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The Crystal Structures of Monoclinic 5-Ethylbarbituric Acid and 5-Hydroxy-5-ethylbarbituric Acid

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The crystal data for the two forms of 5-ethylbarbituric acid (EBA) are (I) monoclinic (m.p. 194–196°), $a=11\cdot151$, $b=6\cdot838$, $c=9\cdot536$ Å, $\beta=92°21'$, space group $P2_1/c$ with four molecules per cell; (II) triclinic (m.p. 142–145°), $a=6\cdot018$, $b=5\cdot344$, $c=12\cdot121$ Å, $\alpha=93°38'$, $\beta=105°42'$, $\gamma=94°19'$, space group $P1$ or $P\bar{1}$ with two molecules per cell. The crystal structure of (I) is reported together with that of the oxidation product 5-hydroxy-5-ethylbarbituric acid (HEBA) which is monoclinic (m.p. 207–209°), $a=10\cdot088$, $b=6\cdot298$, $c=11\cdot914$ Å, $\beta=99°36'$, space group $P2_1/n$ with four molecules per cell. The X-ray diffraction data (Cu $K\alpha$ radiation) were obtained using an automatic four-circle diffractometer. All hydrogen atoms were found in difference Fourier syntheses. Full-matrix least-squares refinement gave R values of 0·06 and 0·05 respectively. The rings in both EBA and HEBA have a 'flap' conformation with C(5) displaced from an otherwise nearly flat ring. In EBA the ethyl group is *equatorial*, while in HEBA it is *axial.* All NH and OH hydrogen bond donor groups form hydrogen bonds. The acidic hydrogen atom H(5) in EBA is not hydrogen bonded. The non-hydrogen-bonded carbonyl oxygen atom O(6) makes close approaches (2·93 and 3·04 Å) to carbonyl carbon atoms C(4) and C(6) of an adjacent molecule.

Introduction

The crystal structure of a monoclinic form of 5-ethylbarbituric acid (Fig. 1, R = H), hereafter EBA, has been determined for the purpose of a comparison of the molecular structure and stereochemistry of the parent acid with that of the carbanion which is found in the crystal structure of the 5/3 hydrate of the corresponding potassium salt (Gartland & Craven, 1970*a*).

At first, crystals of an apparent monohydrate of EBA were studied. However, a crystal structure determination, which is also reported in this paper, showed the material to be the oxidation product, 5-hydroxy-5-ethylbarbituric acid (Fig. 1, R = OH), hereafter HEBA.

Subsequently, both a triclinic and a monoclinic form of EBA were crystallized. Crystal data are given for the triclinic form, but no further work on this crystal structure is intended.

Experimental

The synthesis of EBA was by condensation of the diethyl ester of ethylmalonic acid with urea in the presence of sodium ethoxide. The reaction mixture, after recrystallization from hot water in air contained the product together with what we have shown by crystal structure determination to be HEBA. The latter can also be formed by the oxidation of EBA with peroxide or dichromate ion (Aspelund, 1933).

The triclinic form of EBA (m.p. 142–145 °C) does not appear to have been previously characterized. It was obtained by recrystallization from absolute ethanol. Recrystallization from isoamyl acetate solution converted the triclinic into the monoclinic form. Both forms were at least partially converted to HEBA when dissolved in water and left for several days in air.

The crystal data for the two forms of EBA and for HEBA are listed in Table 1. The melting points werg determined from single crystals of each material using a hot stage microscope. Crystal densities were meas-

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ured by flotation in mixtures of benzene and carbon tetrachloride. The lattice parameters as well as the X-ray intensity data (Table 2) were measured on a four-circle automatic diffractometer, using Cu $K\alpha$ radiation. The integrated intensities were obtained for all non-symmetry-related reflections with $\sin\theta/\lambda \leq 0{\cdot}59$ Å^{-1}. Reflections were scanned in the $\theta:2\theta$ mode at a rate of 2° in 2θ per minute, with 20 second background counts at the scan limits. Integrated intensities, I, with $I \leq 1{\cdot}2\sigma(I)$ were considered to be unobservably weak and were assigned an intensity of $\sigma(I)/2$. No corrections were made for X-ray absorption or extinction.

The structure determinations

For both crystal structures, direct methods were applied in solving the phase problem (Karle & Karle, 1966). The resulting Fourier syntheses with normalized structure factors as coefficients revealed only the partial crystal structures. Trial models were recognized from four or five atom fragments of the barbiturate ring which were also consistent with NH···O=C intermolecular hydrogen bonding as found in other barbiturate crystal structures (*e.g.* barbital I; Craven, Vizzini & Rodrigues, 1969). At this stage, the remaining atoms were revealed by several cycles of structure factor and Fourier synthesis calculations. The unexpected 5-hydroxyl oxygen atom peak appeared in the Fourier syntheses calculated for HEBA. It was tentatively identified from the observed peak height and the short intermolecular distance O(5)···O(2) which

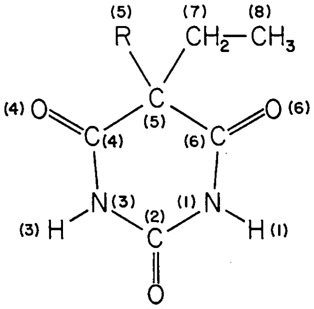


Fig. 1. Molecular structure and atomic nomenclature. (*a*) R=H; 5-ethylbarbituric acid, (*b*) R=OH; 5-hydroxy-5-ethylbarbituric acid.

Table 1. *Crystal data for 5-ethylbarbituric acid (two forms) and 5-hydroxy-5-ethylbarbituric acid*

	5-Ethylbarbituric acid ($C_6H_8N_2O_3$)		5-Hydroxy-5-ethylbarbituric acid ($C_6H_8N_2O_4$)
	Monoclinic	Triclinic	Monoclinic
Melting point (°C)	194–196°	142–145°	207–209°
Crystal habit	Lozenge-shaped plates on (100)	Thin plates on (001)	Prisms, elongated on *b*.
a	11·151 (7) Å	6·018 (5) Å	10·088 (8) Å
b	6·838 (3)	5·344 (5)	6·298 (4)
c	9·536 (7)	12·121 (7)	11·914 (8)
α		93°38 (2)′	
β	92°21 (1)′	105°42 (2)′	99°36 (1)′
γ		94°19 (2)′	
Z	4	2	4
d_{obs}	1·423 (5) g.cm^{-3}	1·411 (5) g.cm^{-3}	1·534 (5) g.cm^{-3}
d_{calc}	1·427 g.cm^{-3}	1·390 g.cm^{-3}	1·532 g.cm^{-3}
Space group	$P2_1/c$	$P1$ or $P\bar{1}$	$P2_1/n$
μ(Cu $K\alpha$)	10·0 cm^{-1}	9·9 cm^{-1}	11·4 cm^{-1}

Table 2. *Intensity data and refinement criteria for 5-ethylbarbituric acid (monoclinic) and 5-hydroxy-5-ethylbarbituric acid*

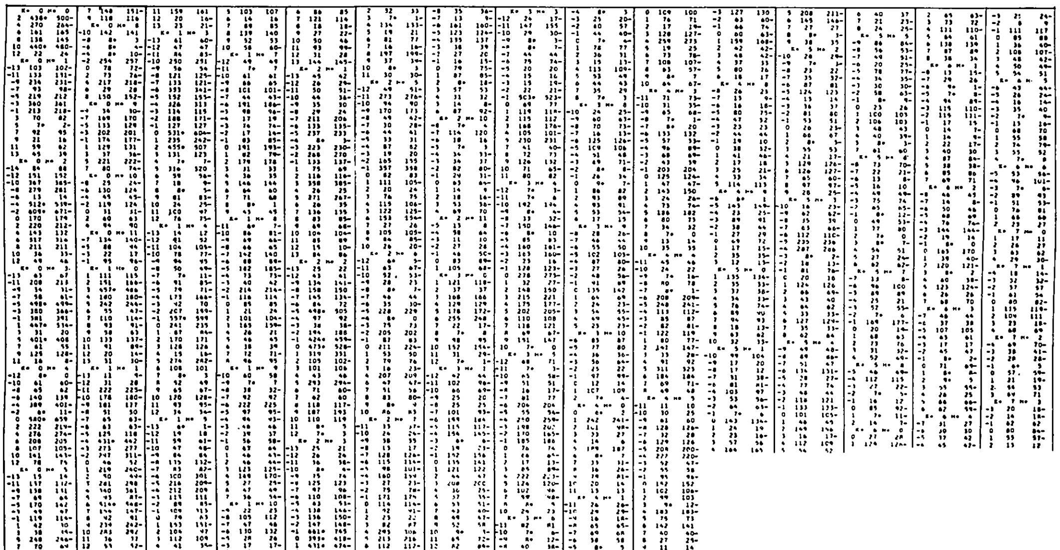
	5-Ethylbarbituric acid (monoclinic)	5-Hydroxy-5-ethylbarbituric acid
Crystal dimensions (mm)	0·2 × 0·2 × 0·1	0·4 × 0·2 × 0·1
Crystal axis along diffractometer Φ-axis	b	b
Number of independent reflections	1153	1240
Number of unobserved reflections	331	86
R value, all reflections	0·062	0·046
R value, excluding unobserved reflections	0·044	0·039
Assumed variance in structure amplitude [$\sigma^2(F) = A + BF + CF^2$]		
A	0·47	0·25
B	−0·11	0·0
C	$8{\cdot}80 \times 10^{-3}$	$7{\cdot}7 \times 10^{-4}$
Standard deviation in observation of unit weight	0·95	0·83

Table 3. *Observed and calculated structure factors*

Successive columns list l, $10|F_o|$, and $10F_c$. Unobserved reflections and the strong reflections which were given zero weight in the final least-squares refinement are marked by (*).

(*a*) 5-Ethylbarbituric acid

(*b*) 5-Hydroxy-5-ethylbarbituric acid



appeared to be a hydrogen bond. This was confirmed when the hydroxyl hydrogen atom was found together with all other hydrogen atoms in a difference Fourier synthesis. All hydrogen atoms in EBA were also found in a difference Fourier synthesis.

A full-matrix least-squares procedure was used for the refinement of atomic positional parameters (including those of the hydrogen atoms), and anisotropic thermal parameters for nonhydrogen atoms. Hydrogen atoms were assumed to have the same thermal parameters as the heavier atoms to which they are bonded.

The X-ray atomic scattering factors were taken from *International Tables for X-ray Crystallography* (1962) for the heavy atoms and from Stewart, Davidson & Simpson (1965) for the hydrogen atoms. The function minimized in the least-squares refinement was $\sum w\Delta F^2$ with weighting $w=1/\sigma^2(F)$ where $\sigma^2(F)$ is as defined in Table 2. In the case of HEBA, all 16 reflections with $F_{\rm calc}|>45$ were given zero weight in the final least-squares cycles. The final R values (Table 2) are defined as $\sum|\Delta F_{\rm meas}|/\sum|F_{\rm meas}|$. The final observed and calculated structure factors are listed in Table 3,

Table 4. *Atomic positional and thermal parameters with their e.s.d.'s*

The positional parameters are given as fractions of the lattice translations. Thermal parameters are defined by the expression $T=\exp\left[-(\beta_{11}h^2+\beta_{22}k^2+\beta_{33}l^2+2\beta_{12}hk+2\beta_{13}hl+2\beta_{23}kl)\right]$.

The e.s.d.'s are given in brackets and refer to the least significant digits in the parameter values. For each parameter, the value for 5-ethylbarbituric acid is above the value for 5-hydroxy-5-ethylbarbituric acid. The $U(1)$, $U(2)$ and $U(3)$ values are thermal vibrational amplitudes (Å). They are the square roots of the principal values of the mean-square vibrational tensors and are derived from β_{ij}.

	x	y	z	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}	U(1)	U(2)	U(3)
N(1)	0.1736(2)	0.7430(3)	0.2498(2)	0.0098(2)	0.0109(4)	0.0116(2)	-0.0001(2)	-0.0022(2)	-0.0002(3)	0.16	0.21	0.27
	0.2709(1)	0.4575(3)	0.6287(1)	0.0052(1)	0.0172(4)	0.0037(1)	0.0041(2)	0.0005(1)	-0.0001(2)	0.13	0.16	0.21
H(1)	0.174(2)	0.867(4)	0.246(2)									
	0.202(2)	0.530(3)	0.618(2)									
C(2)	0.1044(2)	0.6507(3)	0.1486(2)	0.0074(2)	0.0125(5)	0.0098(3)	-0.0003(2)	-0.0006(2)	-0.0003(3)	0.17	0.20	0.23
	0.3023(2)	0.3701(3)	0.5315(1)	0.0047(2)	0.0132(4)	0.0037(1)	0.0001(2)	0.0008(1)	0.0000(2)	0.15	0.16	0.16
O(2)	0.0460(1)	0.7405(2)	0.0588(2)	0.0091(2)	0.0140(4)	0.0110(2)	0.0006(2)	-0.0028(1)	0.0012(2)	0.17	0.20	0.27
	0.2406(1)	0.4110(2)	0.4377(1)	0.0063(1)	0.0222(4)	0.0035(1)	0.0029(2)	-0.0002(1)	0.0009(1)	0.14	0.18	0.22
N(3)	0.1045(2)	0.4509(3)	0.1529(2)	0.0084(2)	0.0136(4)	0.0110(2)	-0.0006(2)	-0.0026(2)	-0.0010(2)	0.17	0.20	0.26
	0.4086(1)	0.2300(2)	0.5456(1)	0.0058(2)	0.0165(4)	0.0028(1)	0.0026(2)	0.0009(1)	-0.0007(2)	0.13	0.16	0.20
H(3)	0.065(2)	0.398(4)	0.093(3)									
	0.419(2)	0.161(3)	0.487(2)									
C(4)	0.1640(2)	0.3353(3)	0.2501(2)	0.0077(2)	0.0129(5)	0.0119(3)	0.0001(2)	-0.0001(2)	0.0005(3)	0.17	0.21	0.24
	0.4769(2)	0.1593(3)	0.6478(1)	0.0046(2)	0.0155(5)	0.0038(1)	0.0012(2)	0.0007(1)	0.0001(2)	0.15	0.16	0.18
O(4)	0.1637(2)	0.1601(2)	0.2357(2)	0.0119(2)	0.0107(4)	0.0159(3)	0.0004(2)	-0.0036(2)	-0.0005(2)	0.16	0.23	0.31
	0.5520(1)	0.0085(2)	0.6541(1)	0.0083(2)	0.0202(4)	0.0043(1)	0.0064(2)	0.0005(1)	-0.0005(2)	0.14	0.17	0.25
C(5)	0.2232(2)	0.4380(3)	0.3756(2)	0.0089(2)	0.0164(5)	0.0095(2)	-0.0007(3)	-0.0010(2)	0.0005(3)	0.20	0.20	0.24
	0.4633(2)	0.2937(3)	0.7520(1)	0.0047(2)	0.0129(4)	0.0030(1)	-0.0003(2)	0.0006(1)	0.0006(2)	0.14	0.15	0.16
H(5)	0.162(2)	0.434(3)	0.447(2)									
	0.553(2)	0.133(3)	0.872(2)									
O(5)	-	-	-	-	-	-	-	-	-	-	-	-
	0.4739(1)	0.1668(2)	0.8497(1)	0.0046(1)	0.0153(3)	0.0033(1)	-0.0001(2)	0.0004(1)	0.0016(1)	0.14	0.15	0.19
C(7)	0.3356(3)	0.3352(4)	0.4311(3)	0.0133(3)	0.0182(6)	0.0153(4)	0.0012(3)	-0.0060(3)	0.0004(4)	0.20	0.22	0.34
	0.5759(2)	0.4644(3)	0.7616(2)	0.0068(2)	0.0168(5)	0.0049(1)	-0.0024(3)	0.0013(1)	0.0010(2)	0.15	0.19	0.21
H(71)	0.316(3)	0.212(4)	0.448(3)									
	0.561(2)	0.547(3)	0.691(2)									
H(72)	0.362(3)	0.400(4)	0.521(3)									
	0.658(2)	0.717(4)	0.870(2)									
C(8)	0.4366(4)	0.3377(7)	0.3313(4)	0.0102(3)	0.0433(12)	0.0241(6)	0.0045(6)	-0.0044(4)	-0.0069(8)	0.22	0.29	0.33
	0.5857(3)	0.6049(4)	0.8660(2)	0.0103(3)	0.0193(6)	0.0078(2)	-0.0044(3)	0.0015(2)	-0.0033(3)	0.16	0.23	0.25
H(81)	0.517(4)	0.293(5)	0.354(4)									
	0.504(3)	0.689(4)	0.864(2)									
H(82)	0.406(3)	0.255(5)	0.240(4)									
	0.659(2)	0.379(3)	0.758(2)									
H(83)	0.445(3)	0.477(6)	0.282(4)									
	0.593(2)	0.523(4)	0.938(2)									
C(6)	0.2406(2)	0.6552(3)	0.3565(2)	0.0082(2)	0.0156(5)	0.0104(3)	-0.0001(3)	-0.0013(2)	-0.0002(3)	0.19	0.20	0.24
	0.3280(2)	0.4060(3)	0.7387(1)	0.0054(2)	0.0133(4)	0.0038(1)	0.0006(2)	0.0009(1)	-0.0006(2)	0.15	0.17	0.17
O(6)	0.3054(2)	0.7517(2)	0.4339(2)	0.0117(2)	0.0184(4)	0.0146(3)	-0.0024(2)	-0.0055(2)	-0.0013(2)	0.18	0.22	0.32
	0.2758(1)	0.4599(2)	0.8187(1)	0.0070(1)	0.0254(4)	0.0039(1)	0.0041(2)	0.0017(1)	-0.0008(2)	0.14	0.18	0.24

and the atomic parameters with their estimated standard deviations (e.s.d.'s) are given in Table 4. The square roots of the principal values of the mean square atomic vibrational tensors (U_i) are also given in Table 4. These were derived from the listed β_{ij} values.

The amplitudes of atomic thermal vibrations are somewhat smaller and more nearly isotropic for HEBA. We attribute this to the effect of the additional hydrogen bond which leads to a three-dimensional molecular linkage in the crystal structure. In EBA, the largest atomic thermal amplitudes $U(3)$ excluding C(8) are nearly normal to the ring plane. The greatest deviations from this direction are 20° for C(4) and 13° for C(5).

Discussion

(i) *Molecular conformations*

Molecules of EBA and HEBA are viewed edge-on to pyrimidine rings in Figs. 2(*a*) and 3 respectively. In both molecules, the ring is almost planar except for a displacement of the tetrahedrally bonded carbon atom C(5) from the best least-squares plane of the other five atoms. In HEBA, the ring puckering is greater (Table 5). Folding of the barbiturate ring along C(4)···C(6) to give a 'flap' conformation can be achieved in two ways, and if the 5 substituents are different there will be two different conformers, depending on which substituent is *axial* with respect to the ring and which is *equatorial*. From intramolecular considerations, the ethyl group is expected to be *axial*, since this is bulkier than hydrogen or hydroxyl and the steric repulsion from carbonyl groups at C(4) and C(6) is minimized for the *axial* substituent. This is found to be the case for HEBA, but surprisingly, it is the hydrogen which is *axial* in EBA. It may be that this conformation is favored only in the monoclinic crystal structure and that the other conformation is favored in solution or in the triclinic crystal structure.

The conformation about the C(5)–C(7) bond is also different in HEBA and EBA (monoclinic). In the former, the C(7)–C(8) bond is *gauche* and in the latter it is *trans* with respect to the bond to the other C(5) substituent. The *gauche* conformation (Fig. 3) is presumably preferred because in the case of an *axial* ethyl group, a *trans* conformation about C(5)–C(7) would bring the C(8) methyl group into close contact with the pyrimidine ring atoms.

The 'flap' conformation of the ring has been observed in other barbiturate crystal structures, *e.g.* in

Table 5. *Ring conformations*

(*a*) Best least-squares planes.

The equations of these planes are in the form $AX+BY+CZ=D$, referred to the crystallographic axes, with X, Y, Z in Å.

	A	B	C	D
5-Ethylbarbituric acid	+0·8113	−0·0291	−0·6169	−0·0511
5-Hydroxy-5-ethylbarbituric acid	−0·6715	−0·7407	+0·1306	−2·9723

(*b*) Distances from the plane of atoms which form the plane

	5-Ethylbarbituric acid	5-Hydroxy-5-ethylbarbituric acid
N(1)	+0·004 Å	−0·019 Å
C(2)	−0·008	+0·025
N(3)	+0·008	−0·019
C(4)	−0·004	+0·007
C(6)	+0·000	+0·006

(*c*) Distances from the plane of atoms which do not form the plane.

H(1)	+0·00 Å	+0·09 Å
O(2)	−0·026	+0·107
H(3)	+0·01	+0·14
O(4)	+0·114	+0·212
C(5)	−0·225	−0·367
O(6)	+0·111	+0·233
H(5)	−1·20	–
C(7)	+0·485	−1·911
O(5)	–	+0·306

(*d*) Ring torsion angles

Angles are given for the central bond in each group of four atoms. The angle is calculated for the view down the bond in the sense defined by the arrow. A positive torsion angle is a clockwise twist of the bond nearest the viewer with respect to that which is furthest.

C(6)–N(1)→C(2)–N(3)	+1·5°	−5·6°
N(1)–C(2)→N(3)–C(4)	−1·9	+5·6
C(2)–N(3)→C(4)–C(5)	−8·0	−19·5
N(3)–C(4)→C(5)–C(6)	+17·2	+30·4
C(4)–C(5)→C(6)–N(1)	−17·5	−30·1
C(5)–C(6)→N(1)–C(2)	+8·8	+19·3

5,5-dihydroxybarbituric acid (Singh, 1965) and its trihydrate (Mootz & Jeffrey, 1965), phenobarbital in the 1:2 crystal complex with 8-bromo-9-ethyladenine (Kim & Rich, 1969), 1-methylphenobarbital (Bideau, Marly & Housty, 1969) and 5-methyl-5-phenylbarbituric acid (Bravic, Housty & Bideau, 1969). However, this is not always the case. In barbital, polymorph I (Craven, Vizzini & Rodrigues, 1969), amobarbital (Craven & Vizzini, 1969), γ-amobarbital (Gartland & Craven, 1970*b*) in which both C(5) substituents are alkyl groups and vinbarbital (Craven & Cusatis, 1969) in which one substituent is an alkyl and the other an alkenyl group, the pyrimidine ring is slightly puckered into a skew-boat conformation. In barbital II (Craven, Vizzini & Rodrigues, 1969) the ring is flat. At present there seems to be no basis for reliable prediction of molecular conformation in barbiturate crystal structures.

(ii) *Bond lengths and angles*

The ring C–N and carbonyl C–O bond lengths and angles (Table 6) agree well with those found in other barbiturate crystal structures. The C–C ring bond lengths in the sequence 5,5-diethylbarbituric acid (and other 5,5-dialkylbarbituric acids), 5-ethylbarbituric acid and barbituric acid show a slight progressive shortening (1·52, 1·51, 1·50 Å) which may be significant. The bond length C(5)–C(7) in HEBA is long (1·55 Å) as it is in the 5,5-dialkylbarbituric acids, but in EBA it is significantly shorter (1·51 Å). These effects are consistent with a shortening of the bonds at the tetrahedral carbon atom C(5) with progressive substitution of bulkier groups by hydrogen atoms.

Table 6. *Bond lengths and angles*

These parameters are not corrected for the effect of anisotropic thermal vibration. The e.s.d.'s are given in brackets and refer to the least significant digits in the molecular parameter values.

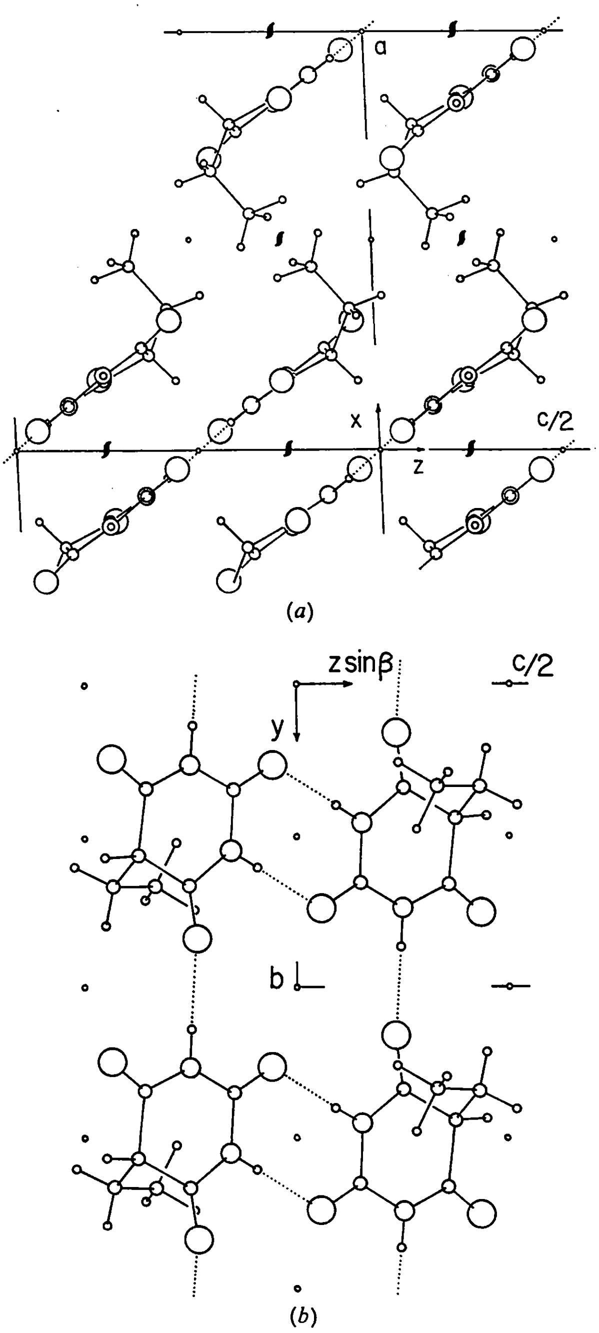
(*a*) Bond lengths

	5-Ethylbarbituric acid	5-Hydroxy-5-ethylbarbituric acid
N(1)-C(2)	1·364 (3) Å	1·365 (2) Å
N(3)-C(2)	1·368 (3)	1·377 (2)
N(1)-C(6)	1·374 (3)	1·380 (2)
N(3)-C(4)	1·368 (3)	1·369 (2)
C(2)-O(2)	1·220 (2)	1·212 (2)
C(4)-O(4)	1·206 (3)	1·208 (2)
C(6)-O(6)	1·209 (3)	1·211 (2)
C(5)-O(5)	–	1·402 (2)
C(4)-C(5)	1·515 (3)	1·527 (2)
C(6)-C(5)	1·509 (3)	1·522 (2)
C(5)-C(7)	1·512 (4)	1·553 (3)
C(7)-C(8)	1·503 (5)	1·516 (3)
N(1)-H(1)	0·85 (2)	0·82 (2)
N(3)-H(3)	0·80 (2)	0·85 (2)
O(5)-H(5)	–	0·83 (2)
C(5)-H(5)	0·98 (3)	–
C(7)-H(71)	0·90 (3)	0·97 (2)
C(7)-H(72)	1·00 (3)	1·01 (2)
C(8)-H(81)	0·95 (4)	0·98 (2)
C(8)-H(82)	1·09 (3)	1·01 (2)
C(8)-H(83)	1·07 (4)	0·99 (3)

Table 6 (*cont.*)

(*b*) Bond angles

C(6)—N(1)–C(2)	126·5 (2)°	126·3 (1)°
N(1)—C(2)–N(3)	116·2 (2)	116·2 (1)
C(2)—N(3)–C(4)	126·6 (2)	125·6 (1)
N(3)—C(4)–C(5)	116·9 (2)	116·2 (1)



(*a*)

(*b*)

Fig. 2. The crystal structure of 5-ethylbarbituric acid. Circles of decreasing size represent oxygen, nitrogen, carbon and hydrogen atoms respectively. Hydrogen bonds are shown dotted. (*a*) The projection down the *b* axis, (*b*) A hydrogen bonded ribbon shown projected down the *a* axis. Overlapping ribbons are omitted.

Table 6 (*cont.*)

C(4)—C(5)–C(6)	114·4 (2)°	111·9 (1)°
C(5)—C(6)–N(1)	116·9 (2)	115·6 (1)
N(1)—C(2)–O(2)	122·2 (2)	122·6 (2)
N(3)—C(2)–O(2)	121·6 (2)	121·2 (2)
N(3)—C(4)–O(4)	119·8 (2)	121·9 (2)
C(5)—C(4)–O(4)	123·3 (2)	121·7 (2)
N(1)—C(6)–O(6)	120·4 (2)	120·9 (2)
C(5)—C(6)–O(6)	122·6 (2)	123·3 (2)
C(4)—C(5)–C(7)	112·9 (2)	106·3 (1)
C(6)—C(5)–C(7)	113·1 (2)	108·6 (1)
C(5)—C(7)–C(8)	113·8 (3)	114·2 (2)
C(6)—N(1)–H(1)	118 (2)	119 (1)
C(2)—N(1)–H(1)	116 (2)	114 (1)
C(4)—N(3)–H(3)	115 (2)	117 (1)
C(2)—N(3)–H(3)	118 (2)	115 (1)
C(5)—C(7)–H(71)	108 (2)	107 (1)
C(5)—C(7)–H(72)	108 (2)	104 (1)
C(7)—C(8)–H(81)	123 (2)	111 (1)
C(7)—C(8)–H(82)	107 (2)	113 (1)
C(7)—C(8)–H(83)	111 (2)	113 (1)
H(71)–C(7)–H(72)	109 (2)	105 (2)
H(81)–C(8)–H(82)	106 (3)	103 (2)
H(81)–C(8)–H(83)	108 (3)	104 (2)
H(82)–C(8)–H(83)	97 (3)	112 (2)
C(4)—C(5)–H(5)	104 (1)	–
C(6)—C(5)–H(5)	102 (1)	–
C(7)—C(5)–H(5)	110 (1)	–
C(4)—C(5)–O(5)	–	110·8 (1)
C(6)—C(5)–O(5)	–	107·0 (1)
C(7)—C(5)–O(5)	–	112·3 (1)
C(5)—O(5)–H(5)	–	110 (1)

The C(5)–O(5) hydroxyl bond length (1·40 Å) is a little shorter than the hydroxyl bond lengths commonly found in acyclic sugar alcohols (1·43 Å; Jeffrey & Kim, 1970), but is the same as those observed in 5,5-dihydroxybarbituric acid (Singh, 1965) and its trihydrate (Mootz & Jeffrey, 1965).

(iii) *Hydrogen bonding and molecular packing*

In both EBA (Fig. 2) and HEBA (Fig. 4) all available NH and OH donor groups are hydrogen bonded to oxygen acceptor atoms. The hydrogen bond distances and angles are in Table 7.

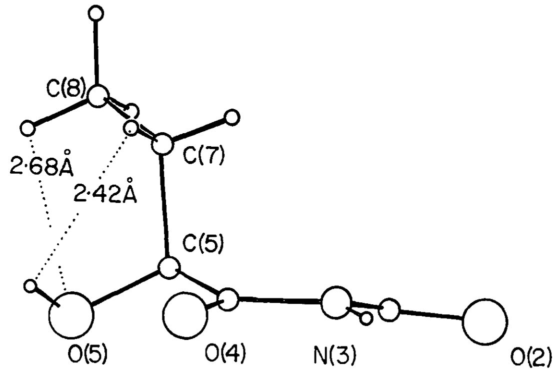


Fig. 3. Molecular conformation of 5-hydroxy-5-ethylbarbituric acid in the crystal structure. The molecule is projected along the direction from C(4) to C(6). Atoms O(6) and N(1) are obscured by O(4) and N(3) respectively.

Table 7. *Intermolecular distances and angles*

(*a*) 5-Ethylbarbituric acid

(i) Hydrogen bonds

	Distance		Angle
N(1)···O(4)	2·85 Å	N(1)–H(1)···O(4)	177°
H(1)···O(4)	2·00	H(1)···O(4)–C(4)	170
N(3)···O(2)	2·89	N(3)–H(3)···O(2)	177
H(3)···O(2)	2·09	H(3)···O(2)–C(2)	123

(ii) Other distances, including all those within 0·2 Å of the appropriate van der Waals distances (Pauling, 1960). The subscripts indicate atoms which are related to those listed in Table 4 by the following symmetry operations:

a	$-x,$	$\frac{1}{2}+y,$	$\frac{1}{2}-z$
b	$x,$	$\frac{3}{2}-y,$	$-\frac{1}{2}+z$
c	$x,$	$\frac{1}{2}-y,$	$-\frac{1}{2}+z$
d	$1-x,$	$1-y,$	$1-z$
e	$x,$	$\frac{1}{2}-y,$	$\frac{1}{2}+z$
f	$1-x,$	$\frac{1}{2}+y,$	$\frac{1}{2}-z$
g	$1-x,$	$-\frac{1}{2}+y,$	$\frac{1}{2}-z$

C(2)···O(4*a*)	3·23 Å	H(72)···H(82*e*)	2·37 Å
C(2)···O(6*b*)	3·17	H(81)···O(6*d*)	2·80
O(2)···C(4*a*)	3·09	H(81)···H(72*d*)	2·76
O(2)···O(4*a*)	3·16	H(81)···H(83*g*)	2·56
O(2)···H(5*a*)	2·67	H(82)···H(83*g*)	2·55
O(2)···H(5*b*)	2·80		
O(2)···C(6*b*)	3·05		
O(4)···H(5*c*)	2·83		
O(6)···C(8*d*)	3·62		
C(7)···C(4*e*)	3·84		
C(7)···O(4*e*)	3·55		
C(7)···C(8*d*)	4·01		
C(7)···C(8*e*)	4·10		
C(8)···C(8*d*)	4·11		
C(8)···C(8*f*)	4·03		
C(8)···C(8*g*)	4·03		

(*b*) 5-Hydroxy-5-ethylbarbituric acid

(i) Hydrogen bonds

	Distance		Angle
N(1)···O(5)	2·85 Å	N(1)–H(1)···O(5)	159°
H(1)···O(5)	2·06	H(1)···O(5)–C(5)	116
H(1)···H(5)	2·68	H(1)···O(5)–H(5)	130
N(3)···O(4)	2·90	N(3)–H(3)···O(4)	179
H(3)···O(4)	2·05	H(3)···O(4)–C(4)	122
O(5)···O(2)	2·76	O(5)–H(5)···O(2)	172
H(5)···O(2)	1·94	H(5)···O(2)–C(2)	131

(ii) Other distances including all those within 0·2 Å of the appropriate van der Waals distances (Pauling, 1960). The subscripts indicate atoms which are related to those listed in Table 4 by the following symmetry operations:

a	$\frac{1}{2}-x,$	$-\frac{1}{2}+y,$	$\frac{3}{2}-z$
b	$1-x,$	$1-y,$	$1-z$
c	$-\frac{1}{2}+x,$	$\frac{1}{2}-y,$	$-\frac{1}{2}+z$
d	$-\frac{1}{2}+x,$	$\frac{3}{2}-y,$	$-\frac{1}{2}+z$
e	$\frac{1}{2}-x,$	$\frac{1}{2}+y,$	$\frac{3}{2}-z$
f	$x,$	$-1+y,$	z
g	$\frac{3}{2}-x,$	$-\frac{1}{2}+y,$	$\frac{3}{2}-z$
h	$1-x,$	$1-y,$	$2-z$

	Distance		Distance
N(1)···O(6*a*)	3·25 Å	N(3)····O(6*a*)	3·16 Å
N(1)···O(6*e*)	3·28	O(4)····C(7*f*)	3·56
C(2)···C(7*b*)	4·03	O(4)····H(82*f*)	3·20
C(2)···C(8*c*)	4·02	O(5)····C(7*f*)	3·71
O(2)···C(7*b*)	3·34	O(5)····H(81*f*)	3·03
O(2)···C(7*c*)	3·40	O(6)····C(6*e*)	3·04
O(2)···H(71*b*)	2·73	O(6)····C(4*e*)	2·93
O(2)···H(72*c*)	2·83	O(6)····C(5*e*)	3·20
O(2)···C(8*d*)	3·47	H(72)···H(82*g*)	2·78
O(2)···H(82*d*)	2·57	C(8)····C(8*h*)	4·10
		H(82)...H(83*h*)	2·59

In EBA, molecules are linked together in hydrogen bonded ribbons which run parallel to the *b* axis [Fig. 2(*b*)]. The same ribbons are found in barbituric acid (Bolton, 1963) and barbital I (Craven, Vizzini & Rodrigues, 1969). However, in EBA, unlike these other crystal structures, the ribbons are stacked in a parallel array [Fig. 2(*a*)] in which the separation between ribbon planes is 3·09 Å.

The hydrogen atom H(5) in EBA might be expected to form a CH···O hydrogen bond (Sutor, 1962) since it is flanked by electronegative carbonyl groups and is the most acidic hydrogen atom in the molecule. However, this is not the case. The C(5)–H(5) bond, being *axial*, projects from the ribbon plane towards a neighbouring ribbon with a closest H···O intermolecular distance of 2·67 Å [Table 7(*a*), (ii)].

The most noteworthy feature of the hydrogen bonding in HEBA (Fig. 4) is that one of the imine groups N(1) H(1) is hydrogen bonded to the O(5) hydroxyl oxygen atom. In barbiturate crystal structures, including 5,5-dihydroxybarbituric acid (Singh, 1965) and its trihydrate (Mootz & Jeffrey, 1965), it is usual to find both imine groups in the molecule hydrogen bonded to carbonyl oxygen atoms. The O(5)–H(5) hydroxyl group in HEBA thus is both a hydrogen bonding donor and acceptor.

The non-hydrogen-bonded carbonyl C(6)–O(6) in HEBA is directed towards carbon atoms C(4) and C(6) of carbonyl groups in a neighbouring molecule with intermolecular distances O···C of 2·93 and 3·04 Å respectively, (Fig. 4). There are similar short carbonyl intermolecular C···O distances in a number of other crystal structures, including several barbiturates. These have been attributed to dipole or induced dipole interactions (Bolton, 1964; Prout & Wallwork, 1966). The close approach of one carbonyl oxygen to *two* other carbonyl carbon atoms has not been previously reported.

In both EBA and HEBA, there are van der Waals interactions between ethyl groups. In EBA, these appear to assume greater importance, since there are distinct 'hydrophobic' regions in the crystal structure which center on the planes at $x=\frac{1}{2}$ [Fig. 2(*a*)].

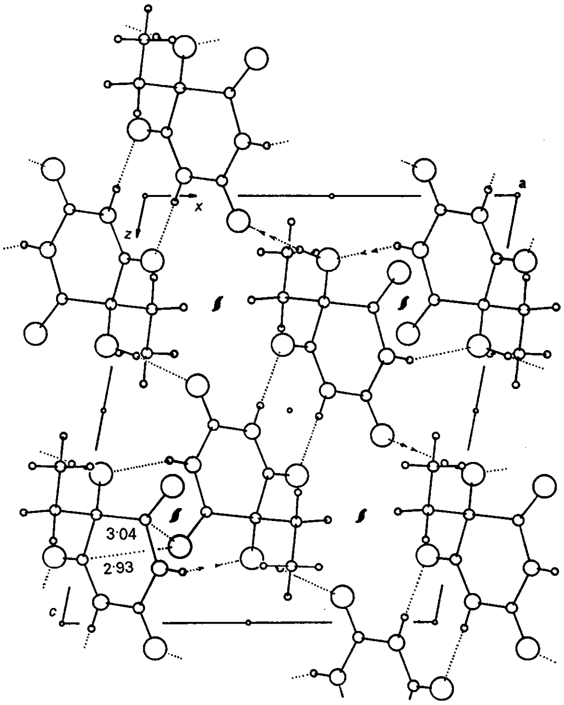


Fig. 4. The crystal structure of 5-hydroxy-5-ethylbarbituric acid projected down the *b* axis. Circles of decreasing size represent oxygen, nitrogen, carbon and hydrogen atoms respectively. Hydrogen bonds are shown dotted. At the bottom left, the short intermolecular O(6)···C(4) and O(6)···C(6) distances are also shown dotted.

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