

A Monoclinic Phase of the Deoxycholic Acid Rubidium Salt

BY V. M. COIRO

*Laboratorio di Strutturistica Chimica 'Giordano Giacomello' del CNR, Area della Ricerca, CP 10,
00016 Monterotondo Stazione, Roma, Italy*

AND E. GIGLIO, S. MOROSETTI AND A. PALLESCHI

Istituto di Chimica Fisica, Università di Roma, 00185 Roma, Italy

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Abstract. $C_{24}H_{39}O_4Rb \cdot H_2O$, monoclinic, $P2_1$, $a = 13.118$ (6), $b = 7.817$ (3), $c = 11.788$ (5) Å, $\beta = 97.74$ (3)°, $Z = 2$, $D_m = 1.36$ (2), $D_c = 1.37$ Mg m⁻³, Mo $K\alpha$ radiation, $\mu(\text{Mo } K\alpha) = 221.6$ mm⁻¹. $R = 0.051$ and $R_w = 0.069$ for 1867 observed data with $I > 3\sigma(I)$. The side-chain and D -ring conformations of the anion are similar to those of the orthorhombic and tetragonal phases of deoxycholic acid. The anions are held together mainly by ion-ion and ion-dipole interactions between Rb^+ and the carboxylate and hydroxyl groups as well as by a hydrogen-bonding scheme to which the water molecules contribute. The crystal packing is characterized by an assembly of bilayers, different from those found in the orthorhombic and tetragonal phases, without empty spaces between them. Zigzag chains of Rb^+ ions running parallel to b are inside the bilayers.

Introduction. The alkali-metal salts of $3\alpha,12\alpha$ -dihydroxy- 5β -cholan-24-oic acid (deoxycholic acid, DCA), which is amphiphilic, containing at the same time a hydrophilic and a hydrophobic part, associate in aqueous solutions to give micellar aggregates (Small, 1971, and references therein). The title compound (hereafter DCARb) has been studied together with analogous DCA derivatives in order to analyse packing models useful in the structure determinations both of the helical macromolecules (Rich & Blow, 1958; Blow & Rich, 1960) and of the micelles, since these systems present in many cases similarities in their X-ray diffraction patterns.

The crystals were grown at room temperature by diffusing acetonitrile into a saturated solution of DCARb in dimethyl sulphoxide. A colourless prismatic specimen with a maximum dimension of 0.8 mm was chosen for the determination of the cell constants, by least squares from 14 reflections, and to collect intensities up to $2\theta = 56^\circ$ on a Syntex $P2_1$ automated diffractometer with graphite-monochromatized Mo $K\alpha$ radiation ($\lambda = 0.71069$ Å). The data were measured by the $\theta/2\theta$ scan mode at a scan rate within the range 1.5 – 29.3° min⁻¹, depending on the peak intensity, with

a scan width of 2.4° . Three reflections, selected for orientation control and monitored after every 100 reflections, showed only the deviations from the mean predicted by counting statistics. Backgrounds were estimated by stationary counting for half the scan time. Lorentz and polarization corrections were applied taking into account the monochromator crystal (Azaroff, 1955). No correction was made for absorption.

Table 1. Fractional coordinates ($\times 10^4$) with e.s.d.'s in parentheses

	<i>x</i>	<i>y</i>	<i>z</i>
Rb	532 (1)	−2 (3)	351 (1)
C(1)	3508 (7)	3643 (13)	3 (7)
C(2)	2420 (7)	4380 (12)	−443 (7)
C(3)	2486 (6)	6320 (12)	−472 (7)
C(4)	2909 (7)	7062 (12)	658 (8)
C(5)	3934 (6)	6333 (12)	1178 (8)
C(6)	4331 (7)	7060 (12)	2353 (8)
C(7)	3691 (6)	6415 (11)	3280 (7)
C(8)	3659 (6)	4489*	3327 (7)
C(9)	3246 (6)	3733 (11)	2143 (7)
C(10)	3935 (6)	4302 (11)	1215 (6)
C(11)	3105 (7)	1804 (11)	2200 (7)
C(12)	2407 (6)	1205 (11)	3078 (7)
C(13)	2837 (6)	1916 (11)	4283 (7)
C(14)	2940 (6)	3869 (11)	4183 (7)
C(15)	3214 (7)	4440 (13)	5438 (7)
C(16)	2588 (7)	3196 (14)	6105 (7)
C(17)	2133 (6)	1770 (12)	5240 (7)
C(18)	3887 (7)	1026 (13)	4686 (8)
C(19)	5051 (6)	3596 (15)	1492 (8)
C(20)	2034 (6)	43 (18)	5830 (6)
C(21)	1537 (8)	−1327 (14)	5011 (9)
C(22)	1438 (6)	151 (20)	6876 (7)
C(23)	294 (7)	647 (14)	6617 (7)
C(24)	−152 (6)	878 (13)	7731 (8)
O(25)	1474 (5)	7034 (9)	−803 (6)
O(26)	1369 (4)	1664 (9)	2707 (5)
O(27)	−669 (5)	−294 (11)	8079 (5)
O(28)	92 (6)	2243 (9)	8298 (6)
O _w	−563 (5)	315 (11)	2717 (6)

* This coordinate was kept fixed during the refinement.

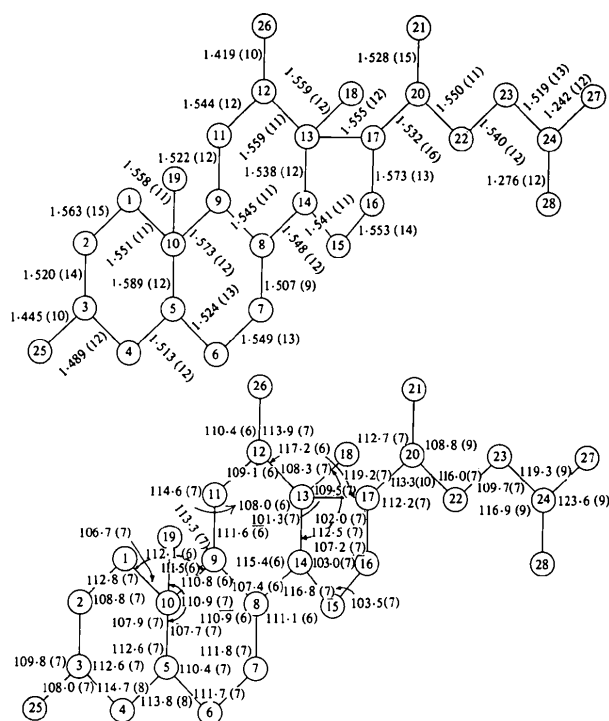


Fig. 1. Bond distances (Å) and angles (°) of the DCA anion.

The structure was solved from the Patterson function. Subsequent Fourier syntheses showed all the C and O atoms. The refinement was carried out by isotropic and anisotropic block-diagonal least squares with programs of Domenicano, Spagna & Vaciago (1969). Scattering factors were taken from *International Tables for X-ray Crystallography* (1974). The function minimized was $\sum w(|F_o| - |F_c|)^2$, with $w = (a + |F_o| + b|F_c|)^{-1}$.

The H atoms were generated at the expected positions, except for those linked to the O atoms. Their B^2 s (4 \AA^2) and positional parameters were kept fixed. R and R_w were 0.051 and 0.069 respectively. The final atomic coordinates are reported in Table 1,* bond lengths and angles in Fig. 1.

Discussion. The geometry and the conformation of the DCA anion are similar to those observed in the orthorhombic and tetragonal phases (Coiro, D'Andrea & Giglio, 1980, and references therein) of choleic acids so far studied. The side-chain and D -ring torsion angles, together with Δ and φ_m , the phase angle of pseudorotation and the maximum angle of torsion respectively (Altona, Geise & Romers, 1968), are listed

* Lists of structure factors and anisotropic thermal parameters have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 35111 (16 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 2. Torsion angles (°) for the side chain and ring D of the DCA anion together with Δ and φ_m

The e.s.d.'s are in parentheses.

C(13)—C(17)—C(20)—C(22)	171.6 (6)	C(13)—C(14)	48.4 (7)
C(17)—C(20)—C(22)—C(23)	65.2 (12)	C(14)—C(15)	-35.5 (8)
C(20)—C(22)—C(23)—C(24)	-174.2 (11)	C(15)—C(16)	9.5 (9)
C(13)—C(17)—C(20)—C(21)	-64.2 (9)	C(16)—C(17)	19.6 (9)
C(16)—C(17)—C(20)—C(21)	176.8 (8)	C(13)—C(17)	-41.1 (7)
C(21)—C(20)—C(22)—C(23)	-61.0 (14)	Δ	12.0
C(22)—C(23)—C(24)—O(27)	-100.1 (11)	φ_m	48.7
C(22)—C(23)—C(24)—O(28)	75.2 (12)		

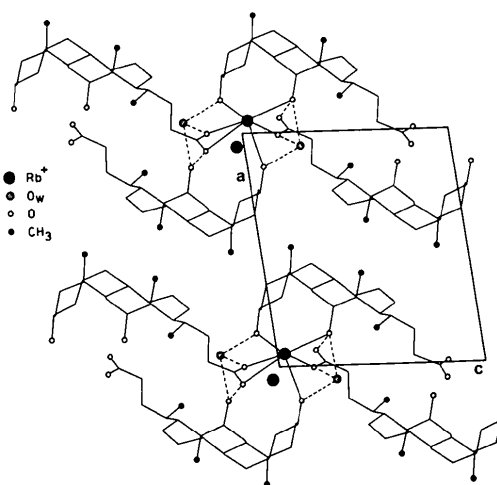


Fig. 2. A partial view of the crystal packing of DCARb along b . Broken lines represent hydrogen bonding. Full lines indicate the rubidium coordination.

in Table 2 according to the convention of Klyne & Prelog (1960). From these values it can be inferred that the D ring assumes an intermediate conformation between half-chair and β -envelope, closer to the half-chair. This situation is invariably found when, as in this case, the side-chain conformation is *gauche* (Giglio & Quagliata, 1975; Coiro, D'Andrea & Giglio, 1980), whereas for a *trans* conformation, as in the hexagonal phases of DCA (Candeloro De Sanctis, Coiro, Giglio, Pagliuca, Pavel & Quagliata, 1978; Candeloro De Sanctis, Giglio, Petri & Quagliata, 1979), the β -envelope symmetry is approached.

The molecular packing is shown in Fig. 2, where for clarity only the coordination of one Rb^+ per unit cell and part of the hydrogen-bonding scheme are shown. The packing is characterized by an assembly of wavy bilayers, growing approximately into the bc plane. The bilayers are packed without giving rise to empty canals as in the orthorhombic phases. Their cohesion energy is mainly due to van der Waals interactions, since their outer surfaces are hydrophobic. The structure of a bilayer (Fig. 3) is stabilized by an efficient scheme of hydrogen bonds, in which the water molecules are

Table 3. Rb...O and O...O distances (Å), with *e.s.d.*'s in parentheses, concerning the metal-ion coordination and the hydrogen bonds in a bilayer

Rb...O(28 ^I)	2.86 (1)	O(25)...O _w ^V	2.76 (1)
Rb...O(27 ^{II})	2.93 (1)	O(26)...O(27 ^{VI})	2.67 (1)
Rb...O(28 ^{III})	2.98 (1)	O(26)...O _w ^{VI}	2.75 (1)
Rb...O(25 ^{III})	3.03 (1)	O(28)...O _w ^{VI}	2.79 (1)
Rb...O(26)	3.13 (1)		
Rb...O(25 ^{IV})	3.18 (1)		

Symmetry code: (I) $-x, -\frac{1}{2} + y, 1 - z$; (II) $x, y, -1 + z$; (III) $x, -1 + y, z$; (IV) $-x, -\frac{1}{2} + y, z$; (V) $x, \frac{1}{2} + y, -z$; (VI) $-x, \frac{1}{2} + y, 1 - z$.

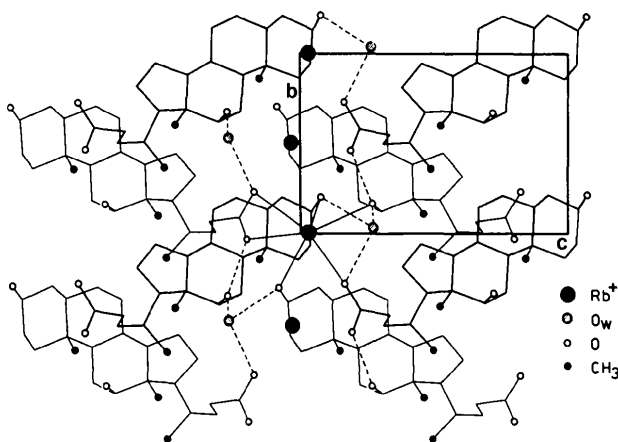


Fig. 3. A partial view of a bilayer along a^* . The symbols have the same meaning as in Fig. 2.

engaged, and by the ion-ion and ion-dipole interactions existing between the Rb⁺ ions, carboxylate ions and hydroxyl groups (Table 3). The two monolayers forming a bilayer are shifted relative to each other by about 3.9 Å along b , a little more than in the orthorhombic phases (~ 3.6 Å). A monolayer is composed of rows of DCA anions linked in each row in a head-to-tail fashion through the water molecule, which forms hydrogen bonds with the O(25)H group of one anion and O(28) of an anion at $1 + z$.

The DCA anions are ordered in an antiparallel array in the two monolayers, at variance with the parallel arrangements in the orthorhombic and tetragonal phases.

The Rb⁺ ions are accommodated in canals, running along b inside the bilayers, with their interior surfaces covered mainly by hydrophilic groups. Zigzag chains of the cations occur, running parallel to b , with Rb⁺...Rb⁺ distances of 4.195 (3) Å and Rb⁺...Rb⁺ angles of 137.40 (3)°. Each Rb⁺ is surrounded by six O atoms, of which three belong to two carboxylate ions and the others to hydroxyl groups (Table 3), giving rise to a non-regular sixfold coordination. The O_w atom, located 3.31 (1) Å from the Rb⁺ ion, is not bonded to Rb⁺ because its lone pairs are not directed towards the cation.

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