

Structures of *N*-Aminoguanine Hydrochloride Salts

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**Abstract.** 1-Aminoguanine hydrochloride (1),  $C_5H_7N_6O^+.Cl^-$ ,  $M_r = 202.6$ , monoclinic,  $P2_1/a$ ,  $a = 17.927$  (2),  $b = 9.219$  (1),  $c = 4.737$  (1) Å,  $\beta = 93.28$  (1)°,  $V = 781.5$  (2) Å<sup>3</sup>,  $Z = 4$ ,  $D_x = 1.722$  Mg m<sup>-3</sup>,  $\lambda(Cu K\alpha) = 1.5418$  Å,  $\mu = 4.17$  mm<sup>-1</sup>,  $F(000) = 416$ ,  $T = 280$  K,  $R = 0.062$  for 1027 reflections. 7-Aminoguanine hydrochloride monohydrate (2),  $C_5H_7N_6O^+.Cl^- \cdot H_2O$ ,  $M_r = 220.6$ , monoclinic,  $P2_1/a$ ,  $a = 14.665$  (5),  $b = 12.907$  (7),  $c = 4.642$  (5) Å,  $\beta = 91.38$  (5)°,  $V = 878.3$  (11) Å<sup>3</sup>,  $Z = 4$ ,  $D_x = 1.668$  Mg m<sup>-3</sup>,  $\lambda(Cu K\alpha) = 1.5418$  Å,  $\mu = 3.84$  mm<sup>-1</sup>,  $F(000) = 456$ ,  $T = 280$  K,  $R = 0.068$  for 897 reflections. 9-Aminoguanine hydrochloride (3),  $C_5H_7N_6O^+.Cl^-$ ,  $M_r = 202.6$ , monoclinic,  $P2_1/n$ ,  $a = 4.778$  (1),  $b = 14.142$  (2),  $c = 11.736$  (2) Å,  $\beta = 97.77$  (1)°,  $V = 785.9$  (2) Å<sup>3</sup>,  $Z = 4$ ,  $D_x = 1.713$  Mg m<sup>-3</sup>,  $\lambda(Cu K\alpha) = 1.5418$  Å,  $\mu = 4.15$  mm<sup>-1</sup>,  $F(000) = 416$ ,  $T = 280$  K,  $R = 0.061$  for 971 reflections. The three *N*-aminoguanine molecules take a cationic form with the protonation at the ring-N atom in the imidazole moiety. For the most part, the corresponding bond lengths and angles of (1), (2) and (3) are in agreement with each other. Extensive hydrogen-bond networks are formed in all three crystals.

**Introduction.** X-ray data for many modified nucleic acid bases have been reported, but the molecular dimensions of the purine bases aminated at the ring-N atoms have not been elucidated. Recently we synthesized all the positional isomers of ring-N monoaminated guanines (Kohda, Yasuda, Ukai, Baba, Yamagata & Kawazoe, 1989). Among them, 1-, 7- and 9-aminoguanines could be crystallized as their hydrochloride salts. In this report, we describe the crystal structures of these *N*-aminoguanine hydrochloride salts.

**Experimental.** 1-, 7- and 9-aminoguanines synthesized as described in a previous paper (Kohda, Yasuda, Ukai, Baba, Yamagata & Kawazoe, 1989) were crystallized from 1M HCl solution. Experimen-

tal conditions and refinement details are listed in Table 1.\* Lp corrections, no absorption corrections. All structures solved by direct methods using *MULTAN78* (Main, Hull, Lessinger, Germain, Declercq & Woolfson, 1978) and refined by block-diagonal least squares (on  $F$ ). All H-atom positions located on difference Fourier maps and refined with isotropic temperature factors. Scattering factors from *International Tables for X-ray Crystallography* (1974, Vol. IV, pp. 72–75), anomalous-dispersion effects not considered, programs used were from *The Universal Crystallographic Computing System—Osaka* (1979) on an ACOS 850 computer at the Protein Engineering Research Center, Institute for Protein Research, Osaka University.

**Discussion.** The final atomic parameters are listed in Table 2. The bond lengths and angles of (1)–(3) are summarized in Table 3. The molecular packing and the atomic numbering of the crystals (1)–(3) are illustrated (Johnson, 1976) in Figs. 1–3.

All *N*-aminoguanine molecules are protonated at the ring-N atom of the imidazole moiety. Each *N*-aminoguanine base is essentially planar and the N(10) atom of the *N*-amino group is displaced from the least-squares purine plane by 0.045 (5) Å for (1), 0.028 (8) Å for (2) and 0.083 (6) Å for (3). In spite of the fact that the site of *N*-amination is different, the corresponding bond lengths and angles of (1), (2) and (3) display similar values for the most part; the greatest deviation is observed in the N—N(10) bond length (Table 2). As expected, the bond angles of all *N*-aminoguanine bases show the typical feature of the N(7)-protonated guanine residue (Taylor & Kennard, 1982), whilst the bond lengths of the three *N*-aminoguanines are in the range between the

\* Lists of structure factors, anisotropic thermal parameters and H-atom coordinates for (1)–(3) have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 54471 (17 pp.). Copies may be obtained through The Technical Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 1. Experimental conditions and refinement details

	(1)	(2)	(3)
Crystal shape	Needle	Needle	Needle
Crystal size (mm)	0.3 × 0.05 × 0.03	0.5 × 0.03 × 0.03	0.3 × 0.1 × 0.05
Diffractometer	Rigaku AFC-5R		
Radiation	Cu K $\alpha$ (40 kV 240 mA)		
Monochromator	Graphite		
Scan mode	$\omega$ -2 $\theta$ scan		
Scan limits, 2 $\theta$ (°)	120		
No. of reflections for measuring lattice parameters	24	24	44
2 $\theta$ range (°) for measuring lattice parameters	27 < 2 $\theta$ < 45	30 < 2 $\theta$ < 47	25 < 2 $\theta$ < 57
Range of $h$	-20 ≤ $h$ ≤ 20	-16 ≤ $h$ ≤ 16	0 ≤ $h$ ≤ 5
$k$	0 ≤ $k$ ≤ 10	0 ≤ $k$ ≤ 14	0 ≤ $k$ ≤ 15
$l$	0 ≤ $l$ ≤ 5	0 ≤ $l$ ≤ 5	-13 ≤ $l$ ≤ 13
Intensity fluctuation (%) of standard reflections	< 3	< 2	< 5
No. of measured reflections	1322	1486	1336
No. of independent reflections	1163	1306	1173
No. of observed reflections	1027	897	971
Criterion for observed reflections	> 1 $\sigma$ ( $F_o$ )	> 3 $\sigma$ ( $F_o$ )	> 3 $\sigma$ ( $F_o$ )
$R_{int}$	0.034	0.060	0.042
No. of parameters	147	164	147
$S$	1.46	1.17	2.37
$R, wR$	0.062, 0.048	0.068, 0.076	0.061, 0.061
$w$	1/ $\sigma^2$	1/( $\sigma^2 + 0.04F_o + 0.001F_o^2$ )	1/ $\sigma^2$
$\Delta\rho_{max}$ (e Å $^{-3}$ )	0.4	0.5	0.4
( $\Delta/\sigma$ ) $_{max}$	0.30	0.30	0.13

Table 2. Final atomic parameters for non-H atoms

$$B_{eq} = (4/3)\sum_i\sum_j\beta_{ij}a_i \cdot a_j$$

	$x$	$y$	$z$	$B_{eq}$ (Å $^2$ )
(1) 1-Aminoguanine hydrochloride				
Cl(1)	0.2525 (1)	0.1123 (1)	0.4943 (2)	2.6 (0)
N(1)	0.5751 (2)	0.2302 (4)	0.9933 (7)	2.2 (1)
C(2)	0.5458 (2)	0.1426 (4)	1.1955 (8)	2.4 (1)
N(3)	0.4739 (2)	0.1455 (4)	1.2508 (7)	2.3 (1)
C(4)	0.4341 (2)	0.2402 (4)	1.0904 (8)	2.0 (1)
C(5)	0.4576 (2)	0.3286 (4)	0.8802 (8)	2.2 (1)
C(6)	0.5345 (2)	0.3283 (4)	0.8191 (8)	2.3 (1)
N(7)	0.3967 (2)	0.4071 (4)	0.7730 (7)	2.4 (1)
C(8)	0.3380 (2)	0.3674 (5)	0.9132 (8)	2.7 (1)
N(9)	0.3583 (2)	0.2676 (4)	1.1056 (7)	2.5 (1)
N(2)	0.5920 (2)	0.0546 (4)	1.3413 (7)	2.7 (1)
O(6)	0.5658 (2)	0.4000 (3)	0.6417 (6)	3.0 (1)
N(10)	0.6534 (2)	0.2170 (4)	0.9608 (7)	2.8 (1)
(2) 7-Aminoguanine hydrochloride monohydrate				
Cl(1)	0.3523 (1)	0.5236 (2)	0.8311 (4)	4.3 (0)
O(W1)	0.2369 (3)	0.3674 (4)	0.2295 (11)	4.5 (1)
N(1)	0.3381 (3)	0.1252 (4)	1.0334 (11)	3.0 (1)
C(2)	0.4024 (4)	0.0805 (5)	1.2086 (13)	2.7 (2)
N(3)	0.4910 (3)	0.1027 (4)	1.1993 (11)	2.9 (1)
C(4)	0.5087 (4)	0.1748 (5)	0.9959 (14)	2.7 (2)
C(5)	0.4470 (4)	0.2240 (5)	0.8140 (13)	2.7 (2)
C(6)	0.3527 (4)	0.2000 (5)	0.8223 (13)	2.8 (2)
N(7)	0.4965 (3)	0.2938 (4)	0.6520 (11)	3.1 (1)
C(8)	0.5834 (4)	0.2850 (5)	0.7265 (14)	3.2 (2)
N(9)	0.5933 (3)	0.2128 (4)	0.9357 (12)	3.3 (1)
N(2)	0.3734 (3)	0.0086 (4)	1.3930 (11)	3.5 (2)
O(6)	0.2892 (3)	0.2340 (4)	0.6744 (10)	3.6 (1)
N(10)	0.4569 (4)	0.3579 (5)	0.4256 (13)	4.2 (2)
(3) 9-Aminoguanine hydrochloride				
Cl(1)	0.5618 (3)	0.1372 (1)	0.0382 (1)	3.5 (0)
N(1)	0.4874 (8)	0.3298 (3)	0.9159 (3)	2.5 (1)
C(2)	0.2981 (10)	0.3937 (3)	0.9488 (4)	2.3 (1)
N(3)	0.2417 (8)	0.4762 (3)	0.8994 (3)	2.3 (1)
C(4)	0.3890 (9)	0.4895 (3)	0.8090 (4)	2.2 (1)
C(5)	0.5773 (9)	0.4282 (3)	0.7695 (4)	2.3 (1)
C(6)	0.6380 (10)	0.3407 (3)	0.8213 (4)	2.7 (1)
N(7)	0.6722 (8)	0.4725 (3)	0.6752 (3)	2.7 (1)
C(8)	0.5487 (11)	0.5547 (4)	0.6594 (4)	2.8 (1)
N(9)	0.3763 (8)	0.5686 (3)	0.7410 (3)	2.4 (1)
N(2)	0.1719 (8)	0.3690 (3)	1.0409 (3)	2.9 (1)
O(6)	0.7945 (7)	0.2773 (3)	0.7967 (3)	3.5 (1)
N(10)	0.2162 (9)	0.6489 (3)	0.7586 (4)	3.2 (1)

Table 3. Bond lengths (Å) and angles (°) for *N*-aminoguanines

	(1)	(2)	(3)
N(1)—C(2)	1.380 (5)	1.360 (8)	1.372 (6)
C(2)—N(3)	1.329 (5)	1.332 (8)	1.315 (6)
N(3)—C(4)	1.337 (5)	1.355 (8)	1.363 (6)
C(4)—C(5)	1.371 (5)	1.378 (8)	1.374 (7)
C(5)—C(6)	1.425 (6)	1.419 (8)	1.393 (7)
N(1)—C(6)	1.400 (5)	1.395 (8)	1.411 (6)
C(5)—N(7)	1.382 (5)	1.390 (8)	1.400 (6)
N(7)—C(8)	1.328 (5)	1.316 (8)	1.306 (7)
C(8)—N(9)	1.331 (5)	1.352 (8)	1.360 (6)
C(4)—N(9)	1.388 (5)	1.370 (8)	1.370 (6)
N(1,7,9)—N(10)	1.427 (5)	1.448 (8)	1.402 (6)
C(6)—O(6)	1.230 (5)	1.225 (7)	1.227 (6)
C(2)—N(2)	1.325 (5)	1.339 (8)	1.352 (6)
C(6)—N(1)—C(2)	125.5 (3)	126.7 (5)	125.1 (4)
N(1)—C(2)—N(3)	122.5 (4)	123.5 (5)	124.4 (4)
C(2)—N(3)—C(4)	113.2 (3)	111.9 (5)	111.7 (4)
N(3)—C(4)—C(5)	128.6 (4)	127.6 (6)	127.4 (4)
C(4)—C(5)—C(6)	119.2 (4)	120.6 (5)	121.3 (4)
C(5)—C(6)—N(1)	110.9 (3)	109.7 (5)	110.1 (4)
C(4)—C(5)—N(7)	108.0 (3)	106.7 (5)	106.5 (4)
C(5)—N(7)—C(8)	107.7 (3)	108.4 (5)	108.7 (4)
N(7)—C(8)—N(9)	109.9 (4)	109.6 (5)	109.5 (4)
C(8)—N(9)—C(4)	108.7 (3)	108.1 (5)	108.1 (4)
N(9)—C(4)—C(5)	105.8 (3)	107.1 (5)	107.2 (4)
N(3)—C(4)—N(9)	125.6 (3)	125.3 (5)	125.4 (4)
C(6)—C(5)—N(7)	132.8 (4)	132.7 (5)	132.2 (4)
N(1)—C(2)—N(2)	117.9 (4)	116.7 (5)	116.0 (4)
N(3)—C(2)—N(2)	119.6 (4)	119.7 (5)	119.6 (4)
N(1)—C(6)—O(6)	120.5 (4)	120.9 (5)	119.7 (4)
C(5)—C(6)—O(6)	128.6 (4)	129.4 (6)	130.2 (5)
C(2)—N(1)—N(10)	116.2 (3)	—	—
C(6)—N(1)—N(10)	118.2 (3)	—	—
C(5)—N(7)—N(10)	—	123.9 (5)	—
C(8)—N(7)—N(10)	—	127.5 (5)	—
C(8)—N(9)—N(10)	—	—	128.0 (4)
C(4)—N(9)—N(10)	—	—	123.9 (4)

neutral and protonated distances. The bond lengths in (3) are closer to those of the neutral guanine residue than the protonated one, although (3) is protonated at N(7). The delocalization of electrons in the N(7)—C(8)—N(9) fragment of (3) is not as strong as it is in (1) and the protonated guanine residue. This may be a result of the different substituent at N(9). It is worth noting that the geometry of the *N*-amino group shows that the N(10) atom is in an  $sp^3$  hybridization state although the amino group does not have the —NH $_3$  structure upon protonation. The N—N(10) bond lengths are distributed in the range 1.402 (6)—1.448 (8) Å, which corresponds to a usual bond length between the  $sp^2$ - and  $sp^3$ -hybridized N atoms (Ardebili & White, 1978; Kashino, Negishi & Hayatsu, 1988). The UV spectra and the  $pK_a$  values of *N*-aminoguanines were very similar to those for the corresponding *N*-methylguanines (Kohda, Yasuda, Ukai, Baba, Yamagata & Kawazoe, 1989). This observation is consistent with the results of the X-ray analyses, which show that the N(10) atom takes an  $sp^3$  hybrid form and that the protonation occurs on the ring-N atom similar to the *N*-methylguanine derivatives.

The crystal packings of the three *N*-aminoguanine hydrochloride salts are shown in Figs. 1, 2 and 3. In (1) and (3), the base-paired dimers with two hydrogen bonds are formed between adjacent *N*-

aminoguanine bases related by a center of symmetry:  $N(7)\cdots O(6)$  2.761 (4),  $H(N7)\cdots O(6)$  1.79 (4) Å and  $N(7)-H\cdots O(6)$  160 (4)° for (1) and  $N(2)\cdots N(3)$  3.092 (6),  $H(N2)\cdots N(3)$  2.10 (6) Å and  $N(2)-H\cdots N(3)$  172 (5)° for (3). Both paired bases stack to the ones related by one unit translation along the *c* axis for (1) and the *a* axis for (3). The major overlappings are observed between the polar substituents

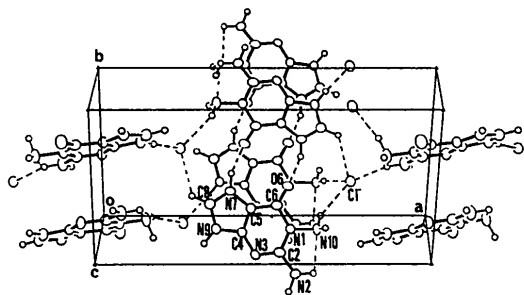


Fig. 1. Crystal structure of (1). Dotted lines indicate the hydrogen bonds.

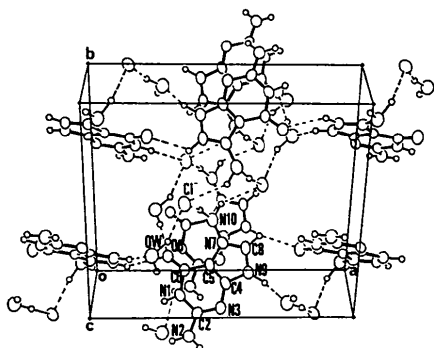


Fig. 2. Crystal structure of (2). Dotted lines indicate the hydrogen bonds.

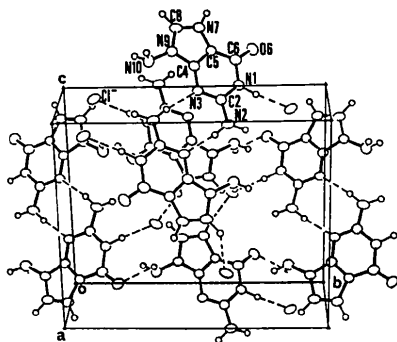


Fig. 3. Crystal structure of (3). Dotted lines indicate the hydrogen bonds.

and the purine rings; the carbonyl group and the pyrimidine moiety with a separation of *ca* 3.2 Å in (1), and the amino group at C(2) and the pyrimidine moiety with a separation of *ca* 3.3 Å in (3). In (2), two amino groups overlap with the pyrimidine moiety and the separation distance is *ca* 3.2 Å. Such overlappings are frequently found in many crystal structures of nucleic acid bases, nucleosides and nucleotides (Bugg, Thomas, Sundaralingam & Rao, 1971). In all three crystals, all the H atoms attached to N and O atoms except one H atom on N(2) participate in hydrogen bonds. In (1) an intramolecular hydrogen bond,  $N(2)-H\cdots N(10)$ , exists [ $N(10)\cdots H$  2.27 (5) Å]. All  $Cl^-$  ions connect to *N*-aminoguanines through  $N-H\cdots Cl$  hydrogen bonds. In addition, the  $Cl^-$  ion in (2) participates in an  $O-H\cdots Cl$  hydrogen bond with the water molecule. Weak  $C-H\cdots Cl/O$  type hydrogen bonds are also found in all crystals, *i.e.*,  $C(8)-H\cdots Cl^-$  [ $C(8)\cdots Cl$  3.331 (4),  $H\cdots Cl^-$  2.64 (5) Å] for (1),  $C(8)-H\cdots O(6)$  [ $C(8)\cdots O(6)$  3.044 (8),  $H\cdots O(6)$  2.39 (6) Å] for (2) and  $C(8)-H\cdots Cl^-$  [ $C(8)\cdots Cl^-$  3.371 (5),  $H\cdots Cl^-$  2.58 (5) Å] for (3). Similarly the H atoms on C(8) of 7-methylguanosine and its hydroiodide with the protonated imidazole ring participate in hydrogen bonds (Yamagata, Fukumoto, Hamada, Fujiwara & Tomita, 1983). These data show that the H atom on C(8) of the protonated guanine has the more positive net charge than an H atom on the usual guanine and has the ability as a donor of a hydrogen bond. Thus all the packing diagrams (Figs. 1–3) reveal extensive three-dimensional networks of hydrogen bonds.

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