l*-α,α'-dimethyltriethylenetetramine. Like the corresponding triethylenetetramine complex the dichlorodimethyltriethylenetetraminecobalt(III) ion has three possible geometric isomers.



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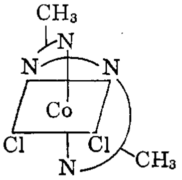

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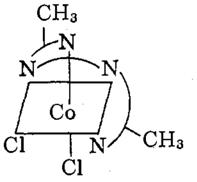
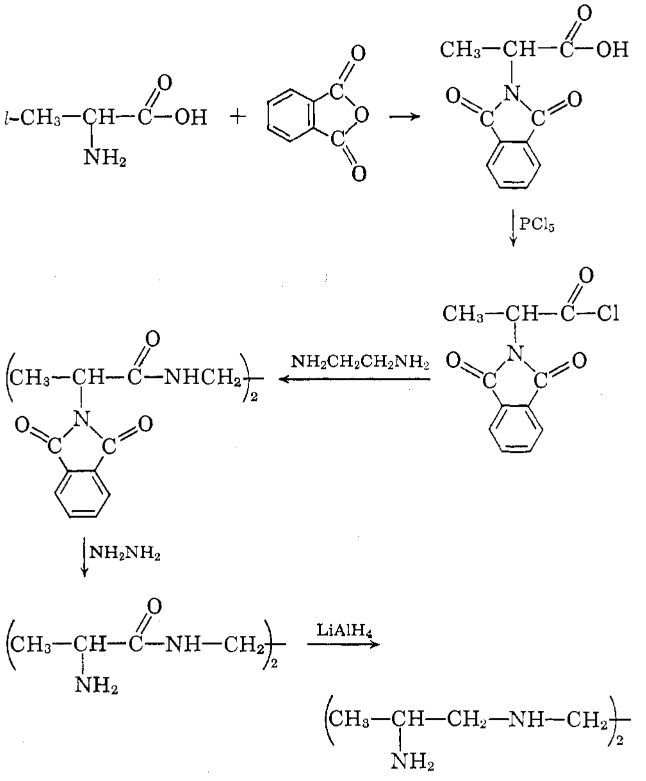


III

In addition there are optical isomers resulting from asymmetry of the *cis* complexes and asymmetry of the ligand. It is the purpose of this investigation to obtain the three possible geometric isomers and assign their configurations. In this study the ligand with con-



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[1] F. Basolo, *J. Am. Chem. Soc.*, **70**, 2634 (1948).
[2] (a) B. Das Sarma and J. C. Bailar, Jr., *ibid.*, **77**, 5480 (1955); (b) J. Selbin and J. C. Bailar, Jr., *ibid.*, **82**, 1524 (1960).
[3] (a) A. M. Sargeson and G. A. Searle, *Nature*, **200**, 356 (1963); (b) A. M. Sargeson and G. A. Searle, *Inorg. Chem.*, **4**, 45 (1965).

figuration designated as *l,l*-α,α′-dimethyltriethylenetetramine was used in the preparation of the complexes. No attempt was made to isolate the diastereoisomers which may result when the complex itself possesses the mirror image configuration.

The synthesis of the ligand was accomplished through the following series of reactions.

Experimental

Reagents.—The *l*-alanine used was purchased from Nutritional Biochemical Corp., Cleveland, Ohio. Lithium aluminum hydride was obtained from Metal Hydrides, Inc., Beverly, Mass. All other chemicals used were commercial reagent grade.

***l*-Phthaloylalanine.**—The following procedure is a modification of the general method of Fling, *et al.*[4]

An intimate one-to-one molar mixture of *l*-alanine and phthalic anhydride was heated in a thermostated oven at 150° with occasional stirring for 2 hr. The molten mixture was cooled at room temperatre and recrystallized from a methanol–water mixture (1:1 by volume). The product was obtained by cooling to 0° and crystallization was induced by scratching the side of the flask with a glass rod. A second crop was obtained by concentrating the filtrate on a steam bath. The product had a melting point of 149–150° (149–150° reported in the literature).[5]

***l*-Phthaloylalanyl Chloride.**—To 1 l. of dry benzene at 50–55° stirred with a magnetic stirrer in a 3-l. three-necked flask fitted with a condenser was slowly added alternately, in 100-g. batches, a total of 1305 g. (5.96 moles) of *l*-phthaloylalanine and 1250 g. (6.0 moles) of phosphorus pentachloride. When the additions were completed, usually after about 45 min., the stirred solution was heated at 50° for 1 hr., then was filtered hot to remove any solid residue. The filtrate was stripped of solvent under reduced pressure until an oil remained.

To purify the phthaloylalanyl chloride the oil was dried *in vacuo* overnight. The resulting yellow solid mass was flushed with dry toluene, and the solid was crystallized from a benzene–petroleum ether (60–95°) mixture (1:1 by volume). The solid was used in subsequent reactions without further purification.

N,N′-Bis(*l*-phthaloylalanyl)ethylenediamine.—In a 4-l. beaker were placed 504 g. (6.0 moles) of $NaHCO_3$, 2.5 l. of H_2O, and 178 g. (2.97 moles) of ethylenediamine. This mixture was cooled in an ice bath to 0–10° and stirred with a mechanical stirrer. To this ice-cold mixture was slowly added during 90 min. 1406 g. (5.96 moles) of crude *l*-phthaloylalanyl chloride dissolved in dry *p*-dioxane (500 ml.). The reaction and formation of solid product was accompanied by much foaming. When the reaction was complete, 2 *N* HCl was added to decompose the excess $NaHCO_3$, and the filtered product was recrystallized from methyl alcohol–H_2O (1:1 by volume). The melting point was 195–195.5°.

Anal. Calcd. for $C_{24}H_{22}N_4O_6$: C, 62.4; H, 4.76; N, 12.1. Found: C, 62.2; H, 4.63; N, 12.1.

N,N′-Bis(*l*-alanyl)ethylenediamine Dihydrochloride.—N,N′-Bis(*l*-phthaloylalanyl)ethylenediamine (80 g., 0.173 mole) was added to a mixture of 347 ml. (0.347 mole) of 1 *M* hydrazine in absolute alcohol and absolute alcohol (1500 ml.) in a 2000-ml. flask and refluxed for 4.5 hr. The solvent was removed under reduced pressure and the residue dried under high vacuum for 8 hr. Then, 2 *N* HCl (90 ml.) was added and the mixture heated for 10 min. at 50° with stirring. After cooling to 0° the solid phthalhydrazide was removed. More phthalhydrazide was removed on concentrating the filtrate under moving air. The resulting viscous oil was treated in the following manner.

To 2 ml. of the viscous oil was added 20 ml. of H_2O, and the resulting solution was washed with two 10-ml. portions of ether followed by two 10-ml. portions of $CHCl_3$. The aqueous phase was concentrated under moving air. From the resulting solution N,N′-bis(*l*-alanyl)ethylenediamine dihydrochloride crystallized.

Anal. Calcd. for $C_8H_{20}N_4O_2Cl_2$: C, 34.9; H, 7.28; N, 20.4. Found: C, 34.3; H, 7.25; N, 19.9.

***l,l*-α,α′-Dimethyltriethylenetetramine Tetrahydrochloride.**—A slurry of 11.8 g. (0.0433 mole) of N,N′-bis(*l*-alanyl)ethylenediamine dihydrochloride was prepared in 500 ml. of dry refluxing *n*-butyl ether in a 2-l. three-necked flask, equipped with a mechanical stirrer and a condenser. This apparatus was flushed with dry nitrogen, and a dry nitrogen atmosphere was kept inside the apparatus throughout the reaction. Then, a total of 6.0 g. (0.159 mole) of $LiAlH_4$ powder in very small batches was added during 0.5 hr. The stirring reaction was refluxed for 21 hr., then cooled to 0°. To the cold slurry a mixture of 6 ml. of H_2O and 6 ml. of 15% NaOH[6] followed by 18 ml. of H_2O was slowly added with vigorous stirring. The resulting slurry was stirred for 2.5 hr., then filtered through a very large Büchner funnel. The residue was triturated with absolute alcohol until fresh aliquots of the washings gave no blue color with copper(II) ion. The combined filtrate was stripped of solvent, then dried for 8 hr. under reduced pressure. The oily residue was then dissolved in absolute alcohol (100 ml.) and filtered, and the residue was washed with five 10-ml. portions of the same solvent. Dry HCl gas was passed into the combined filtrate and washings. A precipitate formed on cooling and standing at 0° for 3 hr. After filtration the residue was dissolved in 20 ml. of 15% NaOH and extracted four times with 200-ml. portions of *n*-butyl alcohol. The combined extracts then were washed with 20 ml. of 15% NaOH and allowed to stand for 4 hr. before separating. The *n*-butyl alcohol phase was evaporated to dryness on a steam bath. The solid was then dissolved in a minimum amount of absolute alcohol. After saturating with HCl gas the precipitate which formed was filtered. This precipitate was recrystallized by dissolving in a minimum amount of methanol–HCl solvent (30 ml. of methanol and 0.5 ml. of concentrated HCl) and cooling to 0°. Precipitation was completed by adding ethyl ether dropwise until no more precipitate was obtained on adding an additional drop.

Anal. Calcd. for $C_8H_{26}N_4Cl_4$: C, 30.02; H, 8.18; N, 17.51; Cl, 44.3. Found: C, 30.16; H, 8.24; N, 17.31; Cl, 44.4.

The optical rotation for this compound was α_{obsd} −0.102° (*c* 1.143 g./5 ml.) or $[\alpha]_D$ −2.23°. Similar rotations were observed for samples whose time of reduction was as short as 8 hr.

Preparation of *cis*-α-[Co(*l,l*-α,α′-dimethyltrien)Cl_2]Cl.—To a mixture of 1.69 g. (5.29×10^{-3} mole) of *l,l*-α,α′-dimethyltriethylenetetramine tetrahydrochloride and 1.26 g. (5.29×10^{-3} mole) of $CoCl_2 \cdot 6H_2O$ in 25 ml. of water was added 0.666 g. (1.59×10^{-2} mole) of $LiOH \cdot H_2O$. The brown solution was aerated for 12 hr. with carbon dioxide free air. The solution was evaporated to half-volume under moving air at room temperature. Then 10 ml. of concentrated HCl was added and the solution evaporated to dryness. The residue was repeatedly extracted with hot acetone until no additional blue compound dissolved in 10 min. The acetone solution was removed by decanting and 10 ml. of methanol was added to the residue. After standing for 4 hr., the solution was cooled to 0° and filtered. The purple product was washed with 1 ml. of ice-cold ethanol.

The product was recrystallized from minimal hot methanol by cooling to 0°. A second crop could be obtained by evaporation of the filtrate to half its original volume.

Anal. Calcd. for $C_8H_{22}NCl_3Co$: C, 28.3; H, 6.53; N, 16.5; Cl, 31.3. Found: C, 28.1; H, 6.51; N, 16.3; Cl, 31.2.

Preparation of *cis*-β-[Co(*l,l*-α,α′-dimethyltrien)Cl_2]Cl.—Into a mixture of 1.69 g. ($5.29 \times \text{mole}^{-3}$ mole) of *l,l*-α,α′-dimethyltriethylenetetramine tetrahydrochloride and 1.26 g. (5.29×10^{-3} mole) of $CoCl_2 \cdot 6H_2O$ in 25 ml. of water was added 0.666 g. (1.59×10^{-2} mole) of $LiOH \cdot H_2O$. To this solution was added 2 g. of activated charcoal (Darco G 60) followed by aeration for 12 hr. with carbon dioxide free air. The charcoal was removed by filtration and washed with 100 ml. of H_2O in small portions. The

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[4] M. Fling, F. N. Minard, and S. W. Fox, *J. Am. Chem. Soc.*, **69**, 2466 (1947).

[5] A. H. Beckett and A. F. Casey, *J. Chem. Soc.*, 900 (1955).

[6] V. M. Micovic and N. L. J. Niheulovic, *J. Org. Chem.*, **18**, 1196 (1963).

filtrate and washings were combined and evaporated to half-volume under moving air. Then 10 ml. of concentrated HCl was added and the solution evaporated to dryness at room temperature. The residue was repeatedly extracted with hot acetone until no additional blue compound dissolved in 10 min. After decanting off the acetone, the resulting red residue was dissolved in minimal hot isopropyl alcohol. The crude red product was precipitated by cooling to room temperature and slowly adding 200 ml. of acetone during 2 days. This product was recrystallized from minimal hot isopropyl alcohol by cooling to room temperature and slowly adding 200 ml. of acetone during 2 days.

Anal. Calcd. for $C_8H_{22}N_4Cl_3Co$: C, 28.3; H, 6.53; N, 16.5; Cl, 31.3. Found: C, 28.0; H, 6.56; N, 16.2; Cl, 31.2.

Some *cis-β*-[Co(*l,l-α,α'*-dimethyltrien)Cl_2]Cl could also be isolated from the preparation of the *cis-α* isomer according to the following procedure. The filtrate from the preparation of the *α* isomer was evaporated to dryness and triturated with 5 ml. of ice-cold alcohol. The red solution was filtered. A residue remained and was kept for the isolation of the *trans* isomer. The red filtrate was evaporated to dryness and redissolved in 2 ml. of ice-cold absolute alcohol. After standing for 1 week, the red product was removed by filtration; yield 0.1 g.

Anal. Found: C, 28.1; H, 6.68; N, 16.5; Cl, 31.4.

Preparation of *trans*-[Co(*l,l-α,α'*-dimethyltrien)Cl_2]Cl.—The residue described in the preceding section was triturated with portions of hot absolute alcohol until the washings remained colorless. The green residue was then slowly recrystallized from methanol by addition of acetone; yield 0.1 g.

Anal. Calcd. for $C_8H_{22}N_4Cl_3Co$: C, 28.3; H, 6.53; N, 16.5; Cl, 31.3. Found: C, 28.5; H, 6.95; N, 16.5; Cl, 31.1.

Rotatory Dispersion.—Rotatory dispersion curves were obtained on a Keston polarimeter attachment on a Beckman DU spectrophotometer. The attachment was manufactured by the Standard Polarimeter Co., Hackensack, N. J.

N.m.r. Spectra.—N.m.r. spectra were obtained on a Varian A 60 instrument. D_2O was used as solvent in all cases. The internal standard in all cases was sodium 2,2-dimethyl-2-silapentane-5-sulfonate (SDSS) supplied by Hi Laboratories, Whitmore Lake, Mich.

Elemental Analyses. Elemental analyses were done by the Spang Microanalytical Laboratories, Ann Arbor, Mich.

Results and Discussion

The ligand forms complexes with cobalt(III) quite easily, and all three geometric isomers are obtained in varying quantities when a mixture of the ligand and Co(II) is oxidized. The availability of all three isomers in sufficient quantities makes this an attractive compound for mechanism studies. The results of some studies will be presented elsewhere.

The assignments of configurations of the isomers are largely based on n.m.r. data. This was supported by ORD studies which confirmed the *trans* assignment to the green isomer. The spectrum of the ligand tetrahydrochloride showed the CH_3 peak to be a doublet at τ 8.45. The *cis-α* isomer gave a CH_3 doublet at τ 8.55. The CH_3 doublet of the green *trans* isomer occurred at τ 9.22. In the CH_3 resonance region the β isomer showed no less than seven peaks. The n.m.r. spectra of all samples were reproducible over a period of several days. On the basis of these data the *cis-α* isomer was assigned the configuration II. The *cis-β* isomer was assigned the configuration III, and the green isomer the *trans* configuration I. Molecular models reveal that the methyl groups are in identical chemical environment for configuration I. This is also true for configuration II. In configuration III, however, the two methyls are in different chemical environments so methyl spectra would be expected to consist of more than a doublet. It is currently impossible to predict the exact number of peaks because of the importance of parameters (such as ligand strain and chloro–aquo geometrical isomers) concerning which no experimental information is available. This assignment of configuration is quite comparable to that of the *cis* isomers of the dichlorotriethylenetetraminecobalt(III) ion by Sargeson and Searle on the basis of the similarities of the colors of the compounds and their rotatory dispersion curves. The presence of methyl groups in the present ligand made the assignment of configuration of the complexes quite simple and also quite certain. The incorporation of methyl groups into various ligands coupled with n.m.r. studies may prove to be a good technique in investigating the stereochemistry of complex compounds.

Rotatory dispersion data indicated that the ligand coordinated in a stereospecific manner. The *cis-α* isomer had the same configuration as the D(+)-*α*-dichlorotriethylenetetraminecobalt(III) ion, and the *cis-β* isomer had the configuration of the L(−)-*β*-dichlorotriethylenetetraminecobalt(III) ion described by Sargeson and Searle.

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