A.

The Crystal Structure of 9 - Methyl Guanine Hydrochloride Monohydrate

B.

Preliminary Studies on $[C_{27}H_{56}N_2Cl]^{+} \cdot [H_{13}O_6]^{+} \cdot 2\ Cl^{-}$ a Bicyclic Diammonium Ion Containing a Caged Chloride

Thesis by

Robert Alan Bell

In Partial Fulfillment of the Requirements
For the Degree of
Master of Science

California Institute of Technology
Pasadena, California
1972
(Submitted May 25, 1972)

(*Tractatus Logico-Philosophicus*, 4.5): "The general form of propositions is: This is how things are."——That is the kind of proposition that one repeats to oneself countless times. One thinks that one is tracing the outline of the thing's nature over and over again, and one is merely tracing round the frame through which we look at it.

Ludwig Wittgenstein
Philosophical Investigations
(trans. by G. E. M. Anscombe)

To my parents and to Penney who have shown me the beauty of the world and helped me to find my place in it.

ACKNOWLEDGEMENTS

Many persons have encouraged and guided me in these studies and I wish to express my most sincere thanks. Dr. Richard E. Marsh has always been an ever-present source of optimism and "all too good" advice. His patience and understanding have taught much more than structural chemistry. Benes Trus, Jim Sherfinski, Frank Fronczek, and Gary Christoph have helped me tremendously, often pointing the way out of a seemingly insoluble paradox. To Sharman Christoph, thanks for excellent and speedy typing (A friend in need...). Thanks to Dr. Sten Samson for his excellent equipment.

Finally, I wish to thank the National Science Foundation and the National Institute of Health which partially financed this research.

(Thanks also to Howard Einspahr and good luck down South).

ABSTRACT

The structure of 9-Methyl Guanine HCl Monohydrate, $C_6H_8N_5OCl \cdot H_2O$, has been determined by single crystal x-ray analysis. The whitish salt crystallizes in the monoclinic space group $P2_1/c$ with unit cell dimensions $\underline{a}$ = 5.324(2), $\underline{b}$ = 11.236(15) $\underline{c}$ = 15.533(10) and β = 96.11(3)°. There are four molecules in the unit cell and thus, one in the asymmetric unit. The measured density of 1.581 gm cm^{-3} is in close agreement with the calculated values of 1.578 gm cm^{-3}. Three-dimensional intensity data were collected on a Datex-automated General Electric diffractometer using CoKα radiation. The structure was determined by Patterson and Fourier methods and refined by Fourier and least squares techniques to a final R index of 0.067 for 1224 reflections.

The molecules crystallize in slightly buckled planes which are parallel to and lie half way between the $\bar{1}04$ plane of the unit cell. They are hydrogen bonded to chloride ions and water molecules between the planes and to each other within the plane. The water molecules and the chloride ions form staggered columns perpendicular to the molecular planes. The six hydrogen bonds, N(10A)-H····N(3B), N(10A)-H····O(2) N(1A)-H···Cl^-, N(7A)-H···Cl^-, O(2)-H(9)····Cl^-, and O(2)-H(10)··· ···Cl^- are respectively 3.072, 2.828, 3.294, 3.191, 3.257, and 3.125 Å in length. The molecular planes are 3.17 and 3.33Å apart.

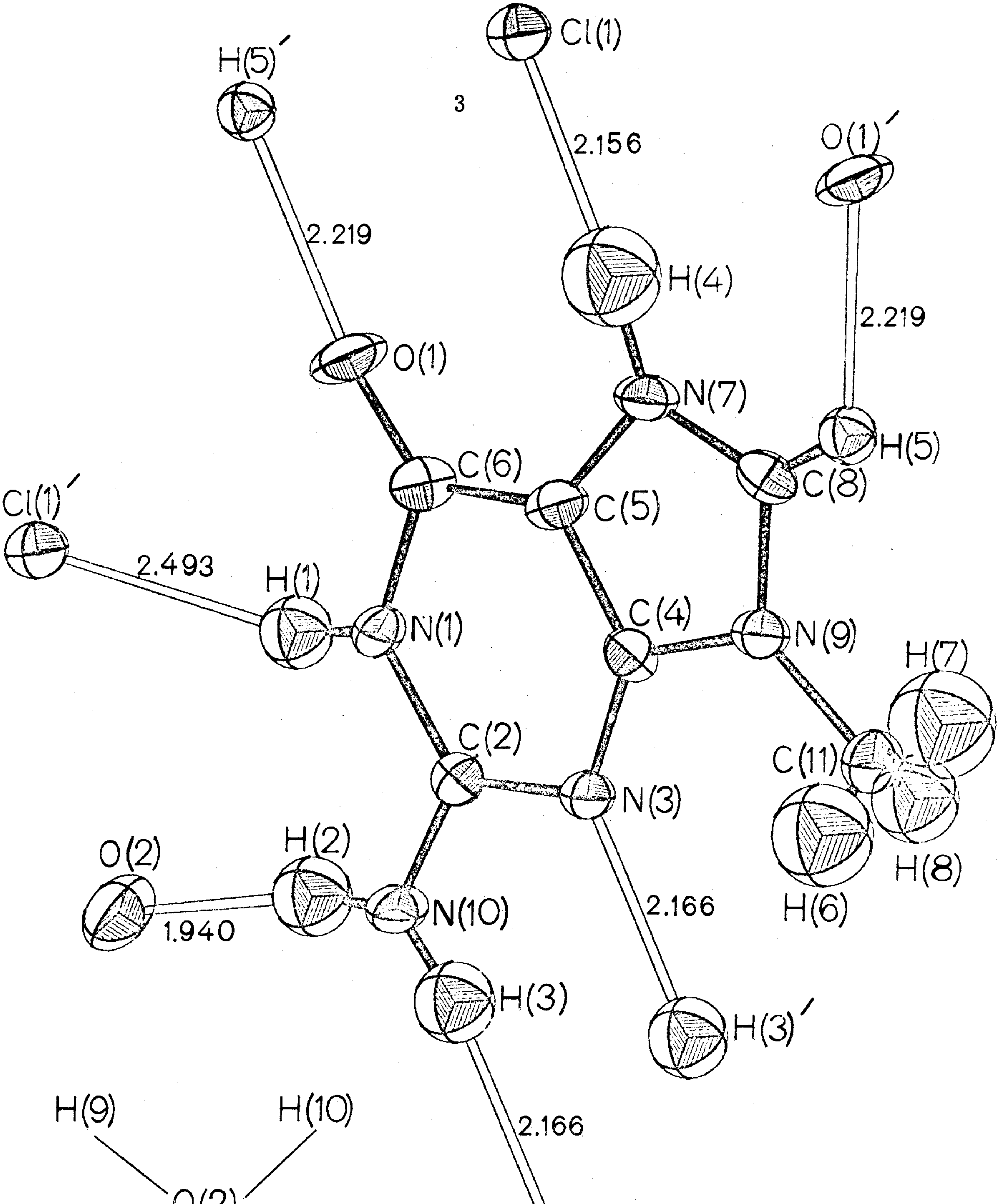
TABLE OF CONTENTS

INTRODUCTION

The crystal structure of 9-Methyl Guanine $HCl \cdot H_2O$ ($MGHCl \cdot H_2O$) (Figure 1) was undertaken as a part of a program of research on the structure of compounds related to nucleic acids. As neutral Guanine is extremely difficult to crystallize, the hydrochloride salt was chosen. The main objective of the investigation was to examine the hydrogen bonding pattern of the substrate, Guanine, in order to gain information on its role in the structure of deoxyribonucleic acid (Watson and Crick, 1953). It was, therefore, of interest to also determine the first site of protonation and the predominant resonance forms of the molecule.

The structure of 9-Methyl Guanine hydrobromide has previously been reported(Sobell and Tomita, 1964). No hydrogen positions were determined and unit cell parameters are significantly different from the hydrochloride. In $MGHCl \cdot H_2O$, the hydrogen atoms were located and better distances and angles were obtainable because of the absence of a very heavy atom.

Figure 1


3
Cl(1)
H(5)'
2.156
O(1)'
2.219
H(4)
2.219
O(1)
N(7)
H(5)
C(6)
C(8)
C(5)
Cl(1)'
2.493
H(1)
N(1)
C(4)
N(9)
H(7)
C(2)
C(11)
N(3)
H(8)
O(2)
H(2)
H(6)
2.166
N(10)
1.940
H(3)
H(3)'
H(9)
H(10)
2.166
O(2)
N(3)'

CRYSTAL DATA

Crystals were obtained in the following manner: 0.1 gm. of 9-Methyl Guanine was added to 2 ml of H_2O and concentrated HCl added drop by drop until all the solid had dissolved (3 - 4 drops). The solution was then allowed to stand. In approximately four hours, tiny clear crystals began to form. After four additional hours of growth, they were of suitable size for diffractometer use. As these crystals decompose in a matter of hours it was mandatory that they be coated to slow the decomposition. A quick-drying epoxy cement was used in this case. The space group was determined from zero and first layer Weissenberg and oscillation photographs about the a, b, and c axes. The unit cell dimensions, given in Table 1, were determined by a least squares fit to values of 2θ measured on the diffractometer for 23 reflections. The density was measured by the flotation method in a mixture of ethyl alcohol and carbon tetrachloride.

Table 1

Crystal Data

$C_5H_8N_5O^+ \cdot Cl^- \cdot H_2O$

Space Group $P2_1/c$

$a = 5.324(2)$Å

$b = 11.236(15)$Å

$c = 15.533(10)$Å

$\beta = 96.11(3)°$

$D_m = 1.581$ gm cm^{-3}

$\mu = 34.7$ cm^{-1}

FW = 207.62

Systematic Absences:
0K0, $K = 2n + 1$
h0l, $l = 2n + 1$

$Z = 4$

$V = 924.0$Å^3

λCoKα = 1.7909Å

$D_x = 1.578$ gm cm^{-3}

EXPERIMENTAL PROCEDURES

Intensity data were measured on a Datex automated General Electric diffractometer using CoKα radiation. Reflections with $3^\circ \leq 2\theta \leq 155^\circ$ were scanned varying from 2.20° at $2\theta = 12^\circ$ to 4.20° at $2\theta = 120.00^\circ$. A thirty second background was recorded on either side of the scan range. Two sets of data were measured and averaged except for 400 low angle reflections which were only recorded once due to a machine error. A standard check reflection (1, 1, 3) was measured every 20 reflections and served to detect any variance in crystal or instrument stability. The intensity of this standard varied by about 4% during the week of data collection. The crystal had approximate dimensions 0.12 by 0.12 by 0.25 mm. Absorption corrections were assumed to be negligible as $\mu R_{max} = 0.48$.

In all, 1225 independent reflections were measured. Squares of the structure factor amplitudes, $|F_o|^2$, and their standard deviations were derived from the net intensities by application of the Lorentz and polarization factors. In the least squares, the weight was assigned a value of $1/\sigma^2(I)$.

The only reflection given a weight of zero in the final data set was the $\bar{1}04$ reflection. As the molecular planes lie parallel to and in phase with this plane, this reflection was extremely strong. The detector saturated on this reflection and an accurate intensity could not be obtained.

STRUCTURE SOLUTION AND REFINEMENT

The structure was solved by interpretation of the three-dimensional Patterson function using the heavy atom method. The heavy atom locations were determined from 874 reflections from a previous crystal. A Fourier synthesis on this data set with $R = (\Sigma|F_o - F_c|/\Sigma|F_o|) = 60.1\%$ based on signs determined from the location of the chloride ion indicated probable locations for the remaining heavy atoms. Using successive Fouriers, difference Fouriers, and least square techniques, the R was dropped to 10.5%. As hydrogen positions were of interest it was felt that more data was necessary. A new data set of 1225 reflections was collected and the R from a Fourier based on the previous heavy atom locations equaled 26.4%. One cycle of full matrix least squares brought the R to 13.7%. Two more cycles of full matrix least squares on isotropic and positional parameters lowered the R to 10.7%. Further refinement included location of the hydrogen positions, addition of a secondary extinction factor, reducing the weight of the $\bar{1}04$ reflection to zero, and four cycles of isotropic and positional refinement on the heavy atoms. The final R was equal to 6.7% with a weighted R $= [\Sigma w(|F_o|^2 - |F_c|^2)/\Sigma w F_o^4]$ of 1.6% and a goodness of fit $= \{[\Sigma w(F_o^2 - F_c^2)^2/(M - S)^{\frac{1}{2}}$ for M observations and S parameters$\}$ of 3.45 (This is large as the crystal was very unstable due to the large thermal motions of the atoms.).

Scattering factors used were those in International Tables for X-Ray Crystallography (1962) except for hydrogen (Stewart, Davidson, and Simpson, 1965). Computations were performed at the Caltech Computing Center on the IBM 360-75 using the CRYM system (D. Duchamp, J. Westphal, Trus, and Wang). Some of the crystallographic drawings were produced by ORTEP (C. Johnston, 1965). The final positional parameters appear in Table 2 and the thermal parameters in Table 3. Observed and Calculated structure factors are compared in Table 4.

DISCUSSION

Molecular Configuration

The bond distances in $MGHCl \cdot H_2O$ are compared to other guanine derivatives in Table 5. The standard deviations in bond distances in MGHBr ($\sigma = 0.03$) and $GHCl \cdot H_2O$ ($\sigma = 0.04$) are too large for accurate comparison, but $GHCl \cdot 2H_2O$ ($\sigma = 0.005$), GC ($\sigma = 0.007$) and GFC ($\sigma = 0.009$) are not. The primary difference between these derivatives is the protonate ion at N(7) which is the site for protonation of all of these quanine salts. The C(5) - N(7) and N(7) - C(8) bond distances were expected to increase slightly with protonation. However, no significant differences in these bond lengths were noted as differences were within the standard deviation of the values of the unprotonated form. The bond distances agree well with those of $GHCl \cdot 2H_2O$ (Iball and Wilson, 1962) and are well within the standard deviations of the values of ($GHCl \cdot H_2O$) (Broomhead, 1951) and MGHBr (Sobell and Tomita, 1964). The C(6) - O bond length of 1.228 Å indicates the molecule is primarily in the keto form. The C(8) - N(2) distance of 1.318Å indicates strong resonance double bond character as does the C(2) -N(3) distance of 1.324Å. The C(2) - N(10) distance of 1.335Å indicates some double bond character which would increase the probability of hydrogen bonding between N(10A) - N(3B) and N(3A) - N(10B).

The bond angles are compared to other Guanine derivatives in Table 6. There are pronounced differences between MGHCl and MGHBr, but the 2.0° standard deviation for MGHBr reduces most of these differences to within experimental error. There is very good agreement between $MGHCl{\cdot}H_2O$ and $GHCl{\cdot}2(H_2O)$. These also agree closely with the angles of the six-membered ring atoms of GC and GFC. The effects of protonation at N(7) are clearly seen as both $GHCl{\cdot}2(H_2O)$ and $MGHCl{\cdot}H_2O$ show an expansion of the C(5) - N(7) - C(8) angle. This change is consistent with previous observations as the CNC angle in ethyl guanine (GC) increased from 104.1° (O'Brien, 1967) to 106.5° (Sobell and Tomita, 1964) upon protonation. Also the CNC angle in methyl cytosine increases 6° upon protonation (Trus, in press). Because the internal ring angle, C(5) - N(7) - C(8), increased 5° in $MGHCl{\cdot}H_2O$ and 4° in $GHCl{\cdot}2(H_2O)$ upon protonation, major ring adjustments are necessary. The adjacent angles, C(4) - C(5) - N(7) and N(7) - C(8) - N(9), decrease by 4° and 5° respectively in $MGHCl{\cdot}H_2O$ and 3° and 5° in $GHCl{\cdot}2(H_2O)$ to help absorb the increase in N(7).

Packing

Figures 1 and 2 illustrate the hydrogen bonding found in MGHCl H_2O. In Figure 3 are found the bonding schemes of other molecules containing guanine. N(1) and N(7) are strong hydrogen bond donors with N - H···Cl distances of 3.29Å and 3.19Å. H(3) participates in a hydrogen bond between N(10) and N(3)′ which is inverted across a center of symmetry [N(10)′ — H(3)′····N(3)]. The chloride ions and water molecules form staggered columns perpendicular to the molecular planes. The water-chloride bonds, O(2) - H(9)···Cl′ (1) and O(2) - H(10)···Cl′ are 3.257 and 3.125Å in length. The water molecules, not shown in Figure 2, lie between the planes and fill the holes passing through them. The water molecules are further stabilized by interaction with H(2), O(2)···H(2) - N(10) distance of 2.828Å. This, however, appears to be rather weak.

C - H···O bonds have been postulated (Sutor, 1962) for short carbon-oxygen distances in the range 3.0 to 3.24Å and carbon-hydrogen···oxygen distances between 2.07 and 2.76Å. The 2.22Å separation between H(5) and O(1)′ (C - O distance of 2.84Å) presents an interesting example of a close C -H···O contact. It might be expected that the more electronegative nitrogens would render C(8) slightly positive thereby making

H(5) a more likely candidate for a weak interaction with O(1)′. However, the N(7) - C(8) - H(5) angle of 128.1° is somewhat larger than the expected 126° indicating this contact may be a repulsion rather than an attraction. This could be chemically reasonable as the electron-donating effect of the methyl group on N(9) would tend to oppose charge asymmetry on C(8). As Christoph (1971) has pointed out, although these contacts are shorter than the expected van der Waals contact, they do not necessarily reflect a bond but can even be repulsive as interpreted by Donohue (1968) in the case of o-nitrobenzaldehyde.

The substrate is planar to within 0.046Å (as seen in Table 8) with O(1) and H(4) deviating by 0.1Å. H(4) is drawn to Cl(1) which lies above the plane and O(1) lies below possibly forced out of the plane by the close contact with H(5)′.

Figure 4 represents the stacking pattern of molecules perpendicular to the molecular planes. Possible interplanar forces consist of stability due to charge asymmetry. As pointed out by Marsh (1968), nitrogen and oxygen atoms of purines and pyrimidines can possess a partial negative charge rendering adjacent carbon atoms positive. The stacking of $MGHCl \cdot H_2O$ indicates considerable charge asymmetry for N(3) (-), C(2) (+), N(10) (-), and C(4) (+). However, expressed over the interplanar distance of 3.3Å this must be regarded as a weak stabilizing force.

Table 2

Positional and Isothermal Parameters

Standard deviations are given in parentheses.

	x	y	z	B
Cl(1)	.17545(18)	.09663(9)	0.16845(6)	---
O(1)	.63388(54)	-.11424(27)	0.26272(19)	---
C(6)	.78990(68)	-.06016(34)	.31196(24)	---
N(1)	.98486(58)	-.12174(26)	.35953(19)	---
C(2)	1.17829(64)	-.06928(30)	.41419(21)	---
N(10)	1.34856(60)	-.14271(27)	.45502(21)	---
N(3)	1.19855(54)	.04722(23)	.42593(19)	---
C(4)	1.00917(63)	.10812(30)	.38200(20)	---
C(5)	.80608(65)	.06334(33)	.32920(23)	---
N(7)	.66511(58)	.16020(28)	.29695(19)	---
C(8)	.77282(66)	.25869(33)	.32870(24)	---
C(11)	1.15085(85)	.31496(35)	.42987(29)	---
N(9)	.98258(54)	.23047(26)	.38080(18)	---
O(2)	.65508(64)	.39401(29)	.55478(25)	---
H(3)	1.47958(1586)	-.10561(647)	.48729(565)	5.2(2.1)
H(2)	1.34130(910)	-.22140(502)	.44388(340)	5.0(1.3)
H(1)	.98416(782)	-.19627(409)	.35635(277)	4.2(1.0)
H(4)	.49098(1150)	.15033(543)	.25865(375)	7.9(1.5)
H(5)	.72051(654)	.33745(323)	.31794(226)	2.7(0.7)
H(8)	1.14508(1014)	.29646(476)	.48457(382)	8.3(1.4)
H(6)	1.31395(959)	.30741(425)	.40900(313)	6.1(1.2)
H(7)	1.08458(1173)	.39029(595)	.42625(407)	9.2(1.6)
H(9)	.55881(1183)	.41121(492)	.58244(389)	9.3(1.6)
H(10)	.81185(1350)	.40559(558)	.59218(445)	10.3(1.7)

Table 3. Thermal Parameters

Standard deviations are given in parentheses.

The thermal expression has the form

$$-[B_{11}h^2 + B_{22}k^2 + B_{33}l^2 + B_{12}hk + B_{13}hl + B_{23}kl]$$

#	B_{11}	B_{22}	B_{33}	B_{13}	B_{13}	B_{23}
1	.03032(42)	.00611(9)	.00391(5)	-.00110(28)	-.00681(20)	.00044(10)
2	.03689(119)	.00772(28)	.00517(15)	-.00390(89)	-.01660(69)	-.00259(33)
3	.02414(141)	.00692(35)	.00303(16)	-.00014(112)	-.00376(81)	-.00064(39)
4	.02937(118)	.00341(24)	.00302(12)	-.00188(81)	-.00641(62)	-.00116(28)
5	.02560(137)	.00443(29)	.00252(14)	-.00180(100)	-.00239(73)	-.00008(33)
6	.02841(125)	.00422(25)	.00395(15)	.00317(90)	-.01019(72)	-.00061(31)
7	.02436(114)	.00403(25)	.00284(13)	.00019(84)	-.00571(63)	.00016(28)
8	.02606(141)	.00433(28)	.00215(14)	.00184(99)	-.00064(72)	.00039(32)
9	.02218(132)	.00648(33)	.00270(15)	-.00202(105)	-.00419(74)	-.00062(36)
10	.02537(117)	.00568(26)	.00285(13)	.00392(94)	-.00683(63)	.00005(31)
11	.02546(145)	.00521(31)	.00336(16)	.00579(104)	-.00399(78)	.00192(37)
12	.02597(122)	.00480(26)	.00268(13)	.00097(85)	-.00501(66)	.00007(29)
13	.03618(177)	.00433(32)	.00423(20)	-.00018(109)	-.00588(96)	-.00107(38)
14	.03773(135)	.00652(27)	.00753(19)	-.00308(91)	-.00933(89)	-.00211(37)

Table 5

Comparison of bond lengths in molecules containing guanine

	MGHCl H_2O	GHCl $2H_2O$	MGHBr	GHCl H_2O	GC	GFC
N(1)-C(2)	1.394 Å	1.374 Å	1.42 Å	1.32 Å	1.388 Å	1.375 Å
N(1)-C(6)	1.392	1.390	1.38	1.41	1.400	1.405
C(2)-N(3)	1.324	1.318	1.33	1.33	1.326	1.336
C(2)-N(10)	1.335	1.339	1.33	1.31	1.335	1.336
N(3)-C(4)	1.343	1.345	1.37	1.35	1.357	1.362
C(4)-C(5)	1.381	1.377	1.32	1.34	1.388	1.363
C(4)-N(9)	1.382	1.375	1.39	1.34	1.375	1.381
C(5)-C(6)	1.414	1.414	1.43	1.40	1.412	1.427
C(5)-N(7)	1.385	1.378	1.39	1.41	1.393	1.395
C(6)-O(1)	1.228	1.237	1.18	1.20	1.233	1.223
N(7)-C(8)	1.318	1.322	1.34	1.33	1.302	1.320
C(8)-N(9)	1.346	1.335	1.40	1.32	1.376	1.381
N(9)-C(11)	1.463	-----	1.41	----	1.485	1.467
sigma	0.01	0.005	0.03	0.04	0.007	0.009

MGHCl·H_2O is 9 - methyl guanine hydrochloride monohydrate, present study; GHCl·$2H_2O$ is guanine hydrochloride dihydrate, Iball and Wilson (1965); MGHBr is 9 - metnyl guanine hydrobromide, Sobell and Tomita (1964); GHCl H_2O is guanine hydrochloride monohydrate, Broomhead (1951); GC is 9 - ethyl guanine – 1 - methyl cytosine, O'Brien (1967); GFC is 9 - ethyl guanine – 1 - methyl - 5 - fluoro cytosine, O'Brien (1967).

Table 6

Comparison of bond angles in molecules containing guanine

Angle	MGHCl H_2O	MGHBr	GC	GFC	GHCl $2H_2O$
N(1)-C(2)-N(3)	123.1°	121.5°	123.3°	123.3°	123.4°
C(2)-N(3)-C(4)	112.8°	112.3°	112.2°	112.3°	112.8°
N(3)-C(4)-C(5)	127.9°	128.3°	128.6°	128.3°	127.6°
C(4)-C(5)-C(6)	119.9°	122.0°	118.9°	119.8°	119.9°
C(5)-C(6)-N(1)	111.1°	109.1°	111.7°	111.0°	110.8°
C(6)-N(1)-C(2)	125.0°	126.5°	125.2°	125.3°	125.6°
C(5)-C(6)-O(1)	128.8°	130.8°	128.6°	129.1°	128.9°
O(1)-C(6)-N(1)	120.1°	120.2°	119.7°	120.0°	120.3°
N(1)-C(2)-N(10)	116.6°	117.7°	115.9°	116.2°	116.0°
N(10)-C(2)-N(3)	120.3°	120.8°	120.8°	120.5°	120.6°
N(3)-C(4)-N(9)	125.7°	119.3°	125.6°	124.5°	126.3°
C(4)-C(5)-N(7)	106.8°	107.8°	110.4°	110.8°	107.4°
C(5)-N(7)-C(8)	109.1°	106.5°	104.1°	103.5°	108.2°
N(7)-C(8)-N(9)	109.1°	110.9°	114.0°	114.0°	109.6°
C(8)-N(9)-C(4)	108.7°	102.4°	105.8°	104.6°	108.6°
N(9)-C(4)-C(5)	106.4°	111.6°	105.8°	107.1°	106.2°
C(8)-N(9)-C(11)	125.7°	123.6°	128.7°	129.8°	-----
C(4)-N(9)-C(11)	125.6°	132.5°	125.5°	125.5°	-----
sigma	1.3°	2.0°	0.4°	0.5°	-----

Key found on Table 5.

Table 7

Intramolecular bond distances and angles*

Bond	Distance	Bond	Distance
O(1)-C(6)	1.228 Å	C(4)-N(9)	1.382 Å
C(6)-N(1)	1.392	C(5)-C(6)	1.414
N(1)-C(2)	1.394	C(5)-N(7)	1.385
C(2)-N(10)	1.335	N(7)-C(8)	1.318
C(2)-N(3)	1.324	C(8)-N(9)	1.346
N(3)-C(4)	1.343	N(9)-C(11)	1.463
C(4)-C(5)	1.381		

Atoms	Angle	Atoms	Angle
O(1)-C(6)-N(1)	120.07°	C(6)-N(1)-C(2)	125.02°
C(5)-C(6)-N(1)	111.11°	N(1)-C(2)-N(10)	116.64°
N(1)-C(2)-N(3)	123.09°	N(10)-C(2)-N(3)	120.27°
C(2)-N(3)-C(4)	112.82°	N(10)-H(3)-N(3)′	170.19°
N(3)-C(4)-C(5)	127.90°	N(3)-C(4)-N(9)	125.73°
C(5)-C(4)-N(9)	106.37°	C(4)-C(5)-N(7)	106.77°
C(5)-N(7)-C(8)	109.09°	N(7)-C(8)-N(9)	109.12°
C(8)-N(9)-C(11)	125.71°	C(8)-N(9)-C(4)	108.65°
C(4)-N(9)-C(11)	125.62°		

---

* Atom numbers from Figure 1

Table 8

Least Squares Plane Calculation

Direction cosines of plane normal (-0.6281 -0.0733 0.8371)
Origin to plane distance = 1.493 Å

Atom	Deviation	Weight
C(6)	-0.0282	1.00
N(1)	-0.0109	1.00
C(2)	0.0098	1.00
N(3)	-0.0012	1.00
C(4)	0.0107	1.00
C(5)	0.0402	1.00
N(7)	0.0125	1.00
C(8)	-0.0160	1.00
N(9)	-0.0168	1.00
C(11)	-0.0110	0.00
H(1)	0.0115	0.00
H(4)	0.1049	0.00
H(5)	-0.0458	0.00
N(10)	0.0318	0.00
O(1)	-0.1022	0.00

Figure 2

Intraplanar bonding

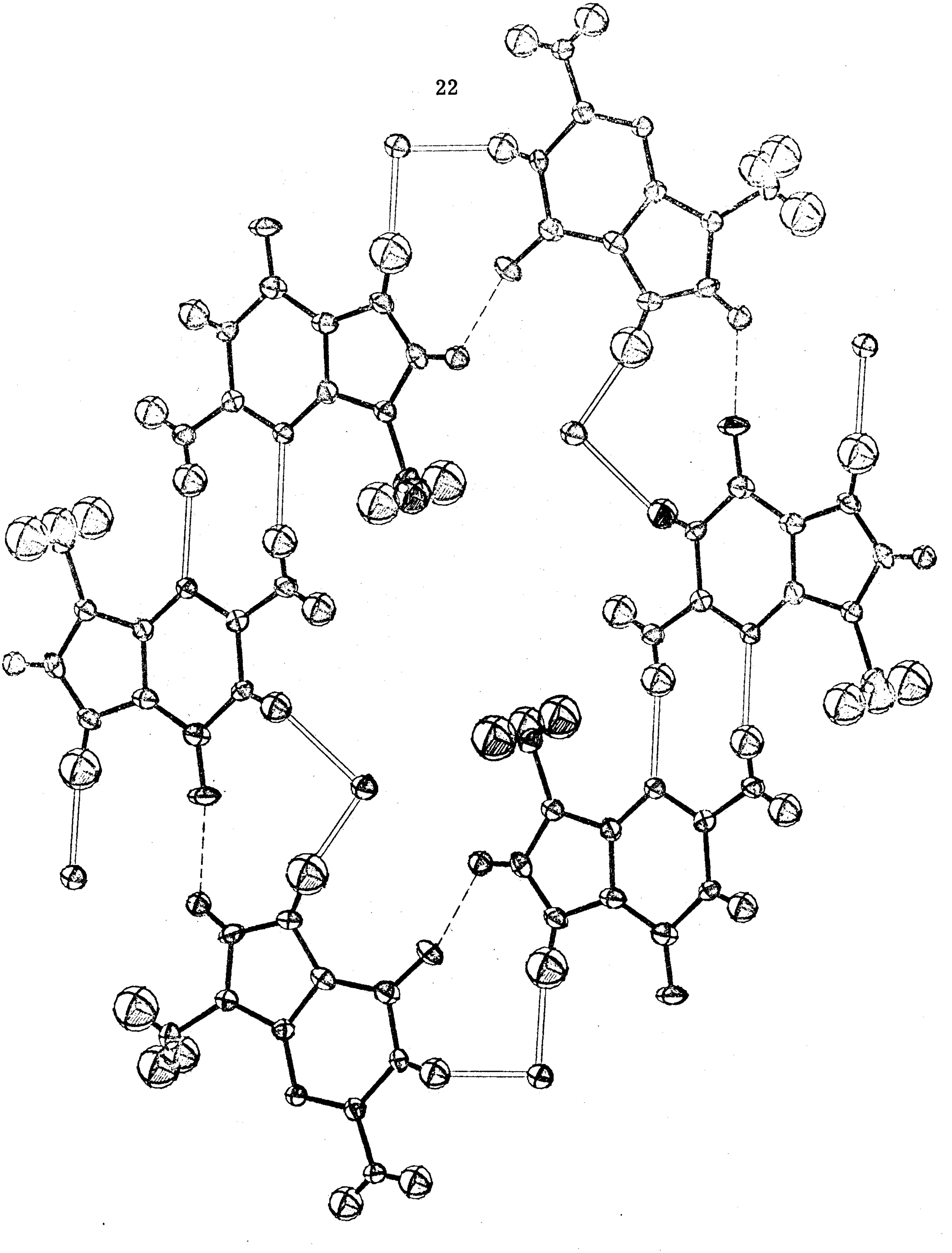
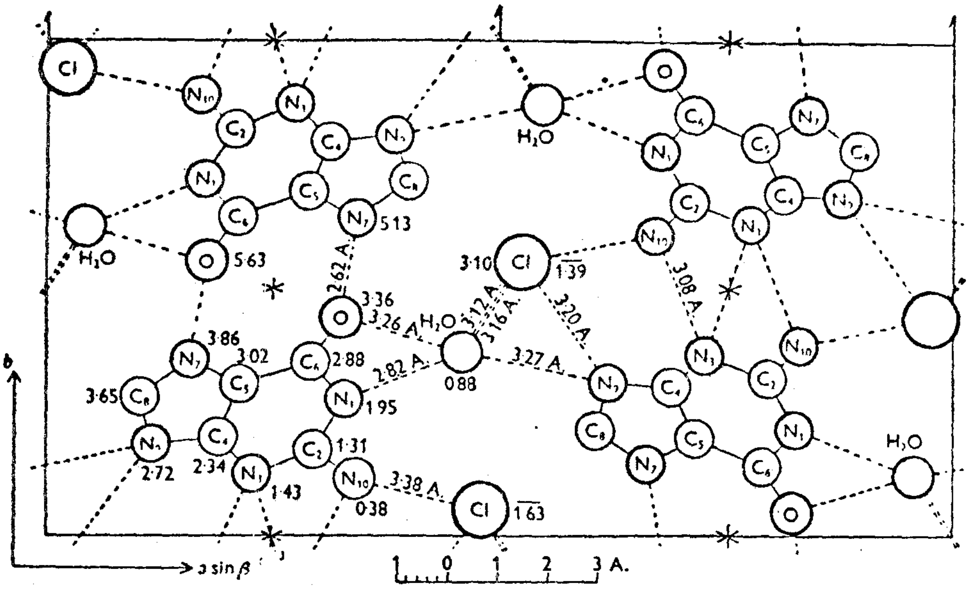


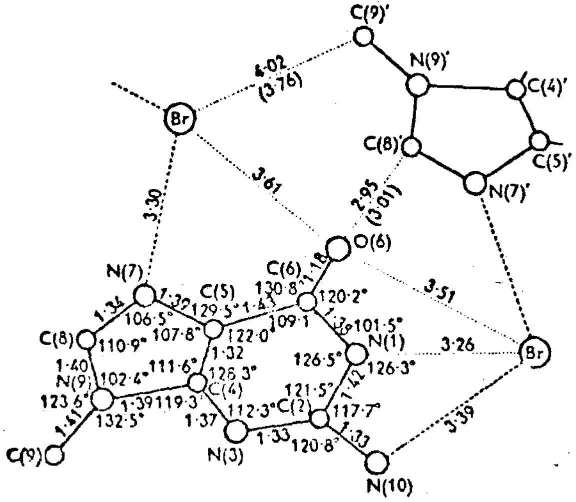
Figure 3

Related structures



Structure of guanine hydrochloride monohydrate projected on to a plane perpendicular to c; distances of atoms above plane of projection indicated. Hydrogen bonds and short van der Waals contacts shown by broken lines.

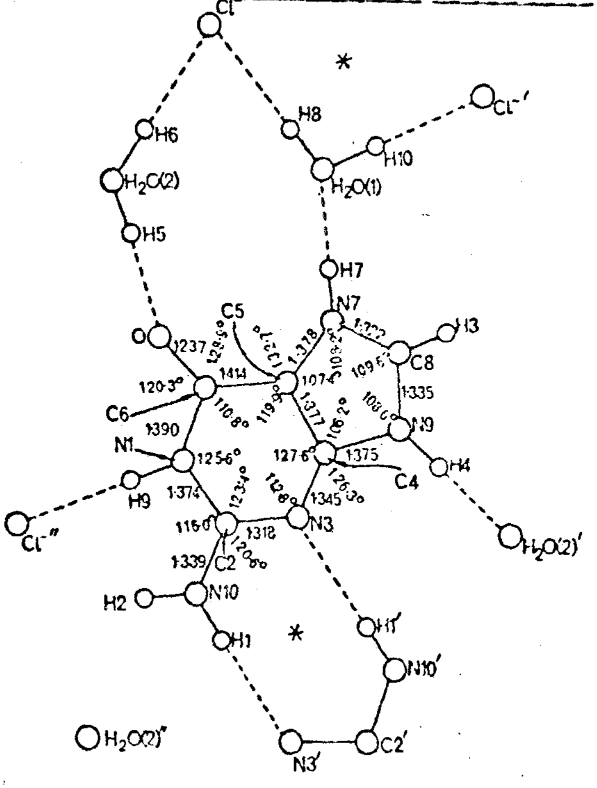
(Broomhead, 1951)



Schematic diagram showing the bond lengths and angles of 9-methylguanine hydrobromide. Hydrogen bonds are indicated by broken lines. Other interatomic distances are shown by dotted lines.

(Sobell and Tomita, 1964)

guanine hydrochloride dihydrate

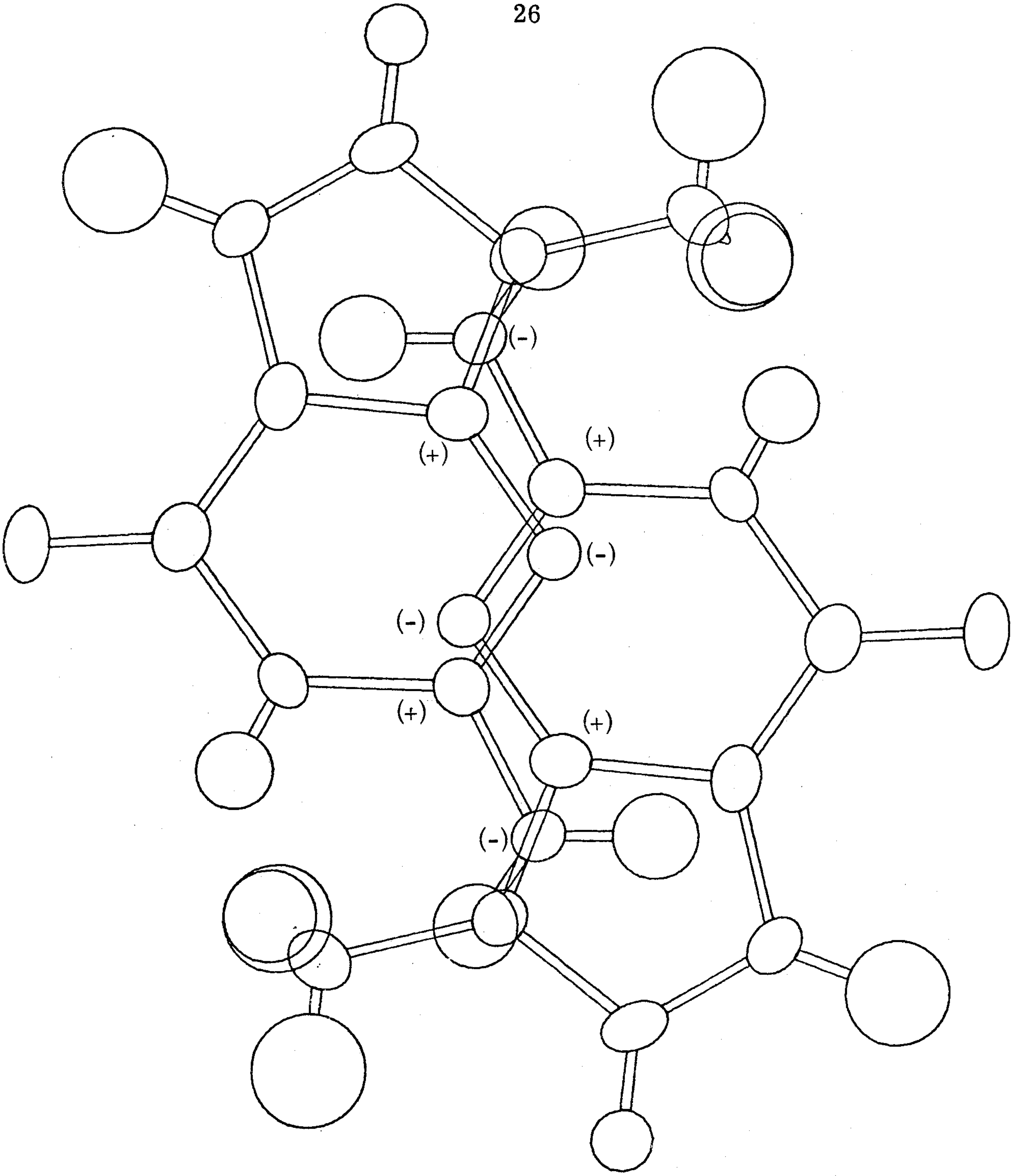


The bond lengths (Å) and angles. Hydrogen bonds are shown as dashed lines.

(Iball and Wilson, 1965)

Figure 4

View normal to molecular planes



B.

A preliminary report on the crystal structure of a bicyclic diammonium ion containing a caged chloride

$[C_{27}H_{56}N_2Cl]^+[H_{13}O_6]^+ 2Cl^-$

The structure of this complex has been solved by single crystal x-ray analysis. The colorless salt of $C_{27}H_{54}N_2$ crystallizes in the orthorhombic space group C_{mcm} with unit cell dimensions $\underline{a}$ = 15.75Å, $\underline{b}$ = 9.429Å, and $\underline{c}$ = 24.58Å. There are four molecules in the unit cell. The calculated density, D_X, is equal to 1.136 gm cm^{-3} while the measured density, D_m, equals 1.10 gm cm^{-3}.

A sample of $C_{27}H_{54}N_2$, referred to as [9.9.9]-diamine, was obtained from Dr. H. E. Simmons, of the Central Research Department of DuPont, Incorporated. Crystals of the present complex were prepared according to the following procedure. Twenty milligrams of [9.9.9]-diamine were dissolved in 5 ml of 10% HCl, filtered, and allowed to stand at room temperature. Needles (~0.1 by 0.1 by 0.5 mm) formed over a five day period. The vial was opened and the solvent was allowed to evaporate to two-thirds volume. According to Chung-Ho Park of the Central Research Department of Dupont, Incorporated, the crystals were unsuitable for x-ray study as they became opaque upon irradiation. We found that sealing the crystals in quick-drying epoxy cement slowed the decomposition and allowed approximately fifty hours of irradiation before large variations in intensities became apparent. Using this technique, space group and rough unit cell constants were determined from zero, first and second layer Weissenberg photographs and oscillation photographs (mounted down c). Systematic absences consisted of

hkl, $h + k = 2n + 1$,

$h0l$, $l = 2n + 1$,

which suggested three possible space groups: C_{mcm}, $C_{mc}2_1$, $A_{ma}2$. As there was no obvious reason for choosing an acentric space group the centric C_{mcm} was assumed. These photographs also indicated large thermal motions. On a second crystal 1223 data ($4° \leq 2\theta \leq 110°$) were collected on a Datex-automated General Electric diffractometer using CuKα radiation with a Nickel filter. A scan speed of 2° per minute was used with 30 second backgrounds taken on either side of the reflection. Check reflections varied approximately 5% during collection.

A Patterson map of the asymmetric unit was produced and tentative chloride positions were found. At this time we felt we were searching for a caged chloride cation (Figure 5) and a chloride anion. Density measurements indicated four molecules in the cell which left approximately 230 AMU for waters or hydrochlorides in the asymmetric unit. As the cage had to occupy a 4-fold special position and was subject to symmetry limitations, the only position with acceptable symmetry was $0, y, \frac{1}{4}$; $0, y, \frac{3}{4}$.

The Patterson map gave clear indications of a chloride at 0.21,0,0, which was an 8-fold special position. At this point we felt a degree of dismay at the lack of charge balance for if a chloride were placed in the cage, a net negative charge resulted. Again consulting the Patterson, the cage was placed at $y = 0.195$ with a chloride at its center. Successive Fouriers indicated water molecules which congregated to harbor a proton and once again neutrality was restored. Again, Fouriers and difference Fouriers were used to place the carbon atoms of the methylene chains. The difference Fouriers showed evidence of disorder, especially in the chain constrained to the yz mirror plane ($x = 0$). To avoid disorder, the chain would have to contain completely eclipsed hydrogens which is energetically unfavorable. It seems more likely that the bonds zig-zag across the mirror with half populated sites.

At this time the R index equals 18% and refinement is continuing. Although there is a considerable amount of disorder and thermal motion is high, the nitrogen, chloride and water positions seem very stable so a lower R appears promising.

The structure is especially interesting for two reasons. The complete encapsulation of a chloride is a novelty. The N - Cl - N distance at 6.28Å appears to be somewhat short and deserves thought. Also interesting is the protonated water conglomerate (Figure 6). The group is essentially planar and all distances appear reasonable except the O(5) - H^+- O(5)′ distance of 2.38 Å. Considering the large standard deviations due to poor cell constants and high thermal motion this cannot yet be viewed as significantly different from the 2.42 - 2.44 Å distance found in similar water-proton aggregates (Olovsson, 1968)(Johnson and Brunton, 1972). A new data set, perhaps at reduced temperature, may shed more light on this anomaly.

References

1. Broomhead, J. M. (1951). Acta Cryst. 4, 92.
2. Christoph, G. G. (1971). Ph.D. dissertation, Un. of Chicago.
3. Donohue, J. (1968). in Structural Chemistry and Molecular Biology, A. Rich and N. Davidson, Eds. W.H. Freeman and Co., San Francisco, Ca. p. 460.
4. Iball, J. and H. R. Wilson (1965). Proc. Roy. Soc. (London), Series A, 288, 418.
5. International Tables for X-ray Crystallography (1962). Vol. III Birmingham: Kynoch Press.
6. Johnson, C. K. and G. D. Brunton, Paper N1, American Crystallographic Association Winter Meeting, Albuquerque, N.M. April 3-7, 1972.
7. Marsh, R. E. in Structural Chemistry and Molecular Biology, A. Rich and N. Davidson, Eds. W. H. Freeman and Co., San Francisco, Ca. 1968, p. 485.
8. O'Brien, E. J. (1963). J. Mol. Biol. 7, 107.
9. O'Brien, E. J. (1967). J. Mol. Biol. 22, 377.
10. O'Brien, E. J. (1967). Acta Cryst. 23, 92.
11. Olovsson, I. (1968). J. Chem. Phys. 49, 1063.

12. Park, C. DuPont, Inc., Central Research Dept., Experimental Station, Wilmington, Del. 19808. personal communication.

13. Simmons, H. E. Assoc. Director of Research, DuPont, Inc. Central Research Dept., Experimental Station, Wilmington, Del. 19808. personal communication.

14. Sobell, H. M. and K. Tomita (1964). Acta Cryst. **17**, 126.

15. Stewart, R. F., E. R. Davidson, and W. T. Simpson (1965). J. Chem. Phys. **42**, 3175.

16. Sutor, D. J. (1962). Nature, **195**, 68.

17. Trus, B. L. (1972). Acta Cryst. in press.

18. Watson, J. D. and F. H. C. Crick (1953). Nature, **71**, 737.

Figure 5

Projection down the Z axis

(molecule viewed down the N-Cl-N axis)

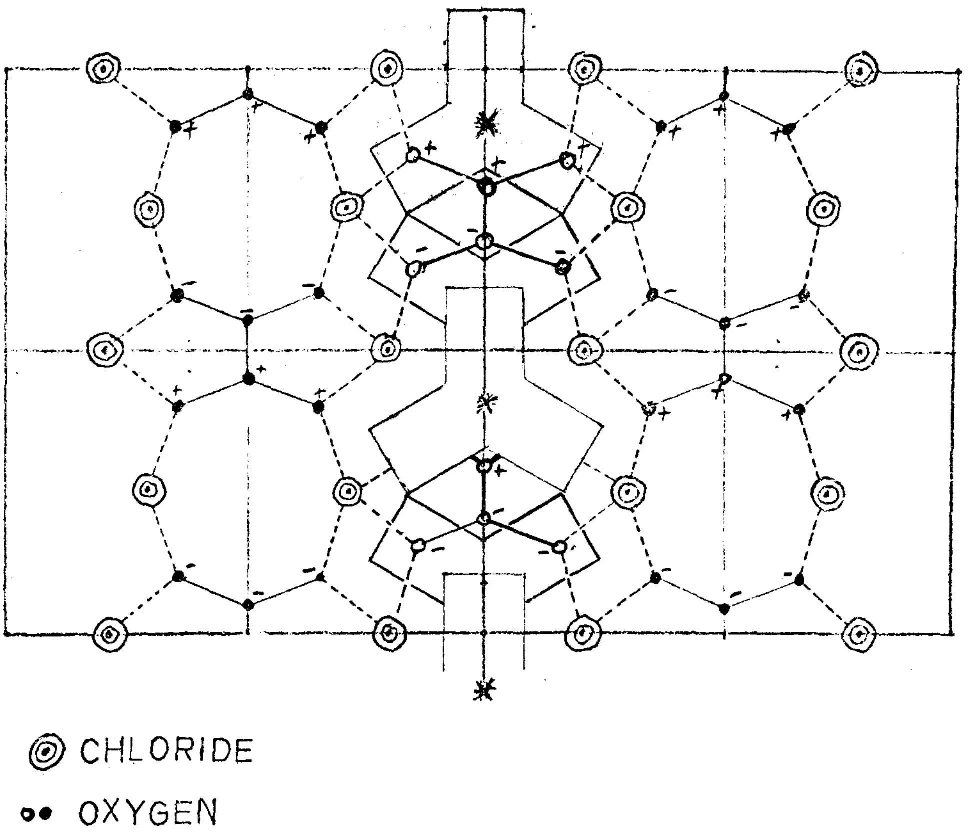
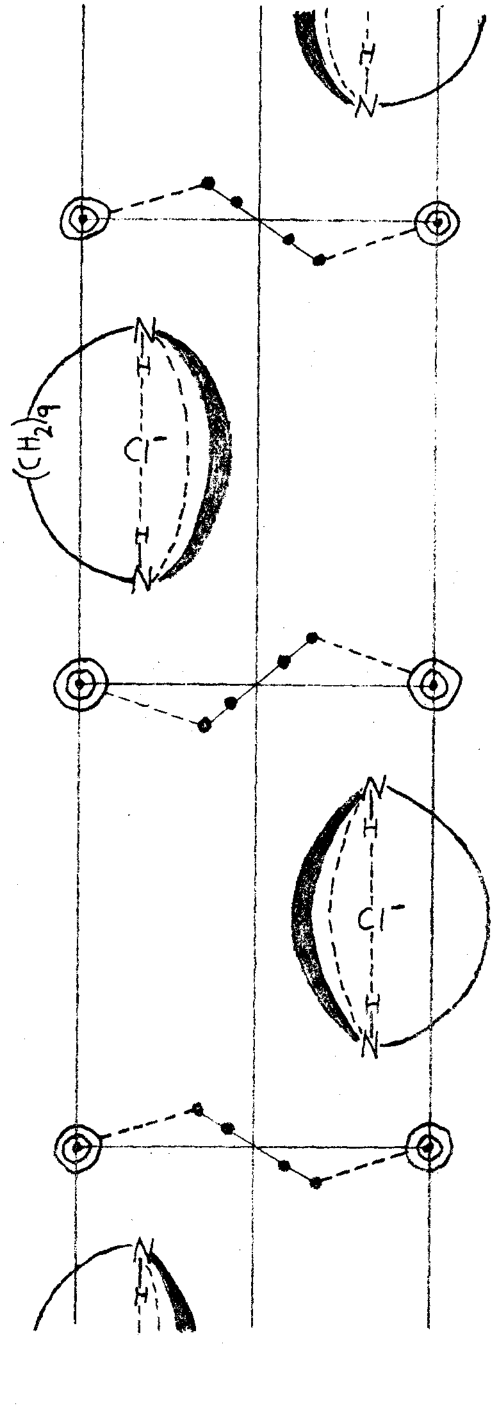

◎ CHLORIDE
○● OXYGEN

Figure 6

Projection down the X axis



◎ CHLORIDE
• OXYGEN