High-resolution ^{13}C N.M.R. Spectroscopy and *X*-Ray Crystallography of Complexes formed by *NN'*-Dimethyl-1,7-diaza-4,10-dioxacyclododecane

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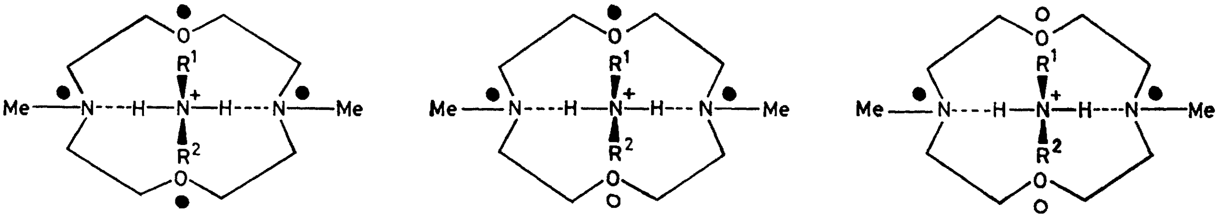
Summary Results obtained from an *X*-ray crystal structure determination of the 1:1 complex formed between *NN'*-dimethyl-1,7-diaza-4,10-dioxacyclododecane (**1**) and benzylammonium thiocyanate and dynamic ^{13}C n m r spectroscopy in CD_2Cl_2 of the 1:1 complex formed between (**1**) and (*S*)-α-phenylethylammonium perchlorate vindicate the constitutional and configurational validity of two-point binding with *syn* stereochemistry between the host and guest species but indicate that conformational isomerism can occur within the host species of such complexes

Recently we established[1] that *NN'*-dimethyl-1,7-diaza-4,10-dioxacyclododecane (**1**) binds both RNH_3^+ and $R_2NH_2^+$ ions and proposed a two-point binding model with the general structure (**1a**)–$R^1R^2NH_2^+$ (where $R^1 = R$ and $R^2 = H$ and $R^1 = R^2 = R$, respectively) for these complexes, on the basis of dynamic ^1H n m r (220 MHz) spectroscopic investigations Now, the results of *X*-ray structure determinations on the crystalline complexes (**1**)–$PhCH_2NH_3^+$-SCN^- and (**1**) $H_2^{2+}(ClO_4^-)_2$ and temperature-dependent ^1H-decoupled ^{13}C n m r spectroscopy in CD_2Cl_2 of the complex (**1**)–(*S*)-$PhCHMeNH_3^+ClO_4^-$ at high resolution (90·52 MHz)



(1a)–$R^1R^2NH_2^+$ (1b)–$R^1R^2NH_2^+$ (1c)–$R^1R^2NH_2^+$

Filled circles indicate *syn* heteroatoms, empty circles indicate *anti* heteroatoms give a much clearer picture of the binding properties of (**1**). Here, we seek to highlight the novel aspects of our findings.

An *X*-ray crystal structure analysis† shows (Figure 1) that the (**1**)–$PhCH_2NH_3^+SCN^-$ complex adopts a two-point binding constitution with hydrogen bonding of the three hydrogens of the NH_3^+ centre to the two nitrogens of (**1**) and the nitrogen of the SCN^- ion. The lengths of the hydrogen bonds between N(17) and N(1), N(7), and N(25) are 2·83, 3·00, and 2·88 Å, respectively, while the contact distances between N(17) and O(4) and O(10) are 2·87 and 2·76 Å, respectively. The conclusion that the hydrogen bonds are formed to the two nitrogens of (**1**), rather than to the two oxygens, is based upon two observations: the direction of the C(18)–N(17) bond which renders hydrogen bonding to the oxygens geometrically unfavourable and the location and successful refinements of the three hydrogens. It is also significant that there is no evidence for migration of the N(17) hydrogens between N(17) and N(1) or between N(17) and N(7) to give a double-minimum condition.[2] The diffraction data are consistent with single asymmetric minima. The torsional angles (see Figure 1) show that the crown component has approximate local C_2 symmetry and

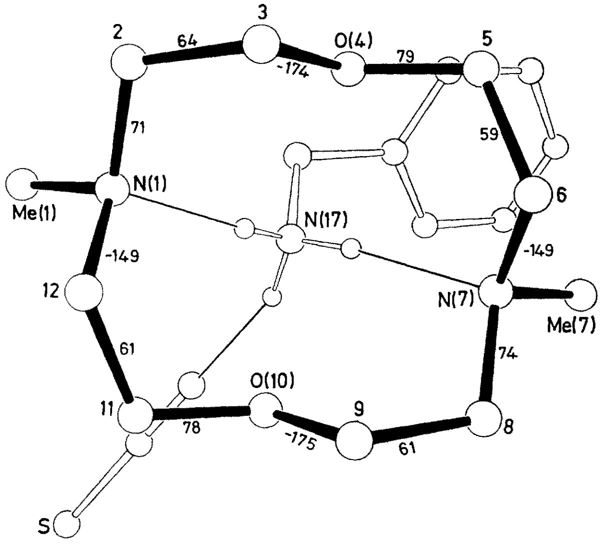


FIGURE 1

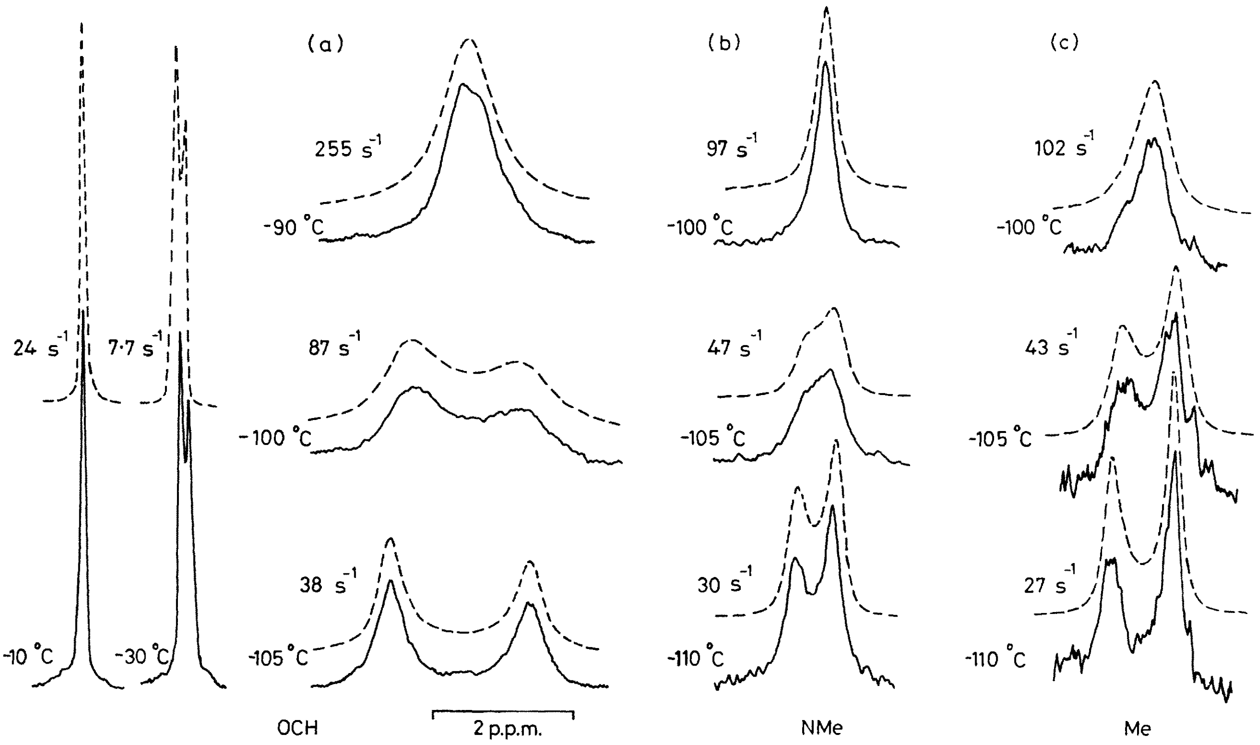


FIGURE 2. The temperature dependence of selected signals in the ^1H-decoupled ^{13}C n.m.r. spectrum of (**1**)–(*S*)-$PhCHMeNH_3^+ClO_4^-$ recorded on a Bruker WH 360 spectrometer with CD_2Cl_2 as solvent, lock, and internal standard.

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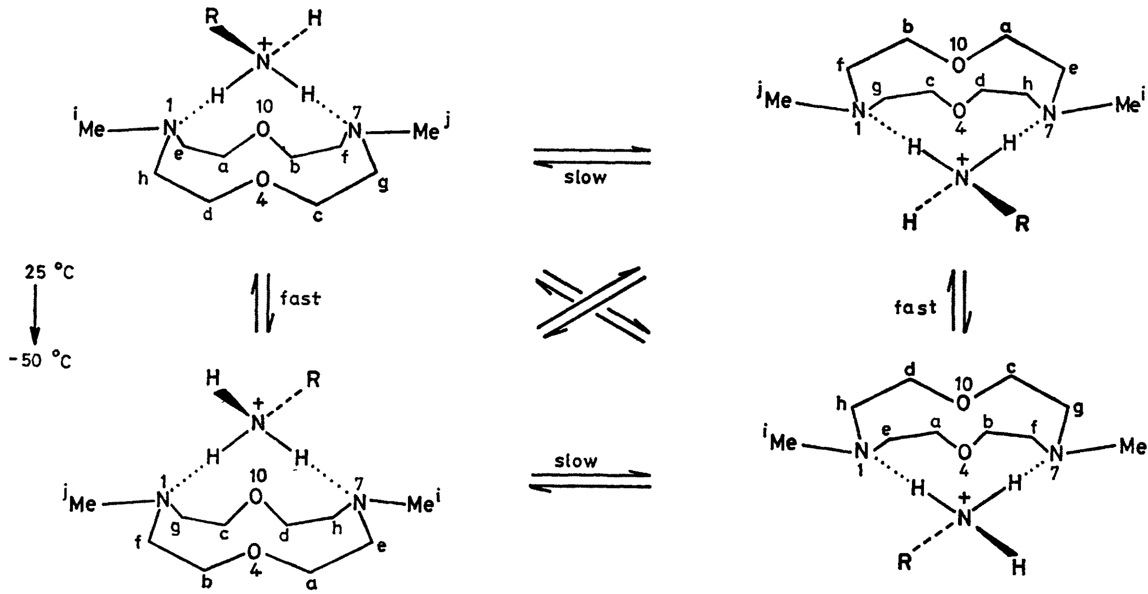
† Crystals of the complex were obtained from ethanol–ether–light petroleum after the CD_2Cl_2 solution of the 1 : 1 complex between (**1**) and $PhCH_2NH_3^+SCN^-$ used in the variable temperature ^1H n.m.r. spectroscopic study (ref 1) had been concentrated to an oily residue. *Crystal data*: monoclinic, space group $P2_1/n$, $a = 12·570(1)$, $b = 16·756(1)$, $c = 10·144(1)$ Å, $\beta = 101·76(1)°$, $Z = 4$. Of the 3113 independent reflections ($\theta \leqslant 60°$) measured on a Siemens diffractometer using Ni-filtered Cu-K_α radiation, 529 were classified as unobserved. The structure was solved by direct methods and refined by full-matrix least squares to $R = 0·049$ The crystals of the (**1**)–$H_2^{2+}(ClO_4^-)_2$ complex are orthorhombic, space group *Pnma*, $a = 8·096(1)$, $b = 10·392(1)$, $c = 20·687(2)$ Å, $Z = 4$. The structure was solved by direct methods from 1579 (of these, 161 were classed as unobserved) independent reflections ($\theta \leqslant 65°$) measured on a diffractometer using Cu-K_α radiation and refined to a current R of 0·072. The other ClO_4^- ion is also disordered about the crystallographic mirror plane and has no significant contacts with (**1**)–$H_2^{2+}ClO_4^-$ The atomic co-ordinates for this work are available on request from the Director of the Cambridge Crystallographic Data Centre, University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW. Any request should be accompanied by the full literature citation for this communication.



SCHEME. R = (S)-PhCHMe. Site exchanges: ac ≠ bd, eg ≠ fh, ij.

is composed of three parallel planes of atoms: (i) one plane comprising the four potential complexing atoms N(1), O(4), N(7), and O(10), (ii) another plane containing C(3), C(6), C(9), and C(12), and (iii) an 'intermediate' plane made up of the remaining carbons. The angles between the N(17)–N(1) and N(17)–N(7) vectors and the respective planes defined by C(2)N(1)C(12) and C(6)N(7)C(8) are 50 and 53°, which is close to tetrahedral geometry. By contrast, the electrostatic bonding approach of the oxygens to the positively charged nitrogen departs considerably[3] from tetrahedral geometry. The angles between the N(17)–O(4) and N(17)–O(10) vectors and the respective planes defined by C(3)O(4)-C(5) and C(9)O(10)C(11) are 39 and 38°.

Formation of the 1:1 complex (**1**)–(*S*)-$PhCHMeNH_3^+$ ClO_4^- in CD_2Cl_2 was accompanied by dramatic chemical shift changes in the ^{1}H-decoupled ^{13}C n.m.r. spectrum of (**1**), which exhibits three resonances at 44·5, 57·7, and 69·2 p.p.m. for the NMe, NCH_2, and OCH_2 carbons, respectively. We have examined (Figure 2) the temperature dependence of the spectra of the 1:1 complex between +25 and −115 °C and have obtained evidence for the existence of two different site exchange processes, (1) and (2). Process (1) is indicated by the separation of both the NCH_2 and OCH_2 peaks into two equally intense signals between +25 and −50 °C. We believe this process arises from the slow dissociative exchange (*d*) of the (*S*)-$PhCHMeNH_3^+$ ion between opposite faces of (**1**), which necessarily must also undergo[1] ring and nitrogen inversion (*rni*). Reorganization of the noncovalent bonding pattern (*rncb*) remains fast on the ^{13}C n.m.r. time scale. The consequence of these relative rates of structural change within (**1**)–(*S*)-$PhCHMeNH_3^+$ in the temperature range +25 to −50 °C for site exchanges involving the OCH_2, NCH_2, and NMe carbons can be understood by reference to the Scheme. Exchange between the pairs of sites a and c, b and d, e and g, f and h, and i and j is fast because *rncb* is fast. Exchange between the resulting averaged sites ac and bd, and eg and fh is slow because (*d* + *rni*) is slow. Line shape analyses (Figure 2a) of suitably expanded signals for the OCH_2 carbons at −10 and −30 °C gave an averaged $\Delta G^{\ddagger}$ (*d* + *rni*) value of 13·4 kcal/mol. This value is in exact agreement with that reported[1] previously for $\Delta G^{\ddagger}$ (*d* + *rni*) as a result of dynamic ^{1}H n.m.r. spectroscopic investigations on (**1**)–(*S*)-$PhCHMeNH_3^+$ ClO_4^- in CD_2Cl_2. Process (2) is clearly evident in the temperature dependent spectra below −50 °C. It is characterized by the appearance of signals of unequal intensities (*ca.* 45:55) for the Me, CH, and Ph carbons of the (*S*)-$PhCHMeNH_3^+$ ion as well as for the NMe, NCH_2, and OCH_2 carbons of (**1**). We interpret this behaviour in terms of an equilibrium between two 'conformationally diastereoisomeric' complexes in solution. In view of the relatively low barriers calculated (an average value of 8·4 kcal/mol) for process (2) from line shape analyses (Figure 2a—c), in the temperature range of −90 to −110 °C, of suitably expanded signals for the OCH_2 and NMe carbons in (**1**) and the Me carbon in the (*S*)-$PhCHMeNH_3^+$ ion, these complexes are probably interconverting by means of torsional changes within the 12-membered ring. We can distinguish between cationic complexes of the conformational type (**1a**)–, (**1b**)–, and (**1c**)–$R^1R^2NH_2^+$ [where R^1 = (*S*)-PhCHMe and R^2 = H] for (**1**)–(*S*)-$PhCHMeNH_3^+$. Two disparate pieces of evidence lend support to the notion implied in this distinction. (i) On complex formation with a range of metal cations, 12-crown-4 has been found[4] to adopt, in the crystalline states, one of two different conformations related to those represented in (**1a**)– and (**1b**)–$R^1R^2NH_2^+$. (ii) An *X*-ray structure determination† we have carried out on the crystalline decomposition product (**1**)–$H_2^{2+}(ClO_4^-)_2$, formed when the complex[1] (**1**)–$Me_2NH_2^+ClO_4^-$ stood in ethanol–ether–light petroleum at 0 °C for several months, has revealed a structure analagous to (**1b**)–$R^1R^2NH_2^+$ for the bisammonium dication (**1**)–H_2^{2+}. It forms (Figure 3) hydrogen bonds (2·92 Å) between the nitrogens and an oxygen of one† of the disordered ClO_4^- ions on the crystallographic mirror plane, and adopts a C_s conformation (as indicated by the torsional angles in Figure 3) in which one of the oxygens is oriented below the plane of the two nitrogens and the other oxygen.

Three important conclusions emerge from these new results. (a) Molecular receptors such as (**1**) have all the essential ingredients to form highly structured face-to-face complexes with $R^1R^2NH_2^+$ ions. (b) Two-point binding[1] of $R^1R^2NH_2^+$ ions by (**1**) is vindicated as a constitutional model. (c) *syn* Stereochemistry is found between the NMe groups of (**1**) and $R^1R^2NH_2^+$ ions in 1 : 1 complexes (*cf.* ref. 5).

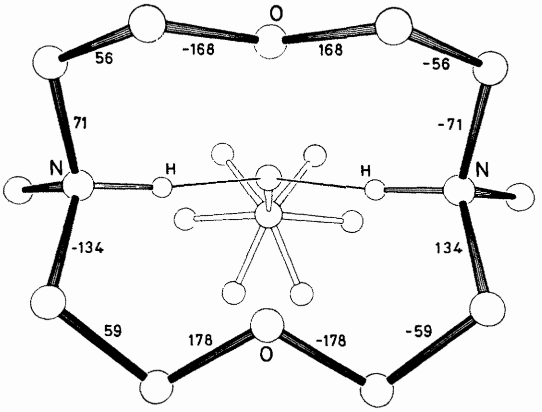


FIGURE 3

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