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## The Crystal Structure of 8-Aza-2,6-diaminopurine Sulfate Monohydrate

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The crystal and molecular structure of 8-aza-2,6-diaminopurine sulfate monohydrate,  $(C_4N_7H_6)_2SO_4 \cdot H_2O$ , has been determined from three-dimensional diffractometer X-ray data. The material crystallizes in space group  $PI$  of the triclinic system with two formula units in a cell of dimensions  $a = 6.813$  (5),  $b = 15.117$  (11),  $c = 8.182$  (5) Å,  $\alpha = 91.71$  (1),  $\beta = 106.21$  (1), and  $\gamma = 93.57$  (1)°. The observed and calculated densities are 1.71 and 1.72 g cm<sup>-3</sup>, respectively. The structure has been refined by full-matrix least-squares techniques to a final value of the conventional  $R$  value (on  $F$ ) of 0.039 for 2706 independent intensities. The two independent 8-aza-2,6-diaminopurine cations (ADPH) are very similar, and the sites of protonation are at N(3) and N(8); this result is similar to that observed in the 8-azaguaninium cation (AGH) but different from that found in the protonated form of natural purines. The hydrogen bonding in the crystal is extremely complicated, with all hydrogen atoms and all acceptor atoms except N(1) of one ADPH cation participating. The bond lengths and angles in the cations are normal, showing the anticipated effects of the protonation at N(3) and N(8).

### Introduction

8-Aza-2,6-diaminopurine and other 8-azapurines are extremely important analogs of the nucleic acid constituents because of their anti-neoplastic properties; the carcinostatic activities of these compounds vary greatly, however (Montgomery, Johnston & Shealy, 1970), with 8-azaguanine showing a broad range of activity while 8-aza-2,6-diaminopurine is only moderately effective against Adenocarcinoma 755 (Montgomery, 1959). In an attempt to obtain a rational correlation between the molecular structures of these compounds and their biological activities, we have undertaken a series of crystallographic investigations of the aza analogs of nucleic acid constituents. We report here the results of our three-dimensional X-ray determination of the crystal and molecular structure of 8-aza-2,6-

diaminopurine sulfate monohydrate. A preliminary account of this structure has appeared elsewhere (Singh, Lewis, & Hodgson, 1974).

### Experimental

8-Aza-2,6-diaminopurine sulfate was obtained from Sigma Chemical Co., St. Louis, Missouri, and plate-like crystals were grown by slow evaporation of a solution of the compound in 1M sulfuric acid. The cell data are reported in Table 1. The space group was obtained from Weissenberg and precession photography, and the cell constants by least-squares refinement of the locations of 12 reflections on a diffractometer. The crystal used for the data collection had approximate dimensions 0.60 × 0.30 × 0.15 mm and was mounted along the long axis; this direction corresponds to the crystallographic  $a$  axis. Intensity data (see Table 1) were collected using a Picker FACS-I automatic

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diffractometer equipped with a scintillation counter and a graphite monochromator and using Mo  $K\alpha$  radiation. For the cell-constant measurement a small take-off angle of  $1^\circ$  and a narrow slit were used. For the measurement of the intensity data a take-off angle of  $2^\circ$  was used with an open counter. The intensities were measured by the  $\theta$ - $2\theta$  scan technique at a scan rate of  $1^\circ \text{ min}^{-1}$ . Each peak was scanned from  $-0.75^\circ$  below the calculated  $\alpha_1$  peak to  $+0.75^\circ$  above the calculated  $\alpha_2$  peak. The backgrounds were measured at each end of the scan for 10 s. The intensities of three reflections, monitored after every 100 measurements to check on the crystal orientation and the instrument stability, remained essentially constant throughout the data collection period. In total, 2706 reflections with intensities above three times their estimated standard deviations were observed up to a value of  $2\theta(\text{Mo})$  of  $55^\circ$ .

Table 1. *Crystal data for 8-aza-2,6-diaminopurine sulfate monohydrate*

Formula:  $(\text{C}_4\text{N}_6\text{H}_6)_2\text{SO}_4 \cdot \text{H}_2\text{O}$ , F.W. 418.4  
 Space group:  $P\bar{1}$  (triclinic)  
 $a = 6.813$  (5),  $b = 15.117$  (11),  $c = 8.182$  (5) Å  
 $\alpha = 91.71$  (1),  $\beta = 106.21$  (1),  $\gamma = 93.57$  (1) $^\circ$   
 $D_o = 1.71$ ,  $D_c = 1.72 \text{ g cm}^{-3}$ ,  $Z = 2$   
 Mo  $K\alpha$ ,  $\mu = 2.70 \text{ cm}^{-1}$   
 $R = 0.039$ ,  $R_w = 0.049$   
 Number of reflections  $> 3\sigma = 2706$   
 Number of parameters refined = 310

Table 2. *Positional and thermal parameters and their estimated standard deviations*

Form of the thermal ellipsoid is  $\exp[-(\beta_{11}h^2 + \beta_{22}k^2 + \beta_{33}l^2 + 2\beta_{12}hk + 2\beta_{13}hl + 2\beta_{23}kl)]$ . Values for S, O, N and C atoms have been multiplied by  $10^4$ . Positional parameters for H atoms have been multiplied by  $10^3$ .

	$x/a$	$y/b$	$z/c$	$\beta_{11}$	$\beta_{22}$	$\beta_{33}$	$\beta_{12}$	$\beta_{13}$	$\beta_{23}$
S	4818 (1)	2506 (0)	147 (1)	105 (1)	20 (0)	71 (1)	18 (0)	50 (1)	11 (1)
O(1)	3022 (3)	3048 (1)	-126 (2)	128 (5)	29 (1)	117 (3)	37 (2)	51 (3)	8 (1)
O(2)	6707 (3)	3083 (1)	933 (2)	128 (5)	36 (1)	90 (3)	1 (2)	20 (3)	0 (1)
O(3)	4636 (3)	1792 (1)	1257 (3)	230 (6)	36 (1)	183 (4)	36 (2)	130 (4)	50 (2)
O(4)	4879 (3)	2153 (1)	-1532 (2)	130 (5)	38 (1)	95 (3)	12 (2)	60 (3)	-13 (1)
O(W)	267 (4)	2203 (1)	1757 (3)	147 (5)	47 (1)	108 (3)	23 (2)	47 (4)	22 (2)
N(1)	3098 (3)	281 (1)	-3719 (2)	110 (5)	22 (1)	93 (3)	12 (2)	61 (3)	11 (1)
C(2)	2640 (4)	889 (1)	-4922 (3)	105 (6)	17 (1)	81 (4)	5 (2)	45 (4)	5 (1)
N(3)	1121 (3)	1438 (1)	-5086 (2)	126 (5)	24 (1)	91 (3)	20 (2)	64 (3)	18 (1)
C(4)	46 (3)	1397 (1)	-3902 (3)	90 (5)	17 (1)	80 (4)	9 (2)	40 (3)	4 (1)
C(5)	474 (3)	806 (1)	-2610 (3)	88 (5)	18 (1)	73 (3)	8 (2)	41 (3)	4 (1)
C(6)	2079 (3)	220 (1)	-2526 (3)	89 (5)	17 (1)	75 (3)	3 (2)	37 (3)	1 (1)
N(7)	-853 (3)	901 (1)	-1670 (2)	134 (5)	27 (1)	95 (3)	17 (2)	62 (3)	7 (1)
N(8)	-1963 (3)	1540 (1)	-2420 (3)	143 (5)	30 (1)	101 (3)	25 (2)	64 (3)	10 (1)
N(9)	-1503 (3)	1869 (1)	-3785 (2)	139 (5)	28 (1)	100 (3)	24 (2)	62 (3)	10 (1)
N(2)	3724 (4)	939 (2)	-6042 (3)	185 (6)	36 (1)	138 (4)	40 (2)	116 (4)	38 (2)
N(6)	2561 (4)	-363 (1)	-1357 (3)	160 (6)	29 (1)	112 (4)	30 (2)	82 (4)	23 (2)
N(1')	-2421 (3)	4209 (1)	-2900 (2)	129 (5)	22 (1)	85 (3)	9 (2)	43 (3)	6 (1)
C(2')	-2505 (3)	4925 (1)	-1911 (3)	76 (5)	25 (1)	78 (4)	4 (2)	34 (3)	0 (2)
N(3')	-2561 (3)	5770 (1)	-2433 (3)	157 (6)	23 (1)	96 (3)	10 (2)	44 (3)	-4 (1)
C(4')	-2576 (3)	5886 (1)	-4094 (3)	85 (6)	20 (1)	93 (4)	5 (2)	16 (4)	4 (2)
C(5')	-2531 (3)	5168 (1)	-5185 (3)	74 (5)	23 (1)	71 (3)	3 (2)	23 (3)	7 (1)
C(6')	-2461 (3)	4292 (1)	-4532 (3)	67 (5)	22 (1)	76 (3)	11 (2)	26 (3)	5 (1)
N(7')	-2612 (3)	5469 (1)	-6733 (2)	139 (5)	29 (1)	88 (3)	-2 (2)	23 (3)	11 (1)
N(8')	-2699 (4)	6328 (1)	-6493 (3)	192 (6)	29 (1)	101 (4)	-5 (2)	4 (4)	20 (2)
N(9')	-2710 (4)	6632 (1)	-4930 (3)	192 (6)	24 (1)	119 (4)	0 (2)	7 (4)	9 (1)
N(2')	-2566 (4)	4790 (2)	-335 (3)	198 (6)	35 (1)	81 (3)	5 (2)	58 (4)	-3 (2)
N(6')	-2444 (4)	3574 (1)	-5483 (3)	195 (6)	25 (1)	80 (3)	22 (2)	49 (4)	4 (1)

Data were processed by the method of Corfield, Doedens & Ibers (1967). The value of  $p$  in their expression for the standard deviation of an intensity

$$\sigma(I) = [C + 0.25(ts/tb)^2(BH + BL) + (pI)^2]^{1/2}$$

was chosen to be 0.045 since the crystal was of medium mosaicity. The effect of using this term in the above expression is to increase the  $\sigma(I)$  for reflections with high intensity and thus reduce their weight in the least-squares refinement of the structure (Busing & Levy, 1957). The intensities and their e.s.d.'s were corrected for Lorentz and polarization effects. No absorption correction was made since the linear absorption coefficient for these atoms with Mo  $K\alpha$  radiation is negligibly small (Table 1).

#### Determination and refinement of the structure

The structure was solved by the heavy-atom method by locating the sulfur atom from the Patterson synthesis and the remaining non-hydrogen atoms from a difference Fourier map phased by the sulfur atom alone. The hydrogen atoms were located from a difference electron-density map calculated after the parameters of the non-hydrogen atoms (with anisotropic temperature factors) were reasonably settled in the least-squares refinement.

The least-squares refinement was carried out on  $F$ , the function minimized being  $\sum w[|F_o| - (1/k)|F_c|]^2$ , where  $k$  is a variable scale factor,  $|F_o|$  and  $|F_c|$  are the ob-

Table 2 (cont.)

	<i>x/a</i>	<i>y/b</i>	<i>z/c</i>	<i>B</i> (Å <sup>2</sup> )
H(2)	351 (4)	135 (2)	-681 (4)	3.1 (6)
H(20)	471 (5)	57 (2)	-604 (4)	3.6 (7)
H(3)	92 (5)	178 (2)	-592 (4)	4.3 (7)
H(6)	193 (5)	-42 (2)	-58 (4)	3.1 (6)
H(60)	342 (5)	-75 (2)	-137 (3)	3.0 (6)
H(8)	-318 (5)	178 (2)	-202 (4)	3.9 (6)
H(2')	-263 (4)	420 (2)	4 (3)	3.0 (6)
H(20')	-258 (4)	522 (2)	35 (4)	2.6 (6)
H(3')	-274 (5)	624 (2)	-170 (4)	4.2 (7)
H(6')	-251 (4)	303 (2)	-501 (3)	2.1 (5)
H(60')	-261 (4)	360 (2)	-653 (3)	2.0 (5)
H(8')	-287 (5)	674 (2)	-736 (4)	4.5 (8)
H( <i>W</i> )	-71 (5)	247 (2)	143 (4)	2.4 (6)
H( <i>W</i> 1)	88 (6)	231 (2)	114 (5)	5.0 (10)

served and calculated structure amplitudes and  $w = 4F_o^2/\sigma^2(F_o^2)$ . The full-matrix least-squares program used in this analysis was Ibers's *NUCLS*, which is a modified version of Busing, Martin & Levy's *ORFLS* (1962). The atomic scattering factors for C, N, and O used in calculating  $F_c$  were taken from *International Tables for X-ray Crystallography* (1962), those for S from Cromer & Waber (1965) and those for H from Stewart, Davidson & Simpson (1965). The effects of the anomalous dispersion of the sulfur atom were included in the calculations of  $F_c$  (Ibers & Hamilton, 1964), the values of  $\Delta f'$  and  $\Delta f''$  being taken from Cromer (1965).

All the non-hydrogen atoms were refined with anisotropic thermal parameters and the hydrogen atoms with isotropic thermal parameters. A small correction for the secondary extinction effect was deemed necessary near the end of the refinement process and was included in a manner described elsewhere (Meyer, Singh, Hatfield & Hodgson, 1972) using the expression given by Zachariasen (1968) for a spherical crystal.

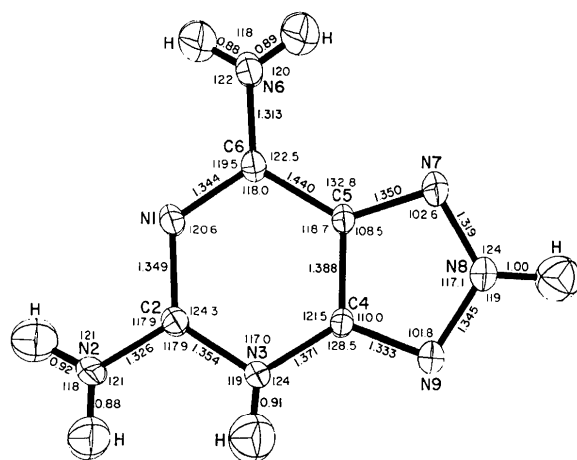


Fig. 1. View of the 8-aza-2,6-diaminopurine cation showing the average values of the bond lengths and angles in the two independent cations.

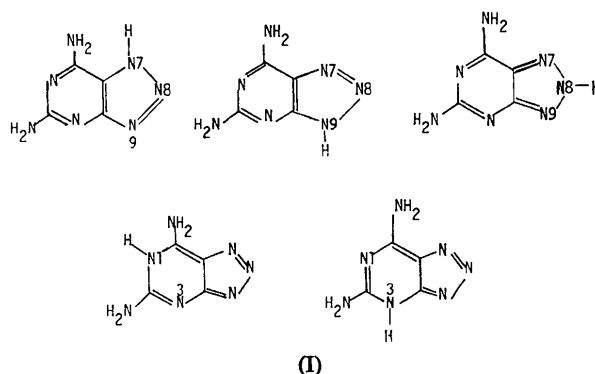
The refinement was monitored in the usual way by examination of the conventional  $R$  values  $R_1 = \sum ||F_o| - |F_c|| / \sum |F_o|$  and  $R_2 = [\sum w(|F_o| - |F_c|)^2 / \sum w(|F_o|)^2]^{1/2}$ ; the final values of  $R_1$  and  $R_2$  were 0.039 and 0.049, respectively, the error in our observation of unit weight (defined by  $\sum [w(|F_o| - |F_c|)^2 / n - v]^{1/2}$ , where  $n$  is the number of independent observations and  $v$  the number of variables) was 1.6, and the value of the extinction coefficient was  $2.2 (9) \times 10^{-8}$ . The maximum shift in a parameter in the final cycle of least-squares refinement was less than 0.2 times its standard deviation. A difference Fourier calculated at the end of the refinement was practically featureless except for some residual density on the bonds, probably indicating the presence of bonding electrons (Dawson, 1965; Beagley & Small, 1963, 1964; Hodgson & Ibers, 1969; O'Connell, Rae, & Maslen, 1966).

The positional and thermal parameters derived from the last cycle of least-squares calculations are shown in Table 2.\*

### Description and discussion of the structure

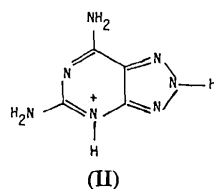
#### The sites of protonation on the cations

In the neutral molecule of 8-aza-2,6-diaminopurine there is only one proton that can directly bind to a ring atom and it can, in principle, occupy any of the five locations depicted in (I).



The N(1)-H and N(3)-H tautomers, however, are very unlikely. This proton is called the 'imidazole proton' (Pullman & Pullman, 1971) in the natural purines and their derivatives [N(8) replaced by C(8)-H] since it is always found at one of the two imidazole nitrogen atoms, N(7) or N(9). The correct tautomer for both independent cations observed in the present crystal structure is shown in (II) (and Fig. 1).

\* A list of structure factors has been deposited with the British Library Lending Division as Supplementary Publication No. SUP 30759 (18 pp., 1 microfiche). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 13 White Friars, Chester CH1 1NZ, England.



The imidazole or, in this case, the triazole proton is attached to N(8) and the extra proton due to the cationic nature of the molecule is attached to N(3). This does not necessarily mean that the triazole proton in the neutral molecule of 8-aza-2,6-diaminopurine is also attached to N(8). In fact, it has been shown previously that while the triazole proton in 8-azaguanine is attached to N(9) (Macintyre, Singh & Werkema, 1965; Sletten, Sletten & Jensen, 1968), it is attached to N(8) in 8-azaguanine hydrochloride (Kozłowski, Singh & Hodgson, 1974), which obviously is a tautomeric shift of the proton from N(9) to N(8). Similarly, in the nucleoside analog formycin (8-aza-9-deazaadenosine) the analogous proton is at N(7) (Prusiner, Brennan & Sundaralingam, 1973) while in formycin hydrobromide this proton is at N(8) and the cationic proton is at N(1) (Koyama *et al.*, 1974). The stability of a particular tautomeric form may, in part, be dependent upon the intermolecular forces in the solid state (Pullman & Pullman, 1971), but it has also been suggested from  $^{13}\text{C}$  n.m.r. spectroscopy on formycin B (8-aza-9-deazaadenosine) in solution that there is a cooperative effect between protonation sites on the two rings (Chenon, Pugmire, Grant, Panzica & Townsend, 1973).

#### Bond lengths and bond angles in the cations

The bond lengths and angles for both the independent cations in the asymmetric unit are presented in Table 3. The agreement between the corresponding bond lengths in the two cations is quite good except for the following bonds which differ by more than  $3.0\sigma$ : C(2)–N(3) ( $3.7\sigma$ ), N(3)–C(4) ( $4.7\sigma$ ), N(1)–C(6) ( $3.7\sigma$ ) C(6)–N(6) ( $3.3\sigma$ ), and N(8)–H(8) ( $3.3\sigma$ ). The agreement between the corresponding bond angles is also quite good, those differing by more than  $3.0\sigma$  being N(1)–C(2)–N(2) ( $4.0\sigma$ ), N(7)–N(8)–N(9) ( $5.0\sigma$ ), and C(4)–C(9)–C(8) ( $4.0\sigma$ ). These differences, although significant, are not large and may reflect a slight underestimation of the e.s.d.'s, the effect of differing intermolecular interactions, a slight difference in their thermal motions, or a combination of all of these. Their average values are shown in Fig. 1. They are in the range normally found in purine and azapurine derivatives (Sletten & Jensen, 1969; Subramanian & Marsh, 1971; Mez & Donohue, 1969; Kozłowski, Singh & Hodgson, 1974). The following features of the molecular geometry are, however, noteworthy. The two carbon–nitrogen bonds C(6)–N(1) and C(2)–N(1) lying between the two C–NH<sub>2</sub> bonds have the same lengths within experimental error, but the C–NH<sub>2</sub> bonds probably have significantly different lengths, C(2)–N(2) being slightly longer ( $0.013 \text{ \AA}$ ) than C(6)–N(6). This difference in the two exocyclic C–NH<sub>2</sub> bonds should be even more pronounced in the neutral molecule of 8-aza-2,6-diaminopurine, since as observed by Sundaralingam & Carrabine (1971) (see also Carrabine & Sundaralingam,

Table 3. Bond lengths ( $\text{\AA}$ ) and bond angles ( $^\circ$ ) in the two independent cations *A* and *A'*

The e.s.d.'s in bond lengths for bonds not involving hydrogens are  $0.003 \text{ \AA}$ , and for those involving hydrogens are  $0.03 \text{ \AA}$ . The e.s.d.'s in angles are  $0.2^\circ$  for those involving no hydrogens,  $2^\circ$  for those involving one hydrogen and  $3^\circ$  for those involving two hydrogens.

	Cation <i>A</i>	Cation <i>A'</i>		Cation <i>A</i>	Cation <i>A'</i>
N(1)–C(2)	1.352	1.345	C(6)–N(1)–C(2)	120.5	120.7
C(2)–N(3)	1.348	1.359	N(1)–C(2)–N(3)	124.3	124.3
N(3)–C(4)	1.369	1.373	N(1)–C(2)–N(2)	118.3	117.5
C(4)–C(5)	1.384	1.391	N(2)–C(2)–N(3)	117.4	118.2
C(5)–C(6)	1.438	1.442	C(2)–N(3)–C(4)	117.0	116.9
C(6)–N(1)	1.349	1.338	N(3)–C(4)–C(5)	121.6	121.3
C(5)–N(7)	1.352	1.347	N(3)–C(4)–N(9)	128.4	128.7
N(7)–N(8)	1.323	1.315	C(5)–C(4)–N(9)	110.0	110.0
N(8)–N(9)	1.342	1.348	C(4)–C(5)–C(6)	118.9	118.5
N(9)–C(4)	1.334	1.332	C(4)–C(5)–N(7)	108.4	108.6
C(2)–N(2)	1.329	1.323	C(6)–C(5)–N(7)	132.7	132.8
C(6)–N(6)	1.308	1.318	C(5)–C(6)–N(1)	117.7	118.3
N(2)–H(2)	0.88	0.95	C(5)–C(6)–N(6)	122.6	122.5
N(2)–H(20)	0.90	0.85	N(6)–C(6)–N(1)	119.7	119.2
N(6)–H(6)	0.86	0.92	C(5)–N(7)–N(8)	102.8	102.4
N(6)–H(60)	0.86	0.83	N(7)–N(8)–N(9)	116.6	117.6
N(3)–H(3)	0.86	0.95	C(4)–N(9)–N(8)	102.2	101.4
N(8)–H(8)	1.05	0.95	C(2)–N(2)–H(2)	121	120
			H(2)–N(2)–H(20)	117	119
			C(2)–N(2)–H(20)	122	121
			C(2)–N(3)–H(3)	117	120
			C(4)–N(3)–H(3)	126	123
			C(6)–N(6)–H(6)	122	118
			C(6)–N(6)–H(60)	122	121
			H(6)–N(6)–H(60)	115	120
			N(7)–N(8)–H(8)	124	124
			N(9)–N(8)–H(8)	120	118

1970), the protonation of N(3) in a 1:1 complex of guanine and copper chloride shortens the length of the C(2)-N(2) bond by 0.037 Å from that observed in

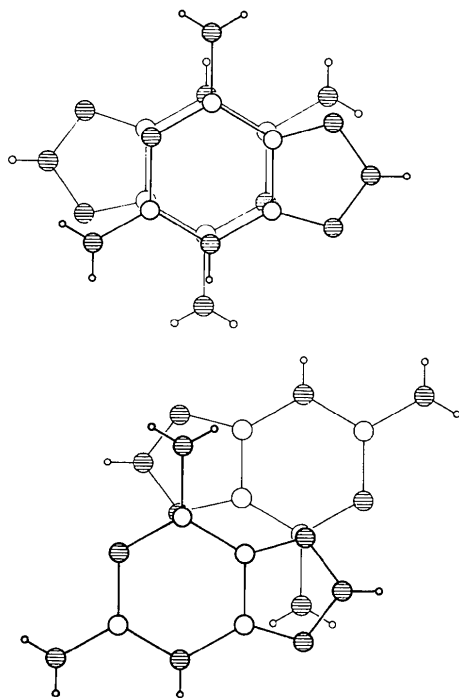


Fig. 2. The stacking interactions in the two independent cations *A* (above) and *A'* (below) of ADPH. Nitrogen atoms are shaded, and hydrogen atoms are shown as small circles. The darker lines indicate bonds in the molecule closer to the viewer.

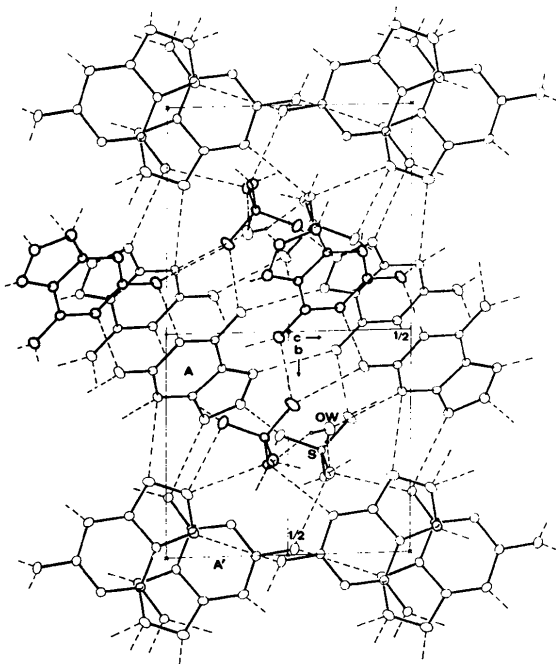


Fig. 3. The hydrogen bonding in 8-aza-2,6-diaminopurine sulfate monohydrate, viewed normal to the crystallographic *bc* plane. *A* and *A'* indicate the two independent ADPH cations in the unit cell.

guanine monohydrate (Thewalt, Bugg & Marsh, 1971), which is not protonated at N(3).

It has been noted (Singh, 1965; Ringertz, 1972) that the internal angles in purines and substituted purines are very sensitive to extraannular substitution, and Ringertz (1972) has predicted the values of these angles for the various modes of substitution. The internal angles found here for ADPH are in excellent agreement both with these predictions and with the values observed in the 8-azaguaninium (AGH) cation (Kozłowski, Singh & Hodgson, 1974) which is also protonated at N(3) and N(8).

#### Planarity of the cations

The deviations of atoms from various least-squares planes are given in Table 4. Both cations of 8-aza-2,6-diaminopurine are significantly non-planar. The six-atom pyrimidine planes, *IIA* and *IIA'*, for both cations are appreciably puckered with atom C(2) having the largest deviations amongst the in-plane atoms. A five-atom least-squares pyrimidine plane including atoms N(1), N(3), C(4), C(5) and C(6) in the plane for the cation *A* indicates that these atoms are indeed coplanar and that atom C(2) and the exocyclic atom N(2), which is covalently bonded to it, are out of this plane by 0.031 and 0.067 Å, respectively, on the same side. Similarly, atoms C(2) and N(2) of cation *A'* are away from the six-atom pyrimidine plane (*II A'*, Table 4) by 0.009 and 0.061 Å, respectively, on the same side.

Table 4. Deviations of atoms from the various least-squares planes through atoms of the two cationic moieties *A* and *A'*

Plane I: 11-Atom purine plane.  
Plane II: 6-Atom pyrimidine plane.  
Plane III: 5-Atom triazole plane.

Deviations (Å)	Plane I		Plane II		Plane III	
	<i>A</i>	<i>A'</i>	<i>A</i>	<i>A'</i>	<i>A</i>	<i>A'</i>
	N(1)	0.020	-0.024	0.011	-0.011	0.046
C(2)	-0.002	-0.008	-0.016	0.009	0.017	0.067
N(3)	0.017	-0.023	0.009	-0.002	0.026	0.025
C(4)	-0.003	-0.026	0.002	-0.004	0.003	-0.005
C(5)	-0.017	-0.017	-0.007	0.002	-0.005	0.002
C(6)	-0.002	-0.009	0.001	0.005	0.021	0.039
N(7)	-0.002	0.012	0.020	0.033	0.005	0.002
N(8)	0.000	0.019	0.023	0.045	-0.003	-0.005
N(9)	0.004	0.014	0.017	0.041	-0.000	0.007
N(2)	-0.017	0.046	-0.042	0.061	0.007	0.147
N(6)	0.002	0.018	0.008	0.029	0.031	0.067
H(2)	-0.07	0.13	-0.10	0.14	-0.05	0.24
H(20)	0.02	0.03	-0.01	0.05	0.05	0.14
H(3)	0.04	0.07	0.02	0.09	0.04	0.12
H(6)	-0.00	0.09	0.01	0.10	0.03	0.16
H(60)	0.10	0.12	0.10	0.13	0.13	0.16
H(8)	0.02	0.10	0.06	0.13	0.01	0.06

#### Equations of the least-squares planes

<i>IA</i>	$-0.4652x - 0.6538y - 0.5967z = -0.0147$
<i>IA'</i>	$-0.9555x - 0.0985y - 0.2781z = 1.3424$
<i>IIA</i>	$-0.4721x - 0.6538y - 0.5913z = -0.0414$
<i>IIA'</i>	$-0.9557x - 0.0950y - 0.2785z = 1.3524$
<i>IIIA</i>	$-0.4597x - 0.6589y - 0.5954z = -0.0316$
<i>IIIA'</i>	$-0.9588x - 0.1128y - 0.2606z = 1.1401$

The five-membered triazole ring is planar in both cations. The dihedral angle between the six-membered pyrimidine and the five-membered triazole planes in cation *A* is 0.8° and that in cation *A'* is 1.5°.

#### Stacking interactions

In view of the fact that the purine moiety in the present crystal is positively charged the observation of significant stacking interactions, depicted in Fig. 2, is rather surprising. Cations *A* and *A'* have different modes of stacking between their centrosymmetric counterparts. They are, however, similar to those commonly observed in purines (Bugg, 1972; Bugg, Thomas, Sundaralingam & Rao, 1971). Cations *A* stack with an almost complete overlap of the six atoms of the pyrimidine moiety in a centrosymmetric fashion with an interplanar separation of 3.40 Å. Cations *A'* stack almost along the *a* axis with two different interplanar separations of 3.20 and 3.31 Å which alternate between the stacked cations. Considerable stacking between charged isoguanine cations was also observed by Subramanian & Marsh (1971) whose suggestion that the stacking observed in the purine cations is made possible due to the distribution of the positive charge throughout the cation and, in part, to the neighboring hydrogen-bonded acceptors, seems reasonable.

#### The hydrogen bonding and packing

The hydrogen bonding in the present crystal is quite complex and is depicted in Fig. 3. The distances and angles associated with the hydrogen bonds are listed in Table 5. There are 14 crystallographically independent hydrogen atoms in the asymmetric unit of the crystal: six on each of the two cations and two on the water molecule. All can and do form hydrogen bonds. There are 11 electronegative acceptor atoms: six unprotonated nitrogen atoms N(1), N(7), and N(9) on each of the two independent cations, four oxygen atoms of the sulfate anion, and one water oxygen, and all,

except N(1'), accept hydrogen bonds. The sulfate oxygen atoms each accept two or more hydrogen bonds. One of the hydrogen bonds to the atom O(1), namely, N(8')-H...O(1), is probably a bifurcated hydrogen bond since the disposition of the hydrogen atom attached to N(8') is such that it can also form a hydrogen bond to O(4) (Table 5). The hydrogen atom H(3) attached to N(3) may also be participating in a bifurcated hydrogen bond, one of which is to the oxygen atom O(W) and the other, less convincing one, to N(9').

Except for the possible bifurcated hydrogen bond, N(3)-H...N(9'), there are no interactions of any kind between cations *A* and *A'*. Cations *A* form hydrogen-bonded dimers running along the *c* axis at *b*=0, and cations *A'*, which lie approximately in the *bc* plane at *a* = ±½, are linked head-to-tail through N(2')-H...

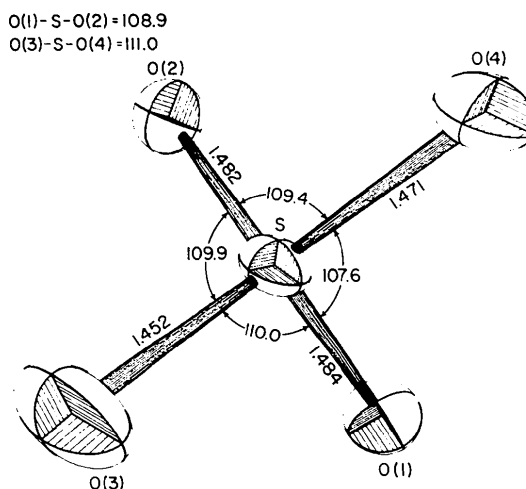


Fig. 4. View of the sulfate anion in 8-aza-2,6-diaminopurine sulfate monohydrate showing the bond lengths and angles. The e.s.d.'s in the bond lengths and angles are 0.002 Å and 0.1°.

Table 5. Distances and angles associated with the probable hydrogen bonds

<i>A</i> —H····· <i>B</i>	Location of <i>B</i>			<i>A</i> —H	H····· <i>B</i>	<i>A</i> ····· <i>B</i>	∠ <i>A</i> —H····· <i>B</i>
N(3)—H·····O(W)	<i>X</i>	<i>Y</i>	<i>Z</i> -1	0.86 Å	1.96 Å	2.79 Å	161°
N(3)—H·····N(9')*	- <i>X</i>	- <i>Y</i> +1	- <i>Z</i> -1	0.86	2.60	3.05	113
N(8)—H·····O(4)	<i>X</i> -1	<i>Y</i>	<i>Z</i>	1.05	1.61	2.66	177
N(2)—H(2)·····O(3)	<i>X</i>	<i>Y</i>	<i>Z</i> -1	0.88	2.05	2.79	140
N(2)—H(20)·····N(1)	- <i>X</i> +1	- <i>Y</i>	- <i>Z</i> -1	0.90	2.07	2.97	175
N(6)—H(6)·····N(7)	- <i>X</i>	- <i>Y</i>	- <i>Z</i>	0.86	2.29	3.12	164
N(6)—H(60)·····O(3)	- <i>X</i> +1	- <i>Y</i>	- <i>Z</i>	0.86	2.11	2.96	173
N(3')—H·····O(1)	- <i>X</i>	- <i>Y</i> +1	- <i>Z</i>	0.95	1.88	2.81	166
N(8')—H·····O(1)†	- <i>X</i>	- <i>Y</i> +1	- <i>Z</i> -1	0.95	2.06	2.90	147
N(8')—H·····O(4)†	- <i>X</i>	- <i>Y</i> +1	- <i>Z</i> -1	0.95	2.28	3.07	140
N(2')—H(2')·····O(2)	<i>X</i> -1	<i>Y</i>	<i>Z</i>	0.95	1.94	2.87	167
N(2')—H(20')·····N(7)	<i>X</i>	<i>Y</i>	<i>Z</i> +1	0.85	2.41	3.10	139
N(6')—H(6')·····N(9)	<i>X</i>	<i>Y</i>	<i>Z</i>	0.92	2.10	2.99	159
N(6')—H(60')·····O(2)	<i>X</i> -1	<i>Y</i>	<i>Z</i> -1	0.83	2.11	2.89	155
O(W)—H(W)·····O(2)	<i>X</i> -1	<i>Y</i>	<i>Z</i>	0.79	1.99	2.77	171
O(W)—H(W1)·····O(1)	<i>X</i>	<i>Y</i>	<i>Z</i>	0.75	2.27	2.99	161

\* Probably a weak bifurcated hydrogen bond.

† Bifurcated.

N(7') hydrogen bonds running along the  $c$  axis at  $b = \pm \frac{1}{2}$ . In between these two types of cations are the sulfate anions and water molecules which form an extensive network of hydrogen bonds with them.

The geometry of the sulfate anion is normal and is shown in Fig. 4. As was discussed above, each sulfate oxygen atom is involved in extensive hydrogen bonding to the cations or water molecules, with O(1) and O(2) apparently each forming three hydrogen bonds and O(3) and O(4) forming two.

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