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The Crystal Structure of the $\frac{5}{3}$Hydrate of Potassium 5-Ethylbarbiturate

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Potassium 5-ethylbarbiturate $\frac{5}{3}$ hydrate (m.p. 282–285 °C) is triclinic, space group $P\bar{1}$ with lattice parameters $a = 12{\cdot}276$ (4), $b = 10{\cdot}843$ (4), $c = 15{\cdot}800$ (4) Å, $\alpha = 103{\cdot}88$ (4), $\beta = 124{\cdot}42$ (4), $\gamma = 106{\cdot}78$ (4)°, and with unit-cell contents $K_6^+[C_6H_7N_2O_3]_6^- . 10H_2O$. The observed and calculated crystal densities are 1·551 and 1·563 g cm^{-3}. The structure determination was by direct methods, based on 4722 X-ray reflections which were measured on a four-circle automatic diffractometer with nickel-filtered Cu $K\alpha$ radiation. The final R for all reflections is 0·071. As in the case of barbituric acid itself, the anion forms by deprotonation at atom C(5), rather than at a ring NH group. Bond lengths and angles suggest that the negative charge is localized principally on O(4) and O(6). The anions are linked by NH···O=C hydrogen bonds to form an unusual snake-like ribbon with six anions per repeat distance of 20·3 Å. The ribbons stack parallel to (11$\bar{4}$), leaving channels along **c** which accommodate the potassium ions and water molecules. The three potassium ions and five water molecules are seven- and four-coordinated, respectively.

Introduction

Barbituric acid (Fig. 1; $R_1 = R_2 = H$), with labile hydrogen atoms at the methylene carbon atom C(5) and at the two ring nitrogen atoms, forms anions by successive deprotonations at these sites. In the crystal structure of the ammonium salt of barbituric acid (Craven, 1964), the first proton was shown to have been lost from C(5). In 5,5-diethylbarbituric acid or barbital (Fig. 1; $R_1 = R_2 =$ ethyl), proton loss is necessarily from a ring nitrogen (Berthou, Rérat & Rérat, 1965; Berking & Craven, 1971; Berking, 1972; McClure & Craven, 1973). There is a marked difference in the dissociation constants (pK_a) of barbituric acid (3·9) and barbital (7·9) in aqueous solution, which is associated with the difference in deprotonation sites. The purpose of the present crystal structure determination was twofold: first, to locate the deprotonation site for 5-monoethylbarbituric acid, the acid which is of a type intermediate between the two cases above; and second, to compare the structure and stereochemistry of the 5-ethylbarbiturate anion (Fig. 2) with that of its parent acid (Gatehouse & Craven, 1971). The acid dissociation constant of 5-ethylbarbituric acid has not been reported.

The results of this structure determination have been used by Gutierrez & Benson (1974) in connection with their electron spin resonance study of 5-ethylbarbiturate radicals formed by X-irradiation of the crystals.

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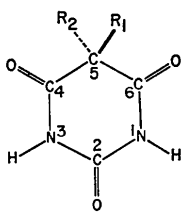


Fig. 1. The molecular structure of barbituric acids.

Experimental

Potassium 5-ethylbarbiturate $\frac{5}{3}$ hydrate was prepared by the addition of potassium hydroxide to a sample of 5-ethylbarbituric acid, which was probably contaminated by the oxidation product 5-hydroxy-5-ethylbarbituric acid (Gatehouse & Craven, 1971). Recrystallization of the salt from water yielded a mixture of colorless hygroscopic orthorhombic and triclinic crystals. Sealing the crystals with a clear lacquer spray prevented the decomposition of only the triclinic crystals of the required salt. It is possible that the orthorhombic crystals (m.p. 264–267 °C) are of the potassium salt of the 5-hydroxy derivative. No further work on the latter is intended.

Determination of the (triclinic) crystal density was by flotation in a mixture of benzene and carbon tetrachloride. Cell parameters and the intensities of diffracted X-rays were measured on a four-circle automatic diffractometer with nickel-filtered Cu $K\alpha$ radiation. The cell parameters (Table 1) that were used for the structure determination are those of the Delaunay reduced cell.

Intensity data were measured with a crystal which exhibited the forms {100}, {010}, {001}. The crystal was mounted with the b^* axis nearly along the φ axis of the goniostat. 4722 independent reflections were scanned in the θ:2θ mode at a rate of 2° in 2θ per min. The 2θ scan width was variable, with a base of 1·5°. Background counts of 20 s were taken at each of the 2θ scan limits. There were 197 reflections for which

Table 1. *Crystal data*

Potassium 5-ethylbarbiturate.$\frac{5}{3}$ hydrate,
$K^+[C_6H_7N_2O_3]^-.\frac{5}{3}H_2O$,
F.W. 224·26, m.p. 282–285°C, triclinic, space group $P\bar{1}$.
Delaunay reduced cell*

$a=12·276$ (4) Å	$\alpha=103·88$ (4)°
$b=10·843$ (4)	$\beta=124·42$ (4)
$c=15·800$ (4)	$\gamma=106·78$ (4)

Unit-cell contents: $K_6^+[C_6H_7N_2O_3]_6^-.10H_2O$
$D_m=1·551$, $D_x=1·563$ g cm^{-3}
μ(Cu $K\alpha$) = 48·77 cm^{-1}
Crystal size: 0·5 × 0·5 × 0·5 mm

* The quartet of Delaunay lattice translations is completed by $d(\bar{1}\bar{1}\bar{1})=11·815$ Å, which is shorter than a and c. The Niggli reduced cell is $a'=10·843$, $b'=11·815$, $c'=12·276$ Å, $\alpha'=91·04$, $\beta'=106·78$, $\gamma'=107·28°$.

the net integrated intensity, I, was less than $1·2\sigma(I)$. These were arbitrarily assigned intensities of $\sigma(I)/2$. X-ray absorption and extinction corrections were neglected.

The most prominent feature in a sharpened Patterson function was an extensive hexagonal pattern of peaks in planes parallel to $(11\bar{4})$, which was considered to arise from a hydrogen-bonded barbiturate network. However, the details of the hydrogen bonding and the potassium ion arrangement could not be deduced from the Patterson function, in part because we assumed incorrectly that the unit cell contained $K_4^+[C_6H_7N_2O_3]_4^-.30H_2O$. This composition is consistent with the observed crystal density.

Subsequently, the phase problem was solved by direct methods, with the initial phases developed by symbolic addition and extended to 310 phases by use of the tangent formula (Karle & Karle, 1966). Details of the procedure are described by Gartland (1971). The E synthesis revealed the potassium and barbiturate anions. Surprisingly, the asymmetric structural unit in space group $P\bar{1}$ contained not two, but three potassium barbiturates. Later, five crystallographically independent water molecules were located by a Fourier refinement.

Because of the large number of atomic parameters, a block-diagonal least-squares refinement procedure was used almost exclusively. The function minimized was $\sum w_H\Delta_H^2$, where $\Delta_H=|F_H^{obs}|-|F_H^{calc}|$. Data were weighted according to $w_H^{-1}=1·6+0·005F_H^2$, which resulted in a nearly constant distribution of $w_H\Delta_H^2$ over ranges of $|F|$. Atomic scattering factors for K^+, C, N and O were taken from *International Tables for X-ray Crystallography* (1962). For H, the values of Stewart, Davidson & Simpson (1965) were used.

The first several cycles of refinement, in which nonhydrogen positional and isotropic temperature parameters were varied, rapidly reduced the R value to 0·14.* Initial refinement of anisotropic temperature parameters gave nonpositive definite values for atoms O(6)C and C(8)C. However, positive definite values were ob-

* $R=\sum_H|\Delta F_H|/\sum_H|F_H^{obs}|$.

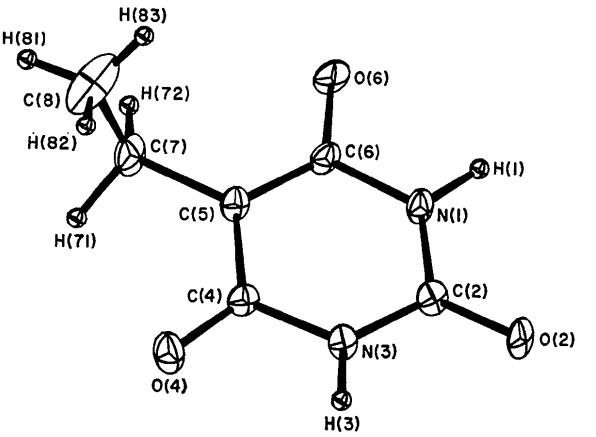


Fig. 2. The observed conformation of 5-ethylbarbiturate (anion A), showing thermal ellipsoids drawn at 50% probability of enclosing atoms.

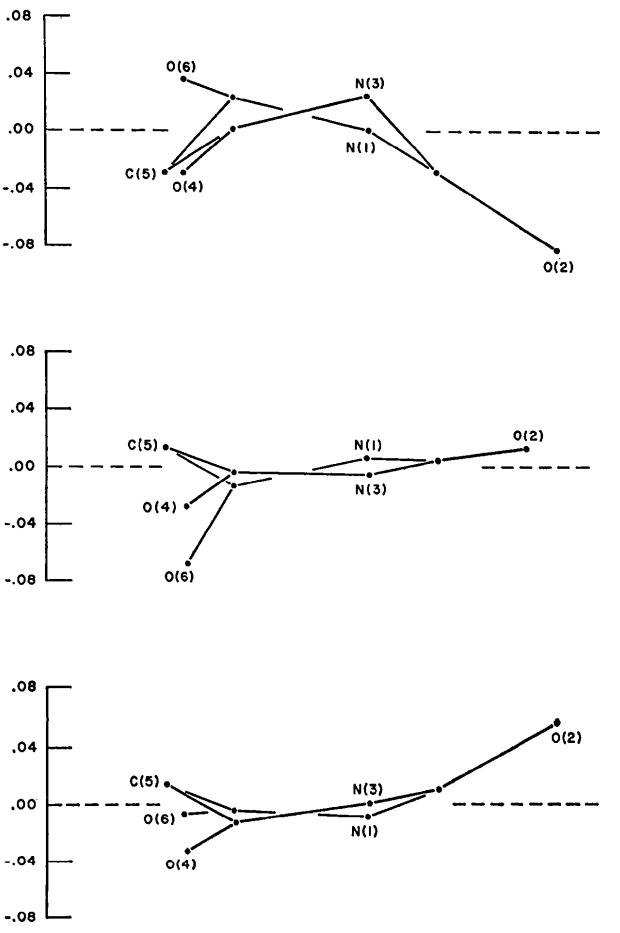


Fig. 3. Ring conformations of the 5-ethylbarbiturate anions in the order A, B, C from the top. The horizontal dashed lines are the traces of the best least-squares planes through the six ring atoms. The vertical scale (Å) is 15 times the horizontal.

Table 2. *Observed and calculated structure amplitudes*

Columns are: l index, $10|F^{obs}|$, $10|F^{calc}|$. Asterisks indicate reflections with $I < 1{\cdot}2\sigma(I)$.

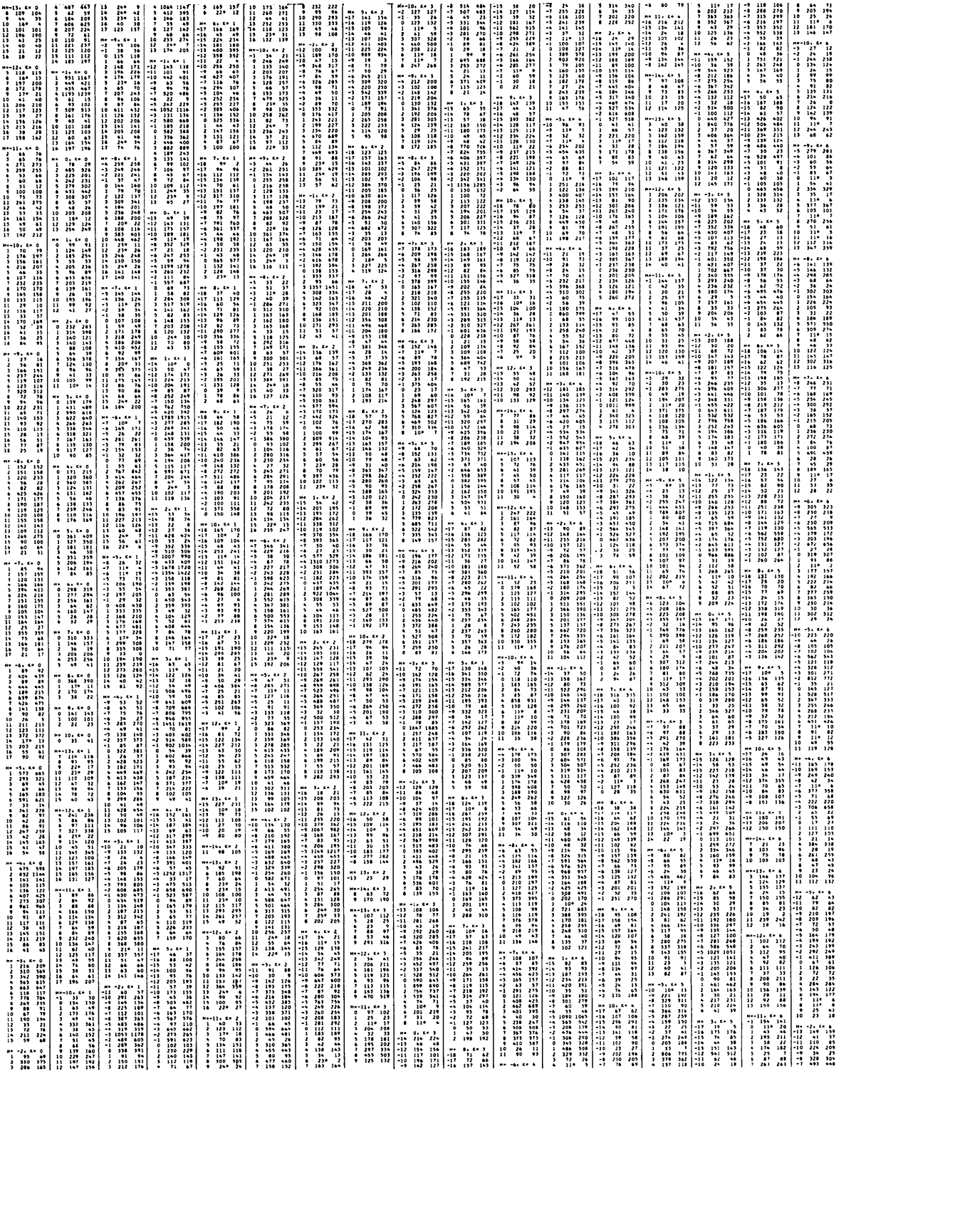
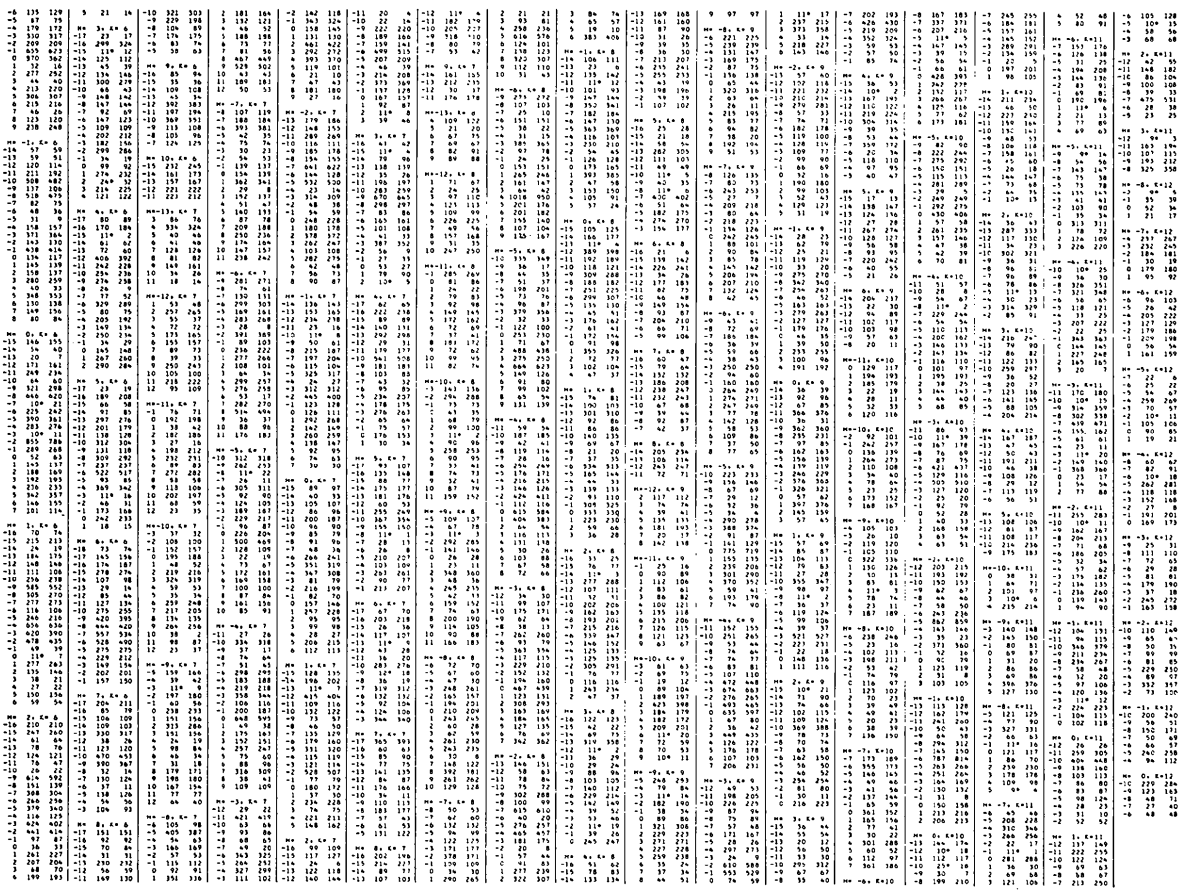


Table 2 (*cont.*)



tained from a cycle of full-matrix least-squares refinement. With the R value equal to 0·082, a difference Fourier synthesis was computed. All hydrogen atoms except those bonded to the water oxygen atom $W(5)$ were located. Block-diagonal least-squares refinement was resumed with variation of all atomic positional parameters and anisotropic (isotropic) temperature parameters for non-hydrogen (hydrogen) atoms. Hydrogen atoms bonded to the methyl carbon C(8)A were consistently shifted outwards from their expected positions, with accompanying increases in their temperature factors. These hydrogen atoms were given fixed parameters consistent with the expected methyl group geometry. Convergence occurred with an overall R value of 0·071.

Final observed and calculated structure amplitudes are listed in Table 2. Final atomic parameters with their e.s.d.'s and the principal r.m.s. atomic vibrational amplitudes appear in Table 3.

The 5-ethylbarbiturate anions

Each of the three crystallographically distinct 5-ethylbarbiturate ions (A,B,C) in the crystal structure has suffered proton loss from atom C(5) of the parent acid. This conclusion is based on the observed hydrogen atom locations and is confirmed by comparison of the detailed molecular structure with that of 5-ethylbarbituric acid (Gatehouse & Craven, 1971). The tendency of the barbiturate C(5) hydrogen atoms in barbituric acid and 5-ethylbarbituric acid to be more labile than the ring NH hydrogen atoms may be attributed to the inductive effect of the carbonyl groups which are bonded to C(5). Further evidence of the lability of the C(5) hydrogen atom has been found in two barbiturate crystal structures which are not salts. In 5-nitrobarbituric acid (Bolton, 1963) and 5-hydroxybarbituric acid monohydrate (Bolton, 1965; Craven & Sabine, 1969), the hydrogen atom nominally at C(5) has migrated to form the 4-hydroxy tautomer.

In the monoclinic crystalline form of the parent 5-ethylbarbituric acid (Gatehouse & Craven, 1971), the barbiturate ring adopts a 'flap' conformation, with a tetrahedrally bonded atom C(5) displaced by 0·23 Å from an otherwise nearly planar ring. The C(5)–H bond is unexpectedly 'axial', and the C(5)–C(7) bond is 'equatorial', so that C(7) is flanked by carbonyl oxygens O(4) and O(6) with short nonbonded C···O

distances of 2·87 and 2·88 Å. With deprotonation of C(5), C(7) is left almost in the same position (C···O distances ranging from 2·90 to 2·94 Å), while atom C(5) has moved into the plane of atoms C(4), C(6) and C(7). In all three anions *A*, *B* and *C*, the atoms C(4), C(5), C(6), C(7) are coplanar within 0·01 Å, as expected for trigonally bonded C(5). Atoms N(1), C(2), N(3), C(4) and C(6) of ions *B* and *C* are coplanar to within 0·005 and 0·008 Å respectively, while atom C(5), in each case, deviates only slightly more (0·03 Å) from this plane (Fig. 3). In anion *A*, there is a folding along N(3)···C(6), to give a conformation somewhat different from those reported for other barbituric acids (Craven, Cusatis, Gartland & Vizzini, 1973). The torsion angles C(4)–C(5)–C(7)–C(8) are 94·8, 86·8 and 85·9° in anions *A*, *B* and *C* respectively.

Bond lengths and angles* for the three anions are given in Table 4 without correction for anisotropic thermal motion. There is generally good agreement between the corresponding dimensions of the different ions. The only two bond-length determinations which may possibly be significantly different are C(7)–C(8) ethyl bond lengths of ions *A* and *B* which differ by $2{\cdot}8\sigma$,† and C(2)–O(2) bond lengths of ions *B* and *C* which differ by $3{\cdot}2\sigma$. No significant differences are

* The standard deviations of all bond lengths and angles were estimated according to Cruickshank & Robertson (1953). Account was taken of the rather large correlations between different coordinates of the same atom (due mainly to the non-orthogonality of the crystal axes).

† σ is the standard deviation of the difference (Δ) between the two parameter determinations.

Table 3. *Atomic parameters*

For the 5-ethylbarbiturate parameters, the values given are for ion *A* (on top), ion *B* (in middle), and ion *C* (at bottom). The e.s.d.'s given in parentheses refer to the least significant figures in tabulated values.

(*a*) Non-hydrogen atom parameters. Positional parameters are given as fractions of the unit-cell translations $\times 10^4$. Temperature parameters ($\times 10^4$) are given according to the expression: $T=\exp(-\sum h_i\beta_{ij}h_j)$. The quantity U_k ($\times 10^2$) is the r.m.s. atomic displacement (Å) along the direction of the *k*th principal axis of the thermal ellipsoid, calculated from the experimental β_{ij} values.

	x	*y*	*z*	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}	U_1	U_2	U_3
K(1)	9560 (1)	2805 (1)	7811 (1)	58 (1)	34 (1)	40 (1)	23 (1)	24 (1)	25 (1)	10	14	20
K(2)	9210 (1)	6447 (1)	9128 (1)	68 (2)	41 (1)	36 (1)	32 (1)	34 (1)	26 (1)	11	15	16
K(3)	9086 (1)	5411 (1)	6191 (1)	71 (2)	55 (1)	48 (1)	18 (1)	38 (1)	28 (1)	13	18	20
N(1)	13212 (3)	9706 (3)	9644 (3)	50 (5)	33 (4)	51 (3)	30 (4)	36 (4)	27 (3)	9	13	19
	7673 (3)	9739 (3)	8097 (3)	40 (5)	32 (4)	38 (3)	23 (4)	24 (3)	21 (3)	10	12	17
	5583 (3)	4159 (3)	6067 (3)	47 (5)	21 (4)	43 (3)	22 (4)	26 (3)	21 (3)	7	13	19
N(3)	11010 (3)	9614 (3)	9089 (3)	38 (5)	29 (4)	42 (3)	20 (4)	26 (3)	22 (3)	10	12	18
	5346 (3)	7520 (3)	6789 (3)	37 (5)	21 (4)	39 (3)	14 (4)	21 (3)	20 (3)	8	12	18
	5412 (3)	1915 (3)	5539 (2)	46 (5)	29 (4)	35 (3)	26 (4)	25 (3)	24 (3)	8	13	16
C(2)	11714 (4)	8856 (4)	9089 (3)	56 (6)	41 (5)	40 (3)	34 (5)	33 (4)	32 (4)	9	14	16
	6910 (4)	8231 (3)	7529 (3)	49 (6)	32 (5)	33 (3)	23 (4)	26 (4)	25 (3)	8	14	15
	6345 (4)	3418 (3)	6222 (3)	57 (6)	25 (5)	37 (3)	23 (5)	33 (4)	24 (4)	7	14	15
C(4)	11683 (4)	11149 (4)	9530 (3)	56 (6)	44 (5)	42 (4)	34 (5)	28 (4)	22 (4)	11	15	18
	4511 (4)	8232 (3)	6593 (3)	52 (6)	34 (5)	27 (3)	25 (5)	26 (4)	20 (3)	10	13	14
	3785 (4)	1120 (3)	4730 (3)	52 (6)	28 (5)	27 (3)	20 (4)	24 (4)	22 (3)	8	13	15
C(5)	13212 (4)	11979 (4)	10049 (4)	68 (7)	44 (6)	74 (5)	34 (5)	50 (5)	32 (4)	12	15	23
	5356 (4)	9806 (3)	7214 (3)	47 (6)	38 (5)	30 (3)	27 (5)	26 (4)	24 (4)	10	13	14
	3063 (4)	1937 (4)	4635 (3)	48 (6)	37 (5)	28 (3)	23 (5)	21 (4)	20 (4)	11	13	16
C(6)	14023 (4)	11256 (4)	10153 (3)	44 (6)	43 (5)	44 (4)	22 (5)	29 (4)	23 (4)	12	13	18
	6965 (4)	10567 (3)	7958 (3)	53 (6)	30 (5)	35 (3)	27 (4)	30 (4)	20 (3)	9	14	15
	3972 (4)	3487 (4)	5301 (3)	58 (6)	33 (5)	37 (3)	33 (5)	31 (4)	27 (4)	8	15	16
C(7)	13974 (5)	13637 (5)	10465 (5)	90 (8)	71 (7)	117 (7)	48 (6)	72 (6)	47 (6)	16	17	29
	4526 (4)	10638 (4)	7044 (3)	68 (6)	57 (6)	47 (4)	47 (5)	34 (5)	36 (4)	10	17	19
	1327 (4)	1143 (4)	3814 (4)	56 (6)	42 (6)	60 (5)	28 (5)	30 (5)	25 (4)	12	15	23
C(8)	14892 (9)	14618 (8)	11743 (7)	250 (20)	123 (10)	119 (9)	95 (10)	93 (10)	50 (8)	21	28	36
	4222 (7)	10920 (6)	7854 (5)	212 (10)	144 (10)	121 (7)	143 (10)	136 (9)	91 (7)	14	21	29
	723 (7)	682 (8)	4363 (7)	122 (20)	301 (10)	175 (9)	111 (10)	123 (10)	152 (10)	16	29	38
O(2)	11010 (3)	7471 (3)	8616 (3)	72 (5)	34 (4)	68 (3)	33 (4)	49 (3)	34 (3)	9	16	22
	7612 (3)	7546 (3)	7684 (2)	48 (4)	34 (4)	52 (3)	31 (3)	29 (3)	32 (3)	7	14	20
	7782 (3)	4083 (2)	6951 (2)	36 (4)	32 (4)	40 (3)	16 (3)	20 (3)	18 (3)	11	12	18
O(4)	10816 (3)	11651 (3)	9385 (3)	50 (4)	40 (4)	73 (3)	32 (4)	40 (3)	23 (3)	10	14	24
	3060 (3)	7392 (3)	5864 (2)	40 (4)	50 (4)	46 (3)	23 (3)	26 (3)	27 (3)	12	14	19
	3100 (3)	−280 (2)	4158 (2)	51 (4)	18 (3)	39 (3)	15 (3)	21 (3)	14 (3)	8	14	20
O(6)	15419 (3)	11879 (3)	10628 (3)	45 (4)	48 (4)	67 (3)	25 (4)	38 (3)	25 (3)	12	14	23
	7891 (3)	11969 (3)	8535 (2)	59 (4)	18 (3)	56 (3)	18 (3)	34 (3)	14 (3)	8	15	21
	3472 (3)	4367 (3)	5287 (2)	68 (5)	30 (4)	64 (3)	38 (4)	37 (3)	28 (3)	7	16	23
W(1)	12231 (4)	5614 (4)	8842 (3)	123 (7)	110 (6)	109 (5)	53 (5)	82 (5)	78 (5)	15	23	28
W(2)	8306 (4)	4534 (3)	9709 (3)	166 (7)	36 (4)	119 (5)	49 (5)	115 (5)	42 (4)	10	20	29
W(3)	9568 (4)	2897 (5)	6101 (3)	126 (7)	177 (8)	83 (4)	85 (7)	69 (5)	80 (5)	20	22	28
W(4)	11932 (4)	6769 (6)	6918 (4)	110 (7)	313 (10)	86 (5)	66 (7)	72 (5)	103 (6)	17	21	39
W(5)	8612 (7)	5898 (7)	4339 (6)	291 (10)	242 (10)	201 (9)	152 (10)	191 (10)	143 (9)	25	31	36

Table 3 (*cont.*)

(*b*) Hydrogen atom parameters. Positional parameters are given $\times 10^3$. Temperature factors are given according to the expression $T=\exp(-B\sin^2\theta/\lambda^2)$ with B in Å^2 units. Asterisks indicate fixed parameters.

	x	*y*	*z*	*B*
H(1)	1367 (6)	920 (6)	961 (5)	3 (1)
	882 (6)	1039 (6)	862 (5)	2 (1)
	629 (7)	535 (7)	657 (6)	4 (1)
H(3)	1001 (6)	910 (6)	868 (5)	3 (1)
	474 (6)	655 (6)	639 (5)	3 (1)
	589 (7)	139 (7)	558 (6)	4 (1)
H(71)	1326 (8)	1391 (8)	990 (6)	5 (2)
	344 (7)	996 (6)	616 (5)	3 (1)
	92 (6)	25 (6)	313 (5)	3 (1)
H(72)	1462 (6)	1424 (6)	1033 (5)	3 (1)
	516 (7)	1172 (7)	725 (6)	4 (1)
	81 (7)	169 (6)	338 (5)	3 (1)
H(81)	1·54*	1·57*	1·20*	7*
	366 (8)	1137 (8)	769 (6)	5 (2)
	−30 (10)	41 (10)	396 (8)	8 (2)
H(82)	1·57*	1·44*	1·22*	7*
	357 (9)	998 (9)	766 (7)	6 (2)
	133 (10)	0 (10)	479 (9)	9 (3)
H(83)	1·42*	1·44*	1·19*	7*
	512 (10)	1133 (10)	866 (8)	11 (2)
	120 (10)	183 (10)	497 (8)	7 (2)
H(1*W*1)	1181 (10)	622 (10)	858 (9)	11 (3)
H(1*W*2)	1313 (10)	592 (10)	890 (8)	9 (2)
H(2*W*1)	781 (10)	348 (9)	913 (8)	7 (2)
H(2*W*2)	792 (8)	436 (8)	986 (6)	4 (1)
H(3*W*1)	1017 (8)	320 (8)	613 (6)	5 (1)
H(3*W*2)	839 (9)	247 (9)	516 (7)	7 (2)
H(4*W*1)	1281 (10)	722 (10)	759 (8)	8 (2)
H(4*W*2)	1212 (10)	683 (10)	646 (8)	9 (2)

found in the internal ring angles of the three ions. Several external angles, however, do show differences which may be significant. The largest discrepancies are in the O(6)–C(6)–N(1) and the O(2)–C(2)–N(3) angles. For the former, the value found in ion *B* is smaller by about 4σ than the values observed for ions *A* and *C*. For the latter, the value in ion *A* is smaller by about 3σ and 4σ than the values in ions *B* and *C* respectively.

Table 4. *Bond lengths* (Å) *and angles* (°) *for the 5-ethylbarbiturate ions and for the water molecules*

For the barbiturate anions, the values given are for *A* (on top), *B* (in middle) and *C* (at bottom). Asterisks indicate dimensions calculated from fixed atomic parameters (see Table 3). The e.s.d.'s given in parentheses refer to the least significant figures in tabulated values.

(*a*) Bond lengths

(i) The 5-ethylbarbiturate ions

C(6)–N(1)	1·394 (4)	C(5)–C(7)	1·519 (6)
	1·392 (4)		1·505 (4)
	1·394 (4)		1·499 (5)
N(1)–C(2)	1·346 (4)	C(7)–C(8)	1·48 (1)
	1·348 (4)		1·513 (6)
	1·361 (4)		1·508 (9)
C(2)–N(3)	1·353 (4)	N(1)–H(1)	0·90 (5)
	1·351 (4)		1·00 (5)
	1·347 (4)		1·06 (6)
N(3)–C(4)	1·392 (4)	N(3)–H(3)	0·87 (5)
	1·399 (4)		0·87 (5)
	1·399 (4)		0·91 (6)

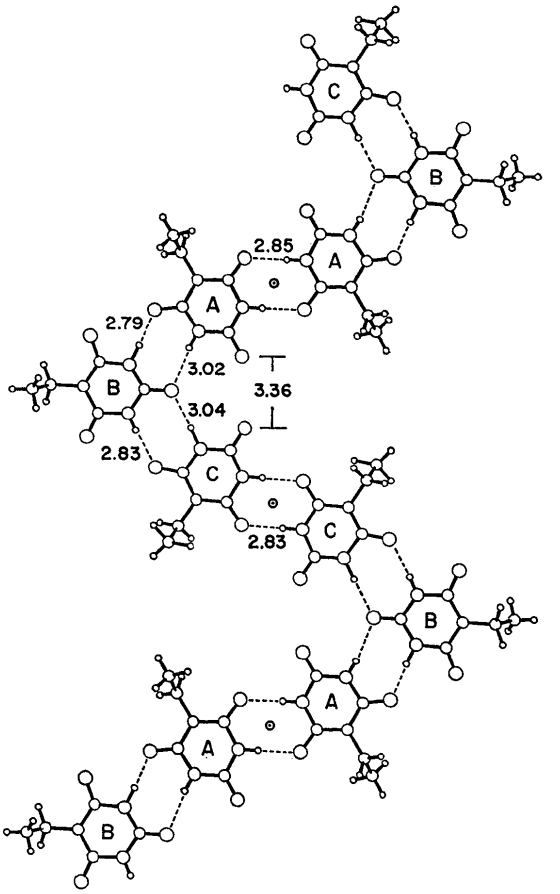


Fig. 4. An isolated hydrogen-bonded ribbon, showing the hydrogen-bond N···O distances (Å).

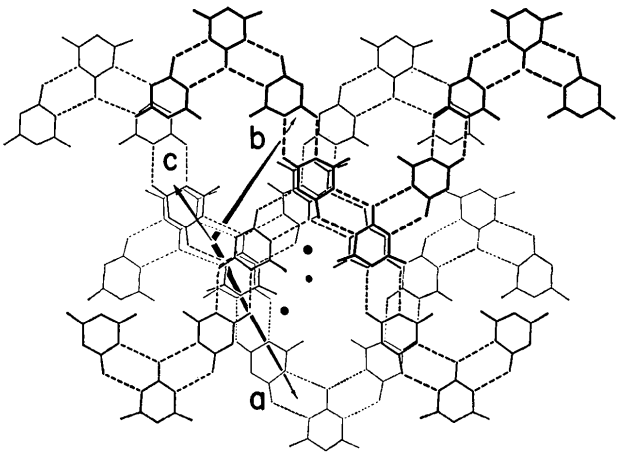


Fig. 5. Schematic view normal to the (11$\bar{4}$) plane, showing the stacking of four hydrogen-bonded ribbons to form channels. The anions are drawn without ethyl groups. Water molecules are also omitted. The solid circles of increasing size in one of the channels represent potassium ions K(3), K(1) and K(2) at distances increasingly closer to the viewer.

Table 4 (*cont.*)

C(6)–O(6)	1·262 (4)	C(7)–H(71)	1·02 (7)
	1·265 (4)		1·05 (6)
	1·274 (4)		0·98 (6)
C(2)–O(2)	1·242 (4)	C(7)–H(72)	1·04 (5)
	1·254 (4)		1·05 (6)
	1·236 (4)		1·07 (6)
C(4)–O(4)	1·265 (4)	C(8)–H(81)	1·00*
	1·253 (4)		0·91 (7)
	1·255 (3)		0·94 (9)
C(5)–C(4)	1·392 (5)	C(8)–H(82)	0·98*
	1·406 (4)		0·94 (8)
	1·400 (5)		1·24 (9)
C(5)–C(6)	1·400 (5)	C(8)–H(83)	1·00*
	1·390 (5)		0·96 (9)
	1·385 (5)		1·01 (9)

(ii) The water molecules

W(1)–H(1*W*1)	1·01 (9)	*W*(3)–H(3*W*1)	0·70 (7)
W(1)–H(1*W*2)	0·96 (9)	*W*(3)–H(3*W*2)	1·17 (8)
W(2)–H(2*W*1)	0·98 (8)	*W*(4)–H(4*W*1)	0·84 (9)
W(2)–H(2*W*2)	0·64 (7)	*W*(4)–H(4*W*2)	0·86 (9)

(*b*) Bond angles

(i) The 5-ethylbarbiturate ions

N(1)–C(2)–O(2)	123·2 (3)	C(4)—C(5)–C(7)	120·4 (3)
	122·0 (3)		120·4 (3)
	122·1 (3)		120·4 (3)
N(1)–C(2)–N(3)	115·4 (3)	C(6)—C(5)–C(7)	120·5 (3)
	115·3 (3)		121·1 (3)
	114·7 (3)		120·5 (3)
N(3)–C(2)–O(2)	121·4 (3)	C(5)—C(7)–C(8)	113·5 (5)
	122·7 (3)		113·9 (3)
	123·2 (3)		114·0 (4)
C(2)–N(3)–C(4)	124·8 (3)	C(6)—N(1)–H(1)	119 (3)
	124·9 (3)		112 (3)
	124·9 (3)		119 (3)
N(3)–C(4)–O(4)	116·1 (3)	C(2)—N(1)–H(1)	116 (3)
	116·1 (3)		123 (3)
	116·3 (3)		116 (3)
N(3)–C(4)–C(5)	117·8 (3)	C(4)—N(3)–H(3)	116 (4)
	117·9 (3)		112 (3)
	118·0 (3)		118 (4)
C(5)–C(4)–O(4)	126·0 (3)	C(2)—N(3)–H(3)	118 (4)
	126·0 (3)		123 (3)
	125·7 (3)		117 (4)
C(4)–C(5)–C(6)	119·1 (3)	H(71)–C(7)–H(72)	77 (5)
	118·4 (3)		113 (5)
	119·1 (3)		101 (4)
C(5)–C(6)–O(6)	125·5 (3)	H(81)–C(8)–H(82)	109*
	126·7 (3)		105 (7)
	125·8 (3)		124 (7)
C(5)–C(6)–N(1)	117·9 (3)	H(81)–C(8)–H(83)	108*
	118·6 (2)		120 (7)
	117·8 (3)		95 (7)
N(1)–C(6)–O(6)	116·5 (3)	H(82)–C(8)–H(83)	110*
	114·7 (3)		100 (7)
	116·4 (3)		115 (7)
C(6)–N(1)–C(2)	124·7 (3)		
	124·9 (3)		
	125·4 (3)		

(ii) The water molecules

H(1*W*1)–*W*(1)–H(1*W*2)	104 (7)
H(2*W*1)–*W*(2)–H(2*W*2)	93 (8)
H(3*W*1)–*W*(3)–H(3*W*2)	110 (7)
H(4*W*1)–W(4)–H(4*W*2)	104 (8)

Since the bond lengths and angles of all three anions are so nearly alike, the following comparisons make use of average values. The largest differences in bond lengths and angles between the ion and the acid molecule occur near the C(5) deprotonation site. The internal ring angle at C(5), which is 114° in the acid, has opened to 119° in the ion, reflecting the change in the bonding of C(5) from tetrahedral to trigonal. Ring bonds adjacent to C(5) in the ion are shorter (1·40 Å), than the corresponding bonds in the acid (1·51 Å), while the C(4)–O(4) and C(6)–O(6) bonds are longer (1·26 *vs* 1·21 Å). These results suggest that the formal negative charge is largely at the oxygen atoms O(4) and O(6). The angles O(4)–C(4)–C(5) and O(6)–C(6)–C(5) are 126°, which is 3° greater than in the acid.

There are other differences which are smaller. For example, in the ion, the N(3)–C(4) and N(1)–C(6) bonds are longer (1·39 Å) than the N(3)–C(2) and N(1)–C(2) bonds (1·35 Å). In the acid, however, there are no significant differences between any of the N–C ring bond lengths, which range from 1·364 to 1·374 Å. A similar effect was noticed in a comparison of the structures of the barbituric acid molecule and its ion (Craven, 1964). The C(2)–O(2) bond length in the 5-ethylbarbiturate ion (1·24 Å) is longer by 0·02 Å than the value found in the parent acid.

Hydrogen bonding and ionic interactions

In the crystal structure of the $\frac{5}{3}$ hydrate of potassium 5-ethylbarbiturate, the barbiturate anions are linked together to form flattened hydrogen-bonded ribbons (Fig. 4) which zigzag about the [221] direction and lie nearly parallel to the $(11\bar{4})$ plane. Each barbiturate ion forms two hydrogen bonds with each of its two neighbors, in so-called cyclic linkages. Ions *A* and *C*, which occur in the straight sections of ribbon, each form one cyclic linkage across a crystallographic center of symmetry. The ribbon repeat unit may be described schematically by a sequence such as
$::C:::B:::A:::A':::B':::C':::C::$, where a prime indicates inversion. The ribbon repeat distance is 20·3 Å. Although this kind of ribbon has not previously been found in barbiturate crystal structures, the ribbon segment $B':::C':::C:::B$ has the same hydrogen bonding as the tetramer unit in the crystal structure of 5-(6′-bromo-3′-ethyl-2′-methylbenzimidazolium) barbiturate monohydrate (Matthews, 1965).

Excluding the hydrogen bonding at atom O(2)*B*, the N···O hydrogen-bonding distances (2·79–2·85 Å) are normal, and the N···O–C angles (121–126°) are characteristic of barbiturate cyclic linkages (Gartland & Craven, 1974). The N···O(2)*B* distances (3·02 and 3·04 Å) are long, with corresponding H···O(2)*B* distances 2·2 and 2·0 Å. The N···O(2)*B*–C(2)*B* angles (112 and 116°) are markedly smaller than the values (124–131°) commonly observed for cyclic linkages. The non-bonded distance O(2)*A*···O(2)*C* is not unusually short (3·36 Å). The departures from normal cyclic hydrogen-bonding distances and angles indicate an opening of the hydrogen-bonded ribbon at ion *B*, pre-

sumably for a better accommodation of the potassium ions and the water molecules.

There is stacking of the hydrogen-bonded ribbons with partial overlap in parallel planes separated by $d(11\bar{4})=3{\cdot}79$ Å (Fig. 5). The stacking brings the apolar ethyl groups from ions *A*, *B* and *C* so as to cluster in regions running parallel to **c**. Along this same direction, making an angle of 73·6° with the ribbon planes $(11\bar{4})$, there are channels which accommodate the potassium ions and the water molecules (Fig. 6). The water molecules are tetrahedrally coordinated by either one or two potassium ions and by other oxygen atoms, and thus serve as hydrogen-bonding cross-links between adjacent barbiturate ribbons. Distances and angles for these hydrogen bonds are in Table 5.

Each of the three crystallographically distinct potassium ions interacts with at least one barbiturate oxygen atom from each of two different barbiturate ribbons, so that the potassium ions also aid in binding together separate hydrogen-bonded ribbons. The potassium ions are each surrounded by seven oxygen atoms (Fig. 6). The ranges of K···O distances are 2·67 to 3·02 Å for K(1), 2·67 to 3·21 Å for K(2) and 2·72 to 2·94 Å for K(3). The polyhedra of oxygen atoms have certain edges in common; namely, the polyhedra about K(1) and K(2) share the edge $O(2)C\cdots W(2)_{7672}$,* polyhedra about K(1) and K(3) share the edge $O(2)C\cdots W(3)$, and polyhedra about K(2) and K(3) share the edge $O(2)C\cdots O(2)A$. All three polyhedra, moreover, share the common vertex O(2)*C* (Fig. 6). Atom O(2)*C* is notably the only barbiturate oxygen atom in the crystal structure which is not hydrogen bonded. There have been two other crystal structure determinations of potassium salts of barbiturates. In the crystal structure of potassium violurate dihydrate (Gillier, 1965), the potassium coordination is similar to that which is presently reported, with each potassium coordinated by seven oxygen atoms at distances ranging from 2·73 to 2·88 Å. However, in anhydrous potassium barbital (Berthou, Rérat & Rérat, 1965), which is isostructural with the sodium salt (Berking & Craven, 1971), the alkali metal ions are tetrahedrally coordinated by barbital oxygen atoms.

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* The subscript is explained in the caption to Table 5.

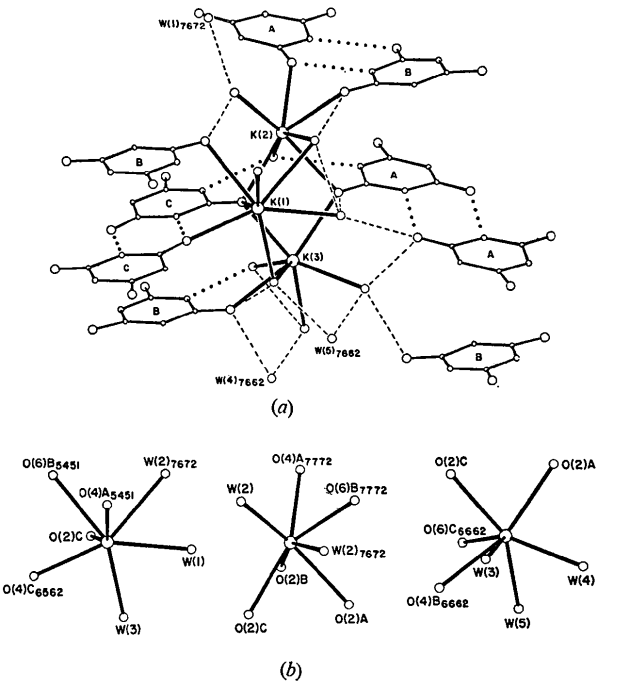

Fig. 6. (*a*) The potassium ion and water molecule environments viewed in the direction which is approximately from the bottom to the top of the page in Fig. 5. Dotted lines represent NH···O hydrogen bonds between anions, and dashed lines represent OH···O hydrogen bonds involving water and barbiturate oxygen atoms. (*b*) The KO_7 coordination is shown left to right for K(1), K(2) and K(3). The orientations are the same as in (*a*). Atomic nomenclature is explained in Table 5.

Table 5. *Atomic distances* (Å) *and angles*(°) *for the hydrogen bonds involving water molecules*

Parameters for atoms not in the crystal chemical unit (as listed in Table 3) may be derived from those in Table 3 by operations specified by the subscripts *i,j,k,l*. The first three digits code a lattice translation of $(i-5)a+(j-5)b+(k-5)c$. The last digit denotes one of the following symmetry operations: $l=1$, x,y,z; $l=2$, $-x,-y,-z$.

A-H···*B*	$d(A\cdots B)$ $\sigma(d)=0{\cdot}01$	$d(H\cdots B)$ $\sigma(d)=0{\cdot}08$	$\theta(A\text{-}H\cdots B)$ $\sigma(\theta)=8$
$W(1)$-H(1$W1$)···O(2)A	2·81	1·86	155
$W(1)$-H(1$W2$)···O(6)A_{8772}	2·84	2·15	128
$W(2)$-H(2$W1$)···O(6)B_{5451}	2·66	1·76	151
$W(2)$-H(2$W2$)···$W(1)_{7672}$	2·74	2·16	152
$W(3)$-H(3$W1$)···$W(5)_{7662}$	2·77	2·11	159
$W(3)$-H(3$W2$)···O(4)B_{6662}	2·79	1·68	156
$W(4)$-H(4$W1$)···O(6)A_{8772}	2·83	2·03	161
$W(4)$-H(4$W2$)···O(4)B_{6551}	2·78	1·96	163
$W(5)$·····O(6)C_{6662}	2·89*	–	–
$W(5)$·····$W(4)_{7662}$	2·72*	–	–

* Hydrogen atoms bonded to $W(5)$ were not located. However, from inspection of a crystal structure model, these distances probably correspond to hydrogen bonds.

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References

BERKING, B. (1972). *Acta Cryst.* B**28**, 98–113.
BERKING, B. & CRAVEN, B. M. (1971). *Acta Cryst.* B**27**, 1107–1115.
BERTHOU, J., RÉRAT, B. & RÉRAT, C. (1965). *Acta Cryst.* **18**, 768–777.
BOLTON, W. (1963). *Acta Cryst.* **16**, 950–956.
BOLTON, W. (1965). *Acta Cryst.* **19**, 1051–1055.
CRAVEN, B. M. (1964). *Acta Cryst.* **17**, 282–289.
CRAVEN, B. M., CUSATIS, C., GARTLAND, G. L. & VIZZINI, E. A. (1973). *J. Mol. Struct.* **16**, 331–342.
CRAVEN, B. M. & SABINE, T. M. (1969). *Acta Cryst.* B**25**, 1970–1978.
CRUICKSHANK, D. W. J. & ROBERTSON, A. P. (1953). *Acta Cryst.* **6**, 698–705.
GARTLAND, G. L. (1971). Ph. D. Dissertation, Univ. of Pittsburgh.
GARTLAND, G. L. & CRAVEN, B. M. (1974). *Acta Cryst.* B**30**, 980–987.
GATEHOUSE, B. M. & CRAVEN, B. M. (1971). *Acta Cryst.* B**27**, 1337–1344.
GILLIER, H. (1965). *Bull. Soc. Chim. Fr.* pp. 2373–2393.
GUTIERREZ, P. & BENSON, B. (1974). *J. Chem. Phys.* **60**, 640–644.
International Tables for X-ray Crystallography (1962). Vol. III. Birmingham: Kynoch Press.
KARLE, J. & KARLE, I. L. (1966). *Acta Cryst.* **21**, 849–859.
MCCLURE, R. J & CRAVEN, B. M. (1973). *Acta Cryst.* B**29**, 1860–1864.
MATTHEWS, B. W. (1965). *Acta Cryst.* **18**, 151–157.
STEWART, R. F., DAVIDSON, E. R. & SIMPSON, W. T. (1965). *J. Chem. Phys.* **42**, 3175–3187.

Acta Cryst. (1975). B**31**, 211

Structural Chemistry of N(7)-Substituted Purines: 7-Methyladenine Dihydrochloride*

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7-Methyladenine dihydrochloride, $C_6N_5H_7.2HCl$, crystallizes in the orthorhombic system, space group *Pbma* or $Pb2_1a$, with crystal data $a=15{\cdot}534$ (8), $b=6{\cdot}589$ (2), $c=9{\cdot}403$ (4) Å, $Z=4$, $D_m=1{\cdot}48$ (2), $D_c=1{\cdot}53$ g cm^{-3}. Intensities for 1206 independent reflections were collected by counter methods. A structural solution in space group *Pbma* has been refined by full-matrix least-squares calculations, based on F, to an R value of 0·069. The final weighted R value and goodness-of-fit are 0·037 and 1·5, respectively. The analysis in *Pbma* requires: (1) exact planarity of the 7-methyladenine dication, (2) staggering of the methyl hydrogen atoms about the molecular plane, and (3) coplanarity of the dication and the chloride anions. The observed sites of protonation are N(3) and N(9). This study provides the first direct evidence of protonation at N(3) for an adenine derivative. The effect of the protonation at N(3) on the structural parameters is discussed. The crystal structure is dominated by a series of N–H···Cl$^-$ hydrogen bonds and C–H···Cl$^-$ interactions. The dications in adjacent layers ($y=\pm\frac{1}{4}$) show a slight overlap of exocyclic amine groups.

Introduction

We have recently studied the crystal and molecular structures of a series of transition-metal complexes containing purines as coordinated ligands (Kistenmacher, Marzilli & Chang, 1973; Marzilli, Kistenmacher & Chang, 1973; Marzilli, Kistenmacher, Darcy, Szalda & Beer, 1974; Kistenmacher & Szalda, 1974; Kistenmacher & Sorrell, 1974). One aspect of this work has centered on the effect on the structural parameters in the purine ligand due to the formation of the coordination bond. In pursuit of such information, we have undertaken a refinement of the structure of adenine hydrochloride hemihydrate (Kistenmacher & Shigematsu, 1974*a*) and determined the structure of adenine dihydrochloride (Kistenmacher & Shigematsu, 1974*b*). Comparison of these results with the structural parameters for protonated adenine coordinated to a transition metal through N(7) (Taylor, 1973) gave an indication of the magnitude of the effects due to coordination (Kistenmacher & Shigematsu, 1974*b*).

In an attempt to take the analysis one step further, we decided to determine the structure of 7-methyladenine dihydrochloride in order to compare the effects of protonation, coordination and alkylation at N(7) on the protonated adenine nucleus. We fully anticipated at the onset of the project that 7-methyladenine would be protonated at N(1) and N(9), as was indicated to be the trend in adenine and N(9)-substituted adenine derivatives. However, our analysis shows (see below) that 7-methyladenine is protonated at N(3) and not

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