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The Crystal Structures of Salts of Methylated Purines and Pyrimidines. II. 9-methyladenine Dihydrobromide

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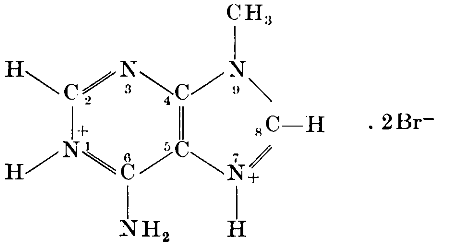
Crystals of 9-methyladenine dihydrobromide are orthorhombic with

$$a = 17{\cdot}59,\ b = 4{\cdot}88, \text{ and } c = 11{\cdot}75 \text{ Å}.$$

The space group is $Pna2_1$ with four molecules in the unit cell. The molecular structure has been determined by means of the heavy atom method from the $h0l$ and $hk0$ projections. Bond lengths and angles are given, e.s.d. 0·1 Å and 6°. Each cation is surrounded by a three-dimensional network of bromine ions and forms three short N–H · · · Br bonds involving the protonated nitrogen atoms N(1) and N(7) and the 6-amino group. There are no inter-purine hydrogen bonds formed.

Introduction

As part of this series of studies of salts of methylated purines and pyrimidines we have determined the crystal and molecular structure of 9-methyladenine dihydrobromide using two-dimensional X-ray diffraction methods.



Preliminary details of this structure analysis have been given previously (Bryan & Tomita, 1961).

Experimental

Crystals of the salt directly suited to X-ray study were obtained by adding an excess of hydrobromic acid to an aqueous solution of 9-methyladenine which was then allowed to evaporate to dryness at room temperature. The crystals so formed are colourless needles elongated along the b-axis.

The unit cell dimensions and space group were determined from 30° precession photographs taken with Cu $K\alpha$ radiation.

Crystal data

9-Methyladenine dihydrobromide,

$$C_6H_7N_5.2HBr,\ M = 311{\cdot}0\,.$$

Orthorhombic prismatic,

$$a = 17{\cdot}59 \pm 0{\cdot}06,\ b = 4{\cdot}88 \pm 0{\cdot}02,\ c = 11{\cdot}75 \pm 0{\cdot}04 \text{ Å}.$$

Volume of the unit cell, 1008·6 Å^3, $D_m = 2{\cdot}06$ g.cm.$^{-3}$, $Z = 4$, $D_c = 2{\cdot}03$ g.cm.$^{-3}$, $F(000) = 600$, $\mu = 98{\cdot}9$ cm.$^{-1}$ for Cu $K\alpha$ radiation.

The systematic absences in the diffraction pattern indicate as possible space groups $Pna2_1$ or $Pnam$. Because there are four molecules in the unit cell the more likely space group is $Pna2_1$, since in such circumstances in $Pnam$ the molecules would be required to lie in mirror planes of symmetry 5·9 Å apart, a situation which seems intrinsically unlikely and for which there is no supporting evidence to be found in the distribution of diffracted intensity.

Intensity data

Intensities were recorded photographically. The $h0l$ reflections were collected from a very small crystal (reflecting cross section 0·1 mm.^{2}) by using the multiple-film technique with Cu $K\alpha$ radiation. 140 structure amplitudes were obtained of which about ten were of zero magnitude. For $hk0$, 30° precession photographs, taken with Mo $K\alpha$ radiation, were used to give 107 structure amplitudes, 88 of which were of non-zero magnitude. In each case the structure amplitudes were placed approximately on an absolute scale by making use of Wilson's (1942) method. Care was taken in selecting the crystals to choose them as nearly equi-dimensional as possible but it is not to be expected that errors due to absorption will be other than sizeable. No corrections for absorption were applied, however, since no very accurate molecular dimensions were sought.

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Structure determination

The relative x- and z-coordinates of the two bromine ions were first determined from the Patterson function $P(u, w)$ and a preliminary trial structure was quickly found from a Fourier synthesis based on the phases due to these two ions. This trial structure was refined by successive Fourier syntheses. The fourth such synthesis is shown in Fig. 1.

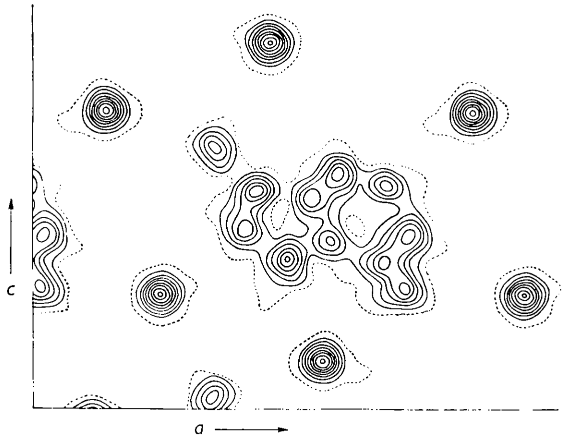

Fig. 1. Electron-density projection $\varrho(x, z)$. Contours are at equal but arbitrary intervals, every fifth contour only being drawn at the bromine ions.

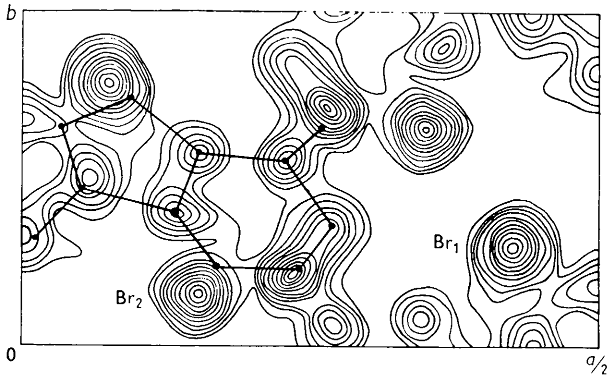

Fig. 2. Electron-density projection $\varrho(x, y)$. Contours as in Fig. 1. The projection of one molecule is indicated by the solid lines.

The y-coordinates of the atoms were found in a similar manner. The final electron-density projection $\varrho(x, y)$ is shown in Fig. 2.

Refinement

Six cycles of least-squares refinement were used to refine the x- and z-coordinates of the atoms. This process was carried out by means of the crystallographic least-squares refinement program of Busing & Levy (1959) on an IBM 709 data processing machine. Isotropic temperature factors were employed and contributions from hydrogen atoms in fixed conventional positions were included in the structure factors. The final value of R, excluding unobserved reflections, was 0·07.

Because of the severe overlapping of atoms in the $hk0$ projection the refinement there was carried on by means of difference syntheses, the values of the x-coordinates being held fixed at the values resulting from the final least-squares cycle in $h0l$. The final R here was 0·11.

Table 1. *Final atomic coordinates expressed as fractions of the unit cell edges*

Origin on the space group diad screw axis

Atom	x/a	y/b	z/c
Br(1)	0·5733	0·2003	0·2354
Br(2)	0·1502	0·1565	0·0987
N(1)	0·2692	0·3577	0·3570
N(3)	0·1678	0·1932	0·4790
N(7)	0·0950	0·7222	0·2953
N(9)	0·0575	0·4978	0·4388
N(10)	0·2597	0·7400	0·2335
C(2)	0·2410	0·2051	0·4439
C(4)	0·1304	0·4045	0·4272
C(5)	0·1549	0·5772	0·3394
C(6)	0·2283	0·5568	0·2987
C(8)	0·0357	0·6934	0·3644
C(11)	0·0083	0·3437	0·5185

The scattering functions which were used were the same as those described in the case of 1-methylcytosine hydrobromide (Bryan & Tomita, 1962).

In Table 1 are listed the final values for the atomic coordinates and in Table 2 structure factors calculated from these coordinates are compared with the structure amplitudes.

Description and discussion of the structure

The standard deviations in atomic coordinates $\sigma(x)$ and $\sigma(z)$ given by the least squares program are both equal to 0·07 Å. Although the value of $\sigma(y)$ might be

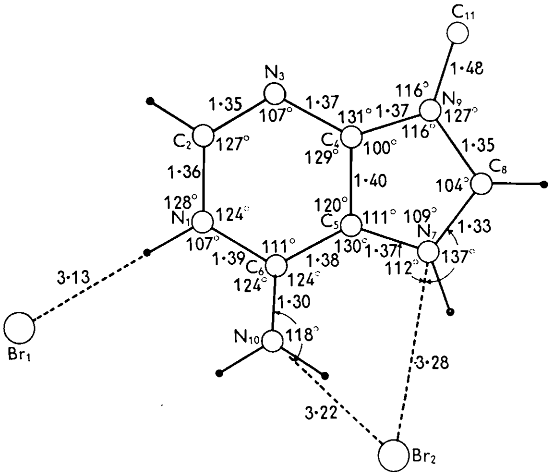

Fig. 3. Bond lengths and angles as determined for the asymmetric unit of 9-methyladenine dihydrobromide.

Table 2. *Observed and calculated structure factors for h0l and hk0 for 9-methyladenine dihydrobromide*

Accidentally absent reflections are omitted for brevity

h 0 l		F_o	F_c
2	0	3.3	7.5
4		39.3	36.5
6		18.9	19.3
8		7.6	6.2
10		58.3	57.2
12		35.5	37.9
14		32.0	34.1
16		8.6	8.0
2	1	16.2	19.5
4		80.8	81.0
6		46.2	52.6
8		55.0	58.1
10		31.1	34.1
12		17.7	19.2
14		11.3	9.4
16		14.2	12.8
18		25.0	24.3
22		7.1	7.8
0	2	43.1	38.6
2		22.4	23.3
4		56.3	52.2
6		96.7	96.4
8		36.7	35.2
10		19.2	22.1
12		21.2	22.1
14		25.5	26.6
16		11.7	9.8
18		9.7	7.4
20		14.4	12.6
22		5.4	5.3
2	3	113.3	117.7
4		43.3	40.3
6		8.0	7.8
8		37.5	35.6
10		27.0	29.0
12		46.0	47.7
14		11.5	10.9
16		19.7	17.8
0	4	21.9	19.8
2		45.1	46.1
4		34.0	29.9
6		80.0	73.9
8		44.2	40.7
10		25.4	25.9
12		16.8	19.3
16		24.0	24.2
20		15.9	13.7
2	5	82.6	76.2
4		45.8	44.7
6		18.7	20.3
8		17.5	18.2
10		26.7	27.7
12		25.3	28.0
14		22.9	22.6
16		18.4	16.9
18		8.0	8.5
0	6	71.8	66.0
2		28.9	27.8
4		42.2	40.6
6		26.6	29.9
8		18.2	18.9
10		27.4	31.0
12		13.4	13.2
14		24.9	22.6
16		6.9	7.9
18		8.8	7.3
20		7.6	7.3
2	7	12.8	11.2
4		46.5	48.9
6		30.6	31.3
8		44.1	46.4
10		19.6	19.4
12		6.8	5.8
16		5.9	3.2
18		17.9	15.8
0	8	65.8	64.9
2		17.4	15.3
4		23.8	24.2
6		8.9	8.2
8		15.6	15.3
10		25.9	27.7
12		20.8	19.2
14		20.9	18.0
16		8.9	7.8
18		3.7	5.2
2	9	28.6	32.3
4		22.0	27.5
6		14.9	14.5
8		25.7	27.0
10		10.9	12.8
12		20.8	18.8
14		5.7	5.4
16		7.2	7.1
18		6.9	9.5
0	10	20.1	21.2
2		17.2	16.4
4		16.5	19.6
6		29.2	29.9
8		15.3	14.3
10		4.1	4.6
12		5.9	6.5
14		8.7	9.1
16		8.8	10.5
2	11	28.5	30.4
4		6.7	7.3
8		6.4	6.6
10		12.8	12.3
12		15.5	14.4
14		6.9	7.5
0	12	11.2	11.1
2		9.1	7.9
4		11.2	8.5
6		20.2	20.5
8		12.9	12.5
10		11.7	12.1
12		6.0	5.4
2	13	14.3	13.6
4		17.2	16.9
6		10.9	9.9
8		10.8	9.0
10		6.4	7.1
0	14	20.0	19.1
4		7.2	5.5

h k 0		F_o	F_c
1	1	15.4	15.3
3		74.3	59.9-
4		187.7	186.0
5		17.1	15.6-
6		84.6	85.9
7		7.7	13.6
8		122.6	116.3-
9		30.0	31.4-
10		70.0	59.6-
12		12.7	10.7
13		43.2	37.8
14		13.1	13.7-
16		17.8	12.8
17		12.8	15.6-
18		27.3	29.9
22		20.0	19.9-
0	2	135.1	142.8-
1		65.2	60.8-
2		17.4	18.9-
3		21.6	24.0
4		15.5	23.9
5		112.6	112.6
6		39.2	45.4
7		28.8	35.7-
8		24.6	22.8
9		76.8	73.5-
10		12.8	20.3
11		16.0	21.4
12		48.0	46.5-
14		28.2	24.8-
15		23.9	18.6-
17		29.1	29.2
18		10.0	14.0
19		20.2	24.0
21		14.0	13.4-
1	3	90.1	81.8-
2		50.3	47.0-
3		72.7	67.3
4		47.3	48.1-
5		24.7	25.4
7		12.6	8.8
9		44.0	51.9
10		27.0	26.6
11		27.9	21.1
12		9.2	8.3
13		55.7	61.0-
15		8.0	10.7-
16		21.1	21.7-
17		6.3	9.3
0	4	26.1	13.5-
2		25.3	18.7
3		26.0	23.8-
4		34.8	23.3
5		45.0	52.8-
6		48.5	45.7-
7		9.0	10.5
8		23.7	22.1-
9		42.5	42.2
10		27.2	16.9
11		12.7	9.0
14		9.0	10.4-
1	5	18.5	22.7
2		26.6	28.5
3		8.0	8.5-
4		18.6	14.1-
5		15.5	13.9-
6		17.7	15.2-
7		14.7	13.9-
8		12.8	21.7
12		13.4	12.3-
13		12.0	18.4
0	6	14.9	18.4
3		16.4	18.2

expected to be lower than this since the y-coordinates were derived from a centrosymmetric projection the general overlap in the [010] projection probably means that in fact $\sigma(y)$ will be about the same magnitude. These values apply to the light atoms, in the case of the bromine ions $\sigma(r)$ is nearer 0·01 Å. For a bond involving light atoms the standard deviation in length is thus around 0·1 Å and for a bond angle is about 6°. No great significance therefore attaches to the dimensions found in this present analysis for the cation of 9-methyladenine which are shown in Fig. 3. Although these dimensions are in fair agreement with those found by Cochran (1951) in his much more accurate analysis of the structure of adenine hydrochloride, no comparison of points of detail is worthwhile.

More worthy of comment is the general arrangement of the molecules within the unit cell. Each cation of 9-methyladenine lies surrounded by a three-dimensional network of bromine ions. The distances $\mathrm{N(1)\cdots Br(1)^{I}}$, $\mathrm{N(7)\cdots Br(2)^{I}}$, and $\mathrm{N(10)\cdots Br(2)^{I}}$ are 3·13, 3·28, and 3·21 Å respectively, and it is deduced that these approaches correspond to hydrogen bond formation. All are shorter, although the diminution in length is of doubtful significance, than the more commonly occurring length of 3·4 Å. The distance $\mathrm{N(10)\cdots Br(1)}$ is 3·64 Å, but is not presumed to represent a hydrogen bond since the proton involved points roughly midway between Br(1) and the corresponding bromine ion at $1+y$. Other intermolecular approach distances are illustrated in Fig. 4.

There are no inter-ring hydrogen bonds formed of

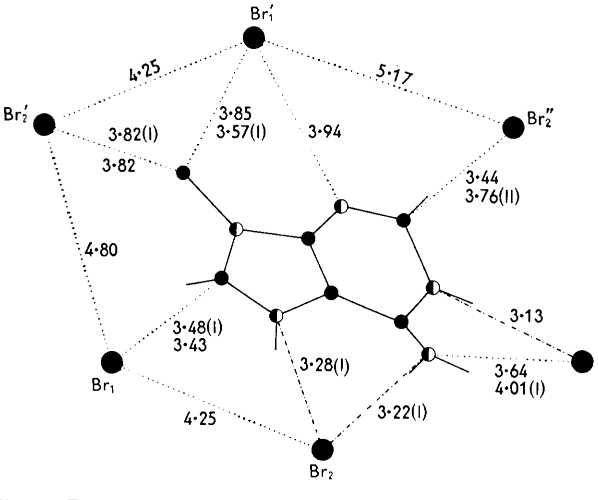

Fig. 4. Projection of the structure on (010) showing the various intermolecular approach distances. Postulated hydrogen bonds are indicated by the broken lines, van der Waals' contacts by the dotted lines. Nitrogen atoms are represented by half-dark circles, carbons by full circles. The larger full circles represent the bromine ions. I represents distance to Br at $y+1$, II represents distance to Br at $y-1$.

the kind which occur in either the structure of adenine hydrochloride (Cochran, 1951), or guanine hydrochloride (Broomhead, 1951). This may be attributed to the difficulty of bringing together the positively charged purine rings so as to form such inter-molecular hydrogen bonds, or to the fact that access to the only remaining acceptor atom N(3) is in some measure hindered by the presence of the 9-methyl group.

The observation that the protonation of the 9-methyladenine molecule occurs on N(1) and N(7) lends support to the structure proposed by Rich, Davies, Crick, and Watson for polyadenylic acid (Rich *et al.*, 1961). The hydrogen bond scheme proposed by these authors involves pairs of bonds between the 6-amino group and N(7). It is observed that at low pH the degree of orientation in the structure is greatly reduced and this finds a logical explanation in the observation that this corresponds to the breakdown of the hydrogen bond system subsequent to the addition of a proton to N(7).

The adenine molecules themselves are planar. The equation describing the molecular plane (Blow, 1960) is

$$0{\cdot}2598X+0{\cdot}6713\,Y+0{\cdot}6945Z-5{\cdot}3613=0\ .$$

The average deviation from this plane is 0·07 Å and the maximum deviation is 0·15 Å. The perpendicular distance between molecules of 9-methyladenine is 3·27 Å.

Many of the calculations involved in this analysis were performed at the M.I.T. Computation Centre with the help of their IBM 709 data processing machinery. The work was supported by grants from the National Cancer Institute of the U.S. Public Health Service and the American Cancer Society. One of us (R. F. B.) was in receipt of a U.S. Public Health Service Postdoctoral Fellowship.

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Short Communications

Contributions intended for publication under this heading should be expressly so marked; they should not exceed about 1000 *words; they should be forwarded in the usual way to the appropriate Co-editor; they will be published as speedily as possible. Publication will be quicker if the contributions are without illustrations.*

Acta Cryst. (1962). **15**, 1182

Additionsverbindungen des Schwefels. Beiträge zur Chemie des Schwefels, 55.

Von F. FEHÉR, D. HIRSCHFELD und K.-H. LINKE, *Institut für Anorganische Chemie der Universität Köln, Deutschland*

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Im Rahmen der am hiesigen Institut durchgeführten Arbeiten über Schwefel und seine Verbindungen wurden die Untersuchungen der erstmals von Auger (1908), Demassieux (1909) sowie Rheinboldt (1929, 1924) und Schneider (1928) beschriebenen Additionsverbindungen des Schwefels mit anorganischen bzw. organischen Jodiden wieder aufgenommen. Es handelt sich dabei um Verbindungen des allgemeinen Typus $R\mathrm{J}_n.n\mathrm{S}_8$ (z.B. $\mathrm{AsJ_3.3S_8}$, $\mathrm{CHJ_3.3S_8}$, $\mathrm{C_2J_4.4S_8}$).

Bei Versuchen, weitere Additionsverbindungen aufzufinden — die Additionsfähigkeit ist auf sehr wenige Jodide beschränkt — gelang es uns, die Verbindung $\mathrm{P_2J_4.4S_8}$ aus $\mathrm{P_2J_4}$ und Schwefel analog den obigen Verbindungen darzustellen. Sie kristallisiert in gut ausgebildeten Prismen, Fp. 66–68 °C., und ist an der Luft sehr unbeständig. (S:ber. 64,29%, gef. 64,58%; J:ber. 31,82%, gef. 32,01%; P:ber. 3,89%, gef. 3,69%).

Während in den oben angegebenen Arbeiten bereits gezeigt wurde, dass einerseits die Additionsfähigkeit für Schwefel verloren geht, wenn Jod teilweise durch andere Substituenten ersetzt wird, ergaben unsere Untersuchungen, dass andererseits auch der $\mathrm{S_8}$-Ring nicht durch andere, ihm sehr ähnliche Ringsysteme ersetzt werden kann. So konnten bei Verwendung von $\mathrm{S_7NH}$, $\mathrm{S_4N_4}$ und $\mathrm{S_4(NH)_4}$ unter analogen Reaktionsbedingungen die entsprechenden Additionsverbindungen nicht aufgefunden werden.

Die IR-Spektren von $\mathrm{CHJ_3.3S_8}$, $\mathrm{AsJ_3.3S_8}$ und $\mathrm{C_2J_4.4S_8}$ zeigten im Bereich von 2–24μ ausser den Banden der einzelnen Komponenten keine zusätzlichen Absorptionen oder Bandenverschiebungen. Auch ramanspektroskopische Untersuchungen (Erregerlinie Hg_c) zeigten keine Veränderungen der Spektren der Additionsverbindungen gegenüber denen der entsprechenden Ausgangsprodukte.

Aufgrund von Debye–Scherrer-, Drehkristall-, Goniometer- und Retigraphenaufnahmen konnten die von Hertel (1931) und West (1937) ermittelten kristallographischen Daten für das $\mathrm{CHJ_3.3S_8}$ bestätigt werden. Von uns mit dem Zählrohrgoniometer durchgeführte Intensitätsmessungen und anschliessende Berechnungen nach der 'Trial and Error'-Methode ergaben für den