

## Antischistosomal Analogs of Hycanthone.

### II.\* Structure of 2-[2-(Diethylamino)ethyl]-2*H*-[1]benzothioopyrano[4,3,2-*cd*]indazole-5-methanol Monohydrate†‡

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#### Abstract

The title compound,  $C_{20}H_{23}N_3OS \cdot H_2O$ , is rhombohedral, space group  $R\bar{3}$  with hexagonal unit-cell parameters  $a = b = 36.685$  (2) and  $c = 7.7432$  (5) Å. The unit cell contains 18 molecules in general positions. The structure was solved by the standard heavy-atom technique, and full-matrix least-squares refinement of the structure led to  $R(F) = 0.042$  for 2804 reflections (corrected for absorption and isotropic extinction) with  $F_o^2 \geq \sigma(F_o^2)$  and  $|\Delta F^2| \leq 4\sigma(F_o^2)$ . All H atoms were located and their parameters were refined, with some of them restrained to retain their proper geometries. Estimated standard deviations of bond lengths and bond angles involving only C, N and O atoms are of the order of 0.004 Å and 0.2°, respectively. All molecular parameters are within the ranges of expected values, and the fused four-ring system is nearly planar. Unlike the case of the chloro-analog cation, the terminal N of the present compound is not protonated. It is, however, hydrogen bonded to the hydroxyl H atom of a neighboring, screw-triad-related  $C_{20}H_{23}N_3OS$  moiety, thus forming an infinite, hydrogen-bonded coil around the screw triad. H atoms of the water molecule are also involved in hydrogen bonding with a hydroxyl O atom and a ring N atom of different chromophore molecules.

#### Introduction

The behavior of hycanthone and its analogous antischistosomal drugs in biological systems has been ascribed to intercalation of these drugs with DNA. It has been considered essential for the thioxanthene ring system to be planar so as to provide a strong

hydrophobic interaction with adjacent DNA base pairs. Furthermore, the terminal N of the side-chain diethylaminoethyl group has been thought to interact with phosphate residues on the periphery of the DNA helix, thus stabilizing the drug–DNA complex (for reviews, see Weinstein & Hirschberg, 1971; Hirschberg, 1975).

Following the X-ray structural study of lucanthone (Neidle, 1976), the structure of its active metabolite, hycanthone, in the form of its methanesulfonate salt has been reported (Wei & Einstein, 1978). Although hycanthone has been widely used for the treatment of schistosomiasis, Bueding (1975) reported that alterations of the thioxanthone fragment of hycanthone to benzothioopyranoindazole-type derivatives yielded marked reduction in mutagenic activity without decreasing antischistosomal potency. Among these derivatives, the chloroindazole analog of hycanthone, designated IA-4 (Bueding, Fisher & Bruce, 1973), has also been shown to be much less toxic than hycanthone (Bueding, Fisher & Bruce, 1973; Bueding, 1975). The crystal structure of the methanesulfonate salt of this drug has recently been reported (Wei, 1981).

The X-ray investigation of the dechloro form of IA-4 monohydrate, the title compound, was undertaken to provide additional information regarding the structural differences of this family of drugs – in particular, to enable detailed comparison of the structures of neutral and cationic species of IA-4.

#### Experimental

Dechloro IA-4 monohydrate was crystallized in the form of a yellow hexagonal prism from a 95% alcoholic solution. Preliminary film data showed that the crystals belong to the rhombohedral system. Systematic absences of  $-h + k + l \neq 3n$  for  $\{hkil\}$  and  $l \neq n$  for  $\{000l\}$  (in terms of the hexagonal unit cell) indicated probable space groups  $R\bar{3}$ ,  $R\bar{3}2$  and  $R\bar{3}$ ; the latter, centrosymmetric space group was later con-

\* Part I: Wei (1981).

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firmed by statistical analysis of the diffraction data\* and by the successful refinement of the structure. All crystallographically independent atoms were found to occupy the general 18-fold set of positions [18(*f*)] (*International Tables for X-ray Crystallography*, 1952).

Twelve strong reflections in the  $2\theta$  range of  $92\text{--}124^\circ$  were centered with an Oak Ridge computer-controlled diffractometer (Busing, Ellison, Levy, King & Roseberry, 1968) by use of Ni-filtered Cu  $K\alpha_1$  ( $\lambda = 1.54051 \text{ \AA}$ ) radiation, and the cell parameters were refined by the least-squares method. A brief summary of crystal data and intensity collection is given in Table 1.

A hexagonal-prism crystal, 0.10 mm on a hexagonal side and 0.46 mm in prism length, was glued on the tip of a thin glass fiber so that the prism axis, corresponding to the *c* axis, was nearly parallel to the  $\phi$  axis of the diffractometer. The maximum mosaic spread of the crystal was estimated to be  $0.8^\circ$ . The intensities were measured up to a  $2\theta$  value of  $125^\circ$  (equivalent to a minimum spacing of  $0.868 \text{ \AA}$ ) with Ni-filtered Cu  $K\alpha$  radiation at 40 kV and 14 mA. Reference reflections were monitored periodically to check crystal stability, and their intensities fluctuated within  $\pm 2\%$  during the course of data collection.† Absorption corrections were

\* Calculations using the program *NORMAL* [part of the program *MULTAN* (Germain, Main & Woolfson, 1971)] showed that the statistical averages were 0.943 and 0.808 for  $|E^2 - 1|$  and  $|E|$ , corresponding to those for a centrosymmetric crystal [theoretical values for centrosymmetric: 0.968, 0.798; for non-centrosymmetric: 0.736, 0.886, respectively (Karle, Dragonette & Brenner, 1965)].

† Data collection was carried out in such a way that *h* and *l* were positive and  $h > -k$  (*k* may have + or - sign). The *h*00 and 0*h*0 reflections are equivalent. The 0*kl* and *kk*l reflections are equivalent due to the threefold symmetry; *hk*0 and *k, h-k, 0* are equivalent due to the sixfold symmetry. For each pair of equivalent reflections, the intensities were averaged.

Table 1. *Crystal data and intensity collection*

$C_{20}H_{23}N_3O_5 \cdot H_2O$	$D_{calc} = 1.23 \text{ Mg m}^{-3}$
$M_r = 371.51$	$D_{obs} = 1.25 (2)$ (flotation in bromobenzene/xylene)
Space group $R\bar{3} (C_3^2, \text{No. } 148)$	$F(000) = 3564$ (on hexagonal unit cell)
Rhombohedral cell parameters:	$\mu(\text{Cu } K\alpha) = 1.542 \text{ mm}^{-1}$
$a = 21.337 (1) \text{ \AA}$ ,	Transmission = 0.733–0.817
$\alpha = 118.5581 (3)^\circ$	Crystal shape: hexagonal prism with side 0.10 mm, length 0.46 mm
Hexagonal cell parameters:*	$T = 297 \text{ K}$
$a = b = 36.685 (2) \text{ \AA}$ ,	
$c = 7.7432 (5) \text{ \AA}$	
$V = 9024.6 \text{ \AA}^3$ (for hexagonal unit cell)	
$Z = 18$ (in hexagonal unit cell)	
Radiation: Cu $K\alpha$	Total background time: 32–60 s‡
Take-off angle: $3^\circ$	Number of unique nonzero reflections: 3060
Scan type: $\theta\text{--}2\theta$ step scan	Number of reflections used in refinement: 2804§
$2\theta$ limit: $125^\circ$	Number of variables: 335
$2\theta$ step size: 0.05°	Data-to-variables ratio: 8.4
Time per step: 2–3 s	
Scan width: 1.8–2.0° †	

\* All computations were carried out with the hexagonal unit cell.

† The width of the  $\alpha_1\text{--}\alpha_2$  separation was added to these values.

‡ Backgrounds were measured at the beginning and end of each scan. The longer times were used for higher  $2\theta$  ranges.

§ Criteria used were  $F_o^2 \geq \sigma(F_o^2)$  and  $|DF^2| \leq 4\sigma(F_o^2)$ .

made by the method of Busing & Levy (1957). Weights used in the least-squares refinement of the structure were reciprocals of variances  $\sigma^2(F_o^2)$ , which were estimated according to the empirical expression routinely employed in our laboratory (Wei & Einstein, 1978).

### Solution and refinement of the structure

All least-squares refinements in this analysis were carried out on  $F^2$  with the program *ORXFLS4* (Busing, Martin & Levy, 1962). Scattering factors used were those of: Dawson (1960) for S; Berghuis, Haanappel, Potters, Loopstra, MacGillavry & Veenendaal (1955) for C, N and O; Stewart, Davidson & Simpson (1965) for H. The real and imaginary corrections,  $f' = 0.319$  and  $f'' = 0.557$ , for S (Cromer, 1974) were also utilized. In the final stage of the refinement, an isotropic-extinction parameter (Coppens & Hamilton, 1970) was also incorporated.

The structure was solved by the standard heavy-atom technique, starting with interpretation of a three-dimensional Patterson function, calculated by the use of a fast Fourier routine (Levy, 1977), to reveal the position of the S atom in the assumed space group  $R\bar{3}$ . After location and anisotropic refinement of 26 nonhydrogen atoms, all 25 H atoms were found at their expected positions in a difference-Fourier map, except that some ambiguities remained for those attached to terminal methyl C atoms of the side chain. Attempts to refine the structure with all H atoms included and assigned isotropic thermal parameters resulted in either stereochemically unreasonable positions or unusually large thermal parameters for some H atoms of the terminal ethyl groups, as in the case of the analogous IA-4 monomethanesulfonate (Wei, 1981). When 10 H atoms of the terminal ethyl groups were fixed at their observed positions and their isotropic thermal parameters were kept at 8 and  $10 \text{ \AA}^2$  for methylene and methyl H atoms, respectively, the refinement converged to yield an  $R(F)$  value of 0.047. Although molecular parameters calculated by the program *ORFFE4* (Busing, Martin & Levy, 1964) indicated the overall correctness of the structure, the fixed positions of the terminal H atoms were considered not fully valid.

Restraints were then applied to retain tetrahedral configurations for the ethyl H atoms by assigning C–H distances of  $1.0 \text{ \AA}$ , and C–C–H or N–C–H angles of  $109.5^\circ$ , with assigned estimated standard deviations (e.s.d.'s) ranging from 0.015 to  $0.03 \text{ \AA}$  and from  $0.5$  to  $1.5^\circ$  (with one exception of  $3.0^\circ$ ).\* In addition, the isotropic thermal parameters for the methyl H atoms

\* These interatomic distances and angles were used as least-squares observations, as suggested by Waser (1963). This useful crystallographic treatment for finding 'best' atomic parameters when Fourier peaks are not well defined is incorporated in the updated version of *ORXFLS4* (Busing, Martin & Levy, 1962).

attached to C(18) were constrained to be equal, as were those for H atoms attached to C(20). After several cycles the values of  $R(F)$  and  $R(F^2)$  stood at 0.042 and 0.063, respectively, for 2804 reflections with  $F_o^2 \geq \sigma(F_o^2)$  and  $|\Delta F^2| \leq 4\sigma(F_o^2)$ . The weighted  $R_w(F^2)$  [defined as  $(\sum w|\Delta F^2|^2/\sum wF_o^4)^{1/2}$ ] was 0.091. When all 3060 unique nonzero reflections were included, the  $R(F)$  value was 0.051. Parameter shifts for non-hydrogen atoms in the last cycle of the refinement were all less than 1% of the corresponding e.s.d.'s, whereas the maximum shift in the H-atom parameters was 3% of the corresponding e.s.d. for the isotropic thermal parameter of H(20a). A final difference-Fourier synthesis showed no residual peaks greater than  $0.3 \text{ e } \text{Å}^{-3}$  (other than those along inversion triads, which ranged from 0.3 to  $0.7 \text{ e } \text{Å}^{-3}$ ).

The final atomic positional parameters and isotropic thermal parameters (equivalent for nonhydrogen atoms, actual for H atoms) are given in Table 2 for nonhydrogen atoms and in Table 3 for H atoms.\*

\* Lists of structure factors, anisotropic thermal parameters and a stereoscopic pair showing the unit-cell packing down *c* have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 36366 (7 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 2. Positional ( $\times 10^5$  for *x* and *y*;  $\times 10^4$  for *z*) and equivalent isotropic thermal parameters ( $\text{Å}^2$ ) for nonhydrogen atoms

The e.s.d.'s of the least significant figures are given in parentheses in all tables and in the text. Equivalent isotropic thermal parameters were calculated from the corresponding anisotropic thermal parameters and unit-cell parameters by the relation  $B_{\text{eq}} = \frac{1}{3}(\beta_{11}a^2 + \beta_{22}b^2 + \beta_{33}c^2 + 2\beta_{12}ab \cos \gamma)$  (Hamilton, 1959).

	<i>x</i>	<i>y</i>	<i>z</i>	$B_{\text{eq}}$
S	11901 (2)	25682 (1)	2016 (1)	4.15 (3)
C(1)	22492 (6)	36131 (6)	598 (2)	3.39 (7)
C(2)	25800 (7)	35408 (7)	1022 (3)	4.38 (8)
C(3)	24675 (7)	31634 (7)	1799 (3)	4.56 (9)
C(4)	20484 (7)	28491 (6)	2166 (3)	4.12 (8)
C(5)	4986 (6)	26170 (7)	1459 (3)	4.56 (8)
C(6)	2606 (7)	27895 (9)	928 (3)	5.39 (8)
C(7)	4500 (7)	31925 (9)	277 (3)	5.38 (11)
C(8)	8800 (7)	34233 (7)	118 (3)	4.41 (8)
C(9)	15848 (5)	34815 (5)	419 (2)	3.26 (7)
C(10)	18354 (6)	33116 (5)	958 (2)	3.15 (6)
C(11)	17267 (6)	29263 (6)	1717 (2)	3.44 (6)
C(12)	9357 (6)	28461 (6)	1314 (2)	3.66 (7)
C(13)	11323 (6)	32544 (6)	619 (2)	3.45 (7)
C(14)	19554 (10)	24477 (8)	3027 (3)	5.16 (11)
C(15)	25748 (7)	43372 (6)	-750 (3)	4.18 (7)
C(16)	27279 (7)	46653 (6)	664 (3)	4.18 (7)
C(17)	33546 (8)	52998 (9)	1616 (3)	5.83 (10)
C(18)	31420 (11)	54384 (14)	2905 (5)	9.52 (16)
C(19)	29774 (9)	52983 (8)	-1059 (4)	6.53 (11)
C(20)	33412 (15)	56420 (13)	-2044 (6)	10.62 (21)
N(1)	22297 (5)	39376 (5)	-154 (2)	3.65 (6)
N(2)	30960 (5)	50583 (5)	116 (2)	3.83 (6)
N(3)	18237 (5)	38628 (5)	-249 (2)	3.51 (6)
O(H)	17815 (7)	21182 (5)	1823 (2)	6.06 (8)
O(W)	16594 (9)	45335 (8)	-1516 (3)	7.44 (11)

Table 3. Positional ( $\times 10^4$  for *x* and *y*;  $\times 10^3$  for *z*) and isotropic thermal parameters ( $\text{Å}^2$ ) for hydrogen atoms

Hydrogen atoms are numbered according to the C atoms to which they are attached, except for H(O) which is bonded to O(H), and H(a) and H(b) which are water hydrogen atoms.

	<i>x</i>	<i>y</i>	<i>z</i>	<i>B</i>
H(2)	2864 (8)	3747 (7)	79 (3)	4.9 (5)
H(3)	2704 (7)	3106 (7)	213 (3)	5.2 (5)
H(5)	373 (7)	2326 (8)	196 (3)	5.1 (5)
H(6)	-35 (9)	2620 (8)	97 (3)	6.4 (6)
H(7)	300 (8)	3307 (8)	-3 (3)	5.7 (6)
H(8)	1035 (8)	3715 (8)	-31 (3)	5.3 (5)
H(14a)	1760 (9)	2380 (9)	397 (4)	6.9 (7)
H(14b)	2209 (11)	2471 (10)	353 (4)	8.7 (8)
H(15a)	2808 (7)	4288 (7)	-119 (3)	4.9 (5)
H(15b)	2477 (8)	4425 (8)	-176 (3)	5.4 (5)
H(16a)	2504 (8)	4710 (7)	97 (3)	5.1 (5)
H(16b)	2816 (7)	4554 (7)	171 (3)	5.3 (5)
H(17a)	3617 (8)	5563 (7)	117 (2)	7.1 (7)
H(17b)	3451 (6)	5126 (7)	221 (2)	6.8 (7)
H(18a)	3047 (9)	5628 (10)	229 (3)	11.9 (7)
H(18b)	3351 (9)	5614 (11)	379 (4)	11.9 (7)*
H(18c)	2880 (10)	5165 (9)	345 (4)	11.9 (7)*
H(19a)	2815 (7)	5431 (6)	-33 (3)	11.4 (11)
H(19b)	2767 (6)	5095 (6)	-193 (2)	11.3 (11)
H(20a)	3226 (8)	5744 (19)	-302 (7)	30.0 (21)
H(20b)	3511 (16)	5526 (10)	-258 (9)	30.0 (21)†
H(20c)	3519 (17)	5888 (13)	-123 (4)	30.0 (21)†
H(O)	1736 (7)	1906 (8)	231 (3)	5.3 (6)
H(a)	1737 (12)	4373 (14)	-134 (5)	10.4 (12)
H(b)	1634 (11)	4539 (11)	-265 (5)	8.6 (9)

\* The *B* values of H(18b) and H(18c) were constrained to be equal to that of H(18a).

† The *B* values of H(20b) and H(20c) were constrained to be equal to that of H(20a).

## Discussion

The crystal structure is built up of neutral dechloro IA-4 bases and water molecules linked together by hydrogen bonds (see below). The closest intermolecular contact between nonhydrogen atoms is  $3.357 (3) \text{ Å}$  for C(17)···O(H); the closest such contact between nonhydrogen and H atoms is  $2.57 (2) \text{ Å}$  for O(W)···H(17b).

Bond lengths, bond angles and their corresponding e.s.d.'s for the dechloro IA-4 molecule are shown in Fig. 1, and the numbering scheme for H atoms and thermal ellipsoids enclosing 50% probability for nonhydrogen atoms are depicted in a stereoscopic view (Fig. 2). These and all subsequent figures were prepared with the program ORTEP II (Johnson, 1976). All bond lengths and angles for nonhydrogen atoms appear normal. Although they are not given, all 25 C—H and O—H distances are similar to those found in X-ray diffraction studies, ranging from  $0.78 (4) \text{ Å}$  [for O(W)—H(a)] to  $1.10 (3) \text{ Å}$  [for C(19)—H(19)], with an average value of  $0.98 \text{ Å}$ . The H—C—C angles for the six ring H atoms range from  $115 (1)^\circ$  [for H(8)—C(8)—C(15)] to  $124 (1)^\circ$  [for

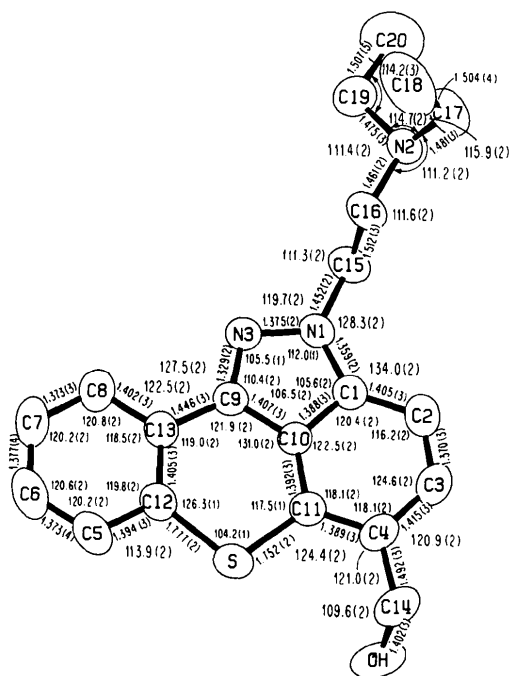


Fig. 1. Bond lengths (Å) and bond angles ( $^{\circ}$ ) with their e.s.d.'s for nonhydrogen atoms of the dechloro IA-4 base.

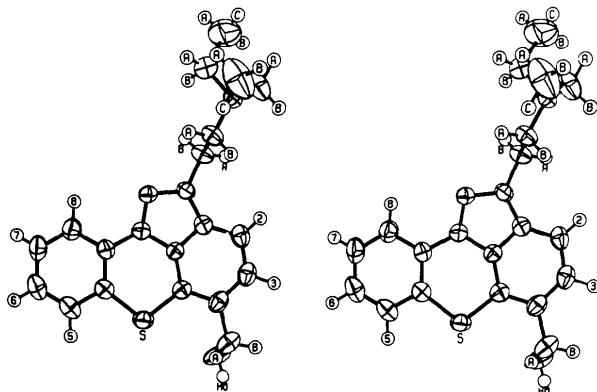


Fig. 2. Stereoscopic pair showing the numbering scheme for H atoms and thermal ellipsoids (enclosing 50% probability) for nonhydrogen atoms of the dechloro IA-4 molecule.

H(8)—C(8)—C(7)]. The H(O)—O(H)—C(14) and H(a)—O(W)—H(b) angles are 108 (2) and 106 (3) $^{\circ}$ , respectively, and the remaining 37 tetrahedral H—C—C, H—C—N and H—C—H angles are in the range of 107 (1) $^{\circ}$  [for H(19a)—C(19)—H(19b)] to 112 (3) $^{\circ}$  [for H(18b)—C(18)—H(18c)], the average value being 109 $^{\circ}$ . Some of these distances and angles were close to ideal because of restraints applied in the refinement, as discussed above. A particularly large thermal parameter [30 (2) Å<sup>2</sup>] was obtained for the H atoms attached to C(20). The terminal methyl groups

of this family of drugs have invariably exhibited large thermal motions, as observed in the structures of hycanthon (Wei & Einstein, 1978) and IA-4 (Wei, 1981) cations.

As in the case of the IA-4 cation, the substitution of the O atom at the 9 position of hycanthon by an N atom and the subsequent formation of a five-membered ring necessitate marked decreases in bond angles for N(1)—C(1)—C(10) and C(10)—C(11)—C(4), but an increase for C(1)—C(10)—C(11). These angles, 105.6 (2), 118.1 (2) and 122.5 (2) $^{\circ}$ , are in close agreement with the corresponding values of 105.7 (3), 117.4 (3) and 123.1 (3) $^{\circ}$ , respectively, found for the IA-4 cation (Wei, 1981).

Equations of some best least-squares molecular planes for the fused four-ring heterocyclic system are given in Table 4. All C atoms of the two outer six-membered rings are coplanar to within 0.009 (2) Å, as shown in Table 4(a) and (b), whereas C(9) and S are much further from these planes. The five-membered ring (Table 4c) is also nearly planar. The dihedral angles between various pairs of best planes for this structure are closely parallel to those reported for the IA-4 cation. The angles between planes (a) and (b), (a) and (c), and (c) and (d) are 177.37 (7), 178.70 (7) and 178.44 (6) $^{\circ}$ , compared with 177.0 (1), 178.6 (2) and 179.6 (1) $^{\circ}$ , respectively, for the IA-4 cation. These values again indicate that the whole fused four-ring system can be regarded as nearly planar.

Table 4. Equations of best molecular planes, and distances (Å) of atoms from these planes

Calculations were performed with program ORFFE4 (Busing, Martin & Levy, 1974). X, Y and Z represent direct-axis coordinates expressed in Å.

- (a)  $0.1534X - 0.4293Y - 0.9004Z = -4.8427$   
 (b)  $0.1379X - 0.3879Y - 0.9194Z = -4.5069$   
 (c)  $0.1310X - 0.4198Y - 0.9030Z = -4.8933$   
 (d)\*  $0.1379X - 0.4021Y - 0.9127Z = -4.6526$

	(a)	(b)	(c)
C(1)	0.001 (1)	C(5) -0.003 (2)	N(1) 0.008 (1)
C(2)	0.005 (1)	C(6) 0.009 (2)	N(3) -0.005 (1)
C(3)	-0.005 (2)	C(7) -0.005 (2)	C(9) -0.000 (1)
C(4)	-0.002 (1)	C(8) -0.003 (2)	C(10) 0.005 (1)
C(11)	0.008 (1)	C(13) 0.008 (1)	C(1) -0.008 (1)
C(10)	-0.008 (1)	C(12) -0.005 (1)	C(15) -0.025 (3)†
C(9)	-0.041 (3)†	C(9) 0.056 (3)†	
S	0.062 (3)†	S 0.019 (3)†	

\* Deviations of atoms are not shown for this plane, which was calculated for all 14 atoms of the thioxanthene ring system. The root-mean-square deviations of the fitted atoms is 0.0266 (5) Å [with the maximum deviation of -0.045 (2) Å for C(4)]. This value can be compared with 0.0057 (7), 0.0059 (9) and 0.0062 (8) Å for planes (a), (b) and (c), respectively.

† Atoms not included in the calculation of the least-squares plane.

Table 5. Torsion angles ( $^{\circ}$ ) involving side-chain atoms

The torsion angle of a chain of atoms  $A$ ,  $B$ ,  $C$  and  $D$  is defined as the angle that the projection of bond  $A-B$  makes relative to the bond  $C-D$  when viewed along the direction  $B-C$ . The sign is positive if a clockwise motion of atom  $A$  would move it toward atom  $D$ .

$A-B-C-D$	IA-4 cation	Dechloro IA-4 base
C(15)-N(1)-C(1)-C(2)	-4.0 (7)	-1.4 (3)
C(16)-C(15)-N(1)-C(1)	175.1 (3)	-90.1 (3)
N(2)-C(16)-C(15)-N(1)	77.3 (5)	175.6 (2)
C(17)-N(2)-C(16)-C(15)	77.8 (4)	-154.5 (2)
C(19)-N(2)-C(16)-C(15)	-157.6 (4)	76.1 (3)
C(18)-C(17)-N(2)-C(16)	58.6 (5)	-61.7 (3)
C(20)-C(19)-N(2)-C(16)	83.3 (6)	-164.4 (3)

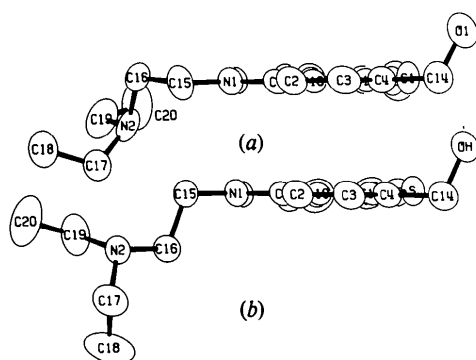


Fig. 3. Comparison of side views of (a) IA-4 cation and (b) dechloro IA-4 base, showing the marked difference in side-chain conformation.

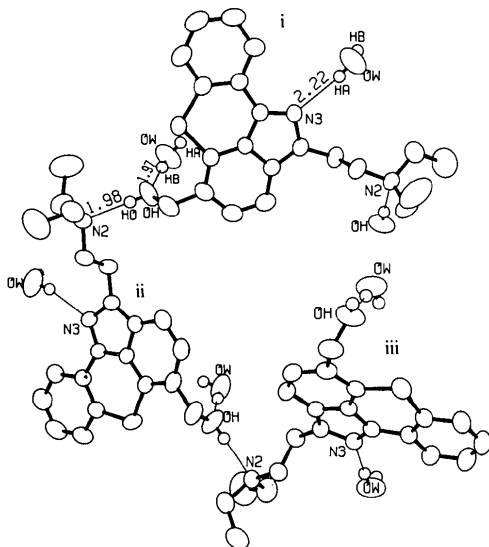


Fig. 4. Intermolecular hydrogen bonds between three molecules related by the counterclockwise screw triad at  $x = y = \frac{1}{3}$ , showing part of an infinite coiled chain. The viewing direction, approximately down  $c$ , passes through the point at  $(\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$ . Symmetry code for chromophore molecules: (i)  $x, y, z$ ; (ii)  $\frac{2}{3} - y, \frac{1}{3} + x - y, \frac{1}{3} + z$ ; (iii)  $\frac{1}{3} - x + y, \frac{2}{3} - x, \frac{2}{3} + z$ .

It was pointed out previously that the diethylaminoethyl side chain is conformationally labile, as evidenced by different configurational arrangements with respect to the chromophore frameworks for luanthone, the hycanthone cation, and the IA-4 cation (Wei, 1981). The framework of the present dechloro IA-4 base is almost identical with that of the IA-4 cation, except that the Cl atom in IA-4 is replaced by an H atom. Nevertheless, the conformations of the side chains are markedly different, as can be seen by comparison of the torsion angles (Table 5). This difference can be seen in side views of the two compounds, as shown in Fig. 3.

The present molecule differs from hycanthone or IA-4 cations in that the terminal N(2) is not protonated. Nevertheless, the tetrahedral geometries of N(2) in all three compounds are similar. The lone pair of electrons occupying the unused  $sp^3$  hybrid orbital in the present molecule causes N(2) to be displaced from the plane formed by C(16), C(17) and C(19) by 0.413 (2) Å - a

Table 6. Hydrogen bonds ( $A-H \cdots B$ )

Symmetry code: (i)  $x, y, z$ ; (ii)  $\frac{2}{3} - y, \frac{1}{3} + x - y, \frac{1}{3} + z$ ; (iii)  $\frac{1}{3} - x, \frac{2}{3} - y, -\frac{1}{3} - z$ .

$A$	$H$	$B$	$A \cdots B$	$A-H$	$H \cdots B$	$\angle A-H \cdots B$
O(H) <sup>i</sup>	H(O) <sup>j</sup>	N(2) <sup>ii</sup>	2.786 (2) Å	0.81 (3) Å	1.98 (3) Å	178 (2) $^{\circ}$
O(H) <sup>j</sup>	H(a) <sup>i</sup>	N(3) <sup>j</sup>	2.977 (3)	0.78 (4)	2.22 (4)	164 (3)
O(H) <sup>iii</sup>	H(b) <sup>iii</sup>	O(H) <sup>i</sup>	2.851 (3)	0.88 (4)	1.97 (4)	177 (3)

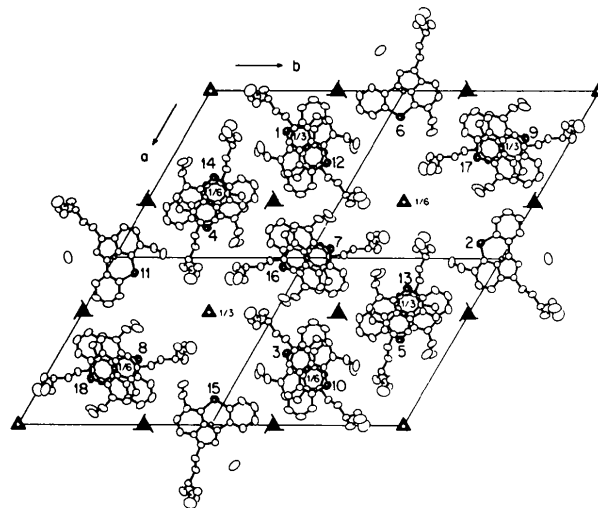


Fig. 5. [001] projection of the centrosymmetric hexagonal unit cell containing 18 symmetry-related molecules. For the sake of clarity, H atoms are not shown. Only S atoms are numbered (1 through 18) according to the following symmetry operations: (1)  $x, y, z$ ; (2)  $\frac{1}{3} + x, \frac{2}{3} + y, \frac{2}{3} + z$ ; (3)  $\frac{2}{3} + x, \frac{1}{3} + y, \frac{1}{3} + z$ ; (4)  $\frac{2}{3} - y, \frac{1}{3} + x - y, \frac{1}{3} + z$ ; (5)  $1 - y, 1 + x - y, z$ ; (6)  $\frac{1}{3} - y, \frac{2}{3} + x - y, \frac{2}{3} + z$ ; (7)  $\frac{1}{3} - x + y, \frac{1}{3} - x, \frac{2}{3} + z$ ; (8)  $\frac{2}{3} - x + y, \frac{1}{3} - x, \frac{1}{3} + z$ ; (9)  $-x + y, 1 - x, z$ ; (10)  $1 - x, 1 - y, 1 - z$ ; (11)  $\frac{2}{3} - x, \frac{1}{3} - y, \frac{1}{3} - z$ ; (12)  $\frac{1}{3} - x, \frac{2}{3} - y, \frac{2}{3} - z$ ; (13)  $\frac{1}{3} + y, \frac{2}{3} - x + y, \frac{2}{3} - z$ ; (14)  $y, -x + y, -z$ ; (15)  $\frac{2}{3} + y, \frac{1}{3} - x + y, \frac{1}{3} - z$ ; (16)  $\frac{2}{3} + x - y, \frac{1}{3} + x, \frac{1}{3} - z$ ; (17)  $\frac{1}{3} + x - y, \frac{2}{3} + x, \frac{2}{3} - z$ ; (18)  $1 + x - y, x, 1 - z$ .

value not much different from the 0.422 (2) Å for hycanthone and the 0.432 (4) Å for IA-4.

As shown in Fig. 4, the hydroxyl H(O) atom of ring system (i) is hydrogen bonded to the N(2) atom of the screw-triad-related ring system (ii). Likewise, the H(O) atom of ring system (ii) is hydrogen bonded to the N(2) atom of ring system (iii), and so on, thus resulting in an infinite intermolecular chain around each screw triad in the *c* direction. Furthermore, each hydroxyl O atom and N(3) atom acts as a hydrogen-bond acceptor of H atoms [H(*b*) and H(*a*), respectively] of different water molecules. The parameters of the three hydrogen bonds are given in Table 6.

Shown in Fig. 5 is the [001] projection of the hexagonal unit cell. Since there are left-handed and right-handed screw triads present in this structure, it follows that there are infinite hydrogen-bonded chains which are opposite in coiling direction; these are partially overlapped in this projection. In the figure, molecule 7, together with molecules 1 and 4, is a member of the left-handed chain around the screw triad at  $x = y = \frac{1}{3}$ , whereas molecule 16 forms a right-handed chain with molecules 13 and 10 around  $x = y = \frac{2}{3}$ . There are stacking interactions, at a distance of roughly 3.6 Å, between the planar ring systems of pairs of molecules, related by centers of symmetry and participating in oppositely coiled hydrogen-bonded chains [e.g. molecules 4 and 14, Fig. 5, related by the center of symmetry at  $(\frac{1}{3}, \frac{1}{6}, \frac{1}{8})$ ].

A stereoscopic pair showing the unit-cell packing down *c* has been deposited.

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