

Acta Cryst. (1975), B31, 273**Medium-Ring Compounds. XXI. Enantholactam Hydrochloride**

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Abstract. Monoclinic, $P2_1/c$, $a=9.85$ (1), $b=6.98$ (1), $c=12.44$ (1) Å, $\beta=95.96$ (10)°, $C_7H_{13}ON.HCl$, $M=163.64$, $Z=4$, $D_m=1.28$, $D_x=1.277$ g cm⁻³. Protonation of the lactam takes place at the oxygen atom. The protonated amide group is *cis* and virtually planar, and the ring conformation is similar to that observed in other eight-membered rings containing a rigid synplanar link. The crystal is built from hydrogen-bonded (N-H...Cl...H-O) chains in the [010] direction, which are pairwise associated by electrostatic interactions.

Introduction. The crystals, prepared in the same way as those of caprolactam hydrochloride (Winkler & Dunitz, 1975), are much less hygroscopic but they were also sealed in capillaries since they disintegrate slowly in air.

Intensities from a crystal of dimensions 0.50 × 0.32 × 0.25 mm were collected on an automated Hilger-Watts Y290 diffractometer with Mo $K\alpha$ radiation ($\lambda=0.71069$ Å, $\mu=3.90$ cm⁻¹) and Sr/Zr balanced filters. All reflexions with scattering angle $\theta < 23^\circ$ were measured, but only those above background in the range $23^\circ < \theta < 30^\circ$. 1477 independent $|F_o|$ values were obtained. The structure was solved by the heavy-atom method and refined by full-matrix least-squares calculations (two cycles isotropic, five cycles anisotropic). All hydrogen atoms were located in a difference synthesis (only reflexions with $\sin \theta/\lambda \leq 0.4$ Å⁻¹) and their parameters (including isotropic B 's) refined by four additional least-squares cycles with Huber-Buser's (1971) criteria. The final R was 0.044.

Final positional and vibrational parameters are given in Tables 1 and 2, bond distances, bond angles and

torsion angles in Table 3. Scattering factors were taken from *International Tables for X-ray Crystallography* (1962).*

Table 2. *Enantholactam hydrochloride: atomic coordinates* ($\times 10^3$, *e. s. d.'s* in parentheses) and isotropic B values for hydrogen atoms

E. s. d.'s for the B values are in the range 0.6 to 1.3 Å².

	x/a	y/b	z/c	$B(\text{Å}^2)$
H(1) C(2)	360 (3)	558 (4)	424 (2)	0.5
H(2) C(2)	384 (3)	398 (4)	340 (2)	1.7
H(1) C(3)	172 (3)	350 (4)	409 (2)	2.0
H(2) C(3)	155 (3)	352 (4)	279 (2)	1.2
H(1) C(4)	-18 (3)	533 (5)	357 (3)	3.5
H(2) C(4)	63 (3)	680 (5)	280 (2)	2.7
H(1) C(5)	159 (4)	671 (5)	506 (3)	4.2
H(2) C(5)	11 (4)	770 (5)	469 (3)	4.1
H(1) C(6)	170 (3)	1012 (5)	481 (2)	3.1
H(2) C(6)	111 (3)	987 (5)	360 (3)	2.6
H(1) C(7)	376 (3)	838 (4)	447 (2)	2.1
H(2) C(7)	356 (3)	1052 (4)	388 (2)	2.5
H(N)	334 (4)	907 (5)	229 (3)	3.7
H(O)	349 (4)	464 (7)	153 (3)	5.2

Discussion. The conformation of the eight-membered ring (Fig. 1) with its *cis*-amide link is similar to that observed earlier in *cis*-9,9-dimethyl-9-azoniabicyclo-[6,1,0]nonane iodide (Trefonas & Majeste, 1963) and in a highly substituted 5-oxa-*cis*-cyclooctene ring of the

* A list of structure factors is given by Winkler (1973) and has been deposited with the British Library Lending Division as Supplementary Publication No. SUP 30619 (3 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 13 White Friars, Chester CH1 1NZ, England.

Table 1. *Enantholactam hydrochloride: atomic coordinates* (*e. s. d.'s* in parentheses) and vibrational tensor components for non-hydrogen atoms (all $\times 10^4$)

The U_{ij} values (in Å²) correspond to the temperature-factor expression $T = \exp[-2\pi^2(U_{11}h^2a^{*2} + \dots + 2U_{12}hka^*b^* \dots)]$ and have *e. s. d.'s* in the range 0.0010–0.0030 Å² (except for Cl, where they are much smaller).

	x/a	y/b	z/c	U_{11}	U_{22}	U_{33}	U_{12}	U_{13}	U_{23}
Cl	3367 (1)	1874 (1)	1247 (0)	679	441	492	19	40	-18
O	3546 (2)	5986 (2)	1679 (1)	895	469	437	-20	161	-5
N	3294 (2)	8307 (3)	2854 (2)	586	410	487	-6	73	30
C(1)	3398 (2)	6491 (3)	2672 (2)	485	431	456	-8	58	8
C(2)	3259 (2)	5027 (3)	3506 (2)	523	427	479	21	48	32
C(3)	1773 (3)	4360 (4)	3478 (2)	609	454	596	-68	70	20
C(4)	732 (3)	5969 (4)	3507 (2)	508	570	778	-41	74	22
C(5)	1018 (3)	7375 (4)	4452 (2)	652	603	759	64	237	5
C(6)	1688 (3)	9258 (4)	4187 (2)	670	499	625	100	98	-35
C(7)	3147 (3)	9176 (3)	3912 (2)	639	438	547	-20	66	-56

natural product laurencin (Cameron, Cheung, Ferguson & Robertson, 1965). Although the conformation of *cis*-cyclooctene has not been determined experimentally, the results of several studies (Favini, Buemi & Raimondi, 1968; Allinger & Sprague, 1972; Ermer & Lifson, 1973) based on energy-minimization calculations with various force fields also lead to the same general conformational type, with a local mirror plane through the double bond and a local twofold axis through the opposite bond. This type of conformation as a whole has no non-trivial symmetry and has been described (Allinger & Sprague, 1972) as a 'nondescript flexible form'. It is all the more remarkable that the bond angles and torsion angles calculated for *cis*-cyclooctene by Ermer & Lifson (1973) with their consistent force field agree so closely with those actually found in the protonated enantholactam cation (Table 3): the r. m. s. deviations between observed and calculated parameters are only 0.8 and 2.5° for the eight bond angles and torsion angles, respectively. Replacement of the C=C double bond by the protonated amide group has apparently almost no effect on the ring conformation.

Analysis of the experimental thermal-motion tensors in terms of rigid-body translational and librational motion (Schomaker & Trueblood, 1968) leads to better agreement between observed and calculated tensor components [$\langle (\Delta U_{ij})^2 \rangle^{1/2} = 0.00167 \text{ \AA}^2$, $\langle \sigma^2(U_{ij}) \rangle^{1/2} = 0.00192 \text{ \AA}^2$] than expected. The rigid-body model thus accounts more than adequately for the averaged molecular motion, which is again out of line with the presumed flexibility of the ring system. The agreement for C(3), C(4), C(5) and C(6), those in the presumably flexible part of the ring, is even significantly better than for the five heavy atoms that make up the presumably rigid amide group [$\langle (\Delta U_{ij})^2 \rangle^{1/2} = 0.00134 \text{ \AA}^2$ compared with 0.00191 \AA^2]. The libration corrections amount to between 0.005 and 0.009 Å for bond lengths and are negligible for bond angles and torsion angles.

The dimensions of the protonated *cis*-amide group, as determined from this analysis, are somewhat more accurate than those from the caprolactam hydrochloride analysis (Winkler & Dunitz, 1975). The bond angles (apart from the poorly determined ones involving the H atoms) agree well, but there are appreciable apparent differences between corresponding bond lengths. The C-N and C-O distances found here are closer to those of the standard *cis*-amide unit (Ramachandran & Sasisekharan, 1968) than are those in caprolactam HCl.

The out-of-plane deformations (Winkler & Dunitz, 1971) of the protonated amide group are small [$\chi_N = -1.6 (3.0)^\circ$, $\chi_C = 4.5 (0.5)^\circ$, $\tau = 2.6 (1.5)^\circ$] and significant only for χ_C . This deformation is usually smaller than the other two, and its anomalously large relative value here is presumably a secondary effect of the molecular packing.

The crystal structure is built from chains of alternating enantholactam cations and chloride anions

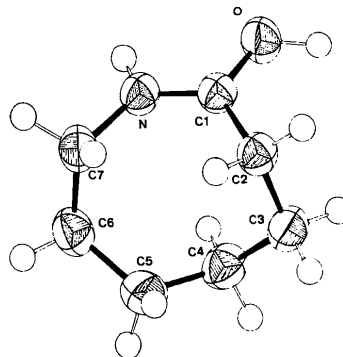


Fig. 1. The protonated enantholactam molecule (with atom numbering shown) viewed along a direction perpendicular to the mean plane of the eight-membered ring. The vibration ellipsoids are drawn at the 50% probability level (Johnson, 1965).

Table 3. *Enantholactam hydrochloride: molecular parameters*

Typical e.s.d.'s are 0.003–0.004 Å for bond lengths, 0.2° for bond angles and 0.4° for torsion angles not involving H atoms. Bond angles and torsion angles calculated for *cis*-cyclooctene (Ermer & Lifson, 1973) are in parentheses.

		Corrected for libration				
C(1)–O	1.307 Å	1.314 Å	O—C(1)–N	116.6°	C(7)–N—C(1)–C(2)	5.6 (2.3)°
N—C(1)	1.293	1.298	O—C(1)–C(2)	120.4	N—C(1)–C(2)–C(3)	91.2 (90.8)
C(1)–C(2)	1.473	1.480	N—C(2)–C(2)	122.8 (124.3)°	C(1)–C(2)–C(3)–C(4)	–51.3 (–48.6)
C(2)–C(3)	1.533	1.542	C(1)–C(2)–C(3)	110.7 (110.9)	C(2)–C(3)–C(4)–C(5)	–53.9 (–55.5)
C(3)–C(4)	1.524	1.530	C(2)–C(3)–C(4)	114.8 (114.7)	C(3)–C(4)–C(5)–C(6)	99.9 (103.0)
C(4)–C(5)	1.535	1.542	C(3)–C(4)–C(5)	114.8 (115.6)	C(4)–C(5)–C(6)–C(7)	–68.4 (–71.4)
C(5)–C(6)	1.522	1.529	C(4)–C(5)–C(6)	115.8 (115.8)	C(5)–C(6)–C(7)–N	71.2 (73.0)
C(6)–C(7)	1.513	1.522	C(5)–C(6)–C(7)	117.4 (116.0)	C(6)–C(7)–N—C(1)	–85.3 (–83.0)
C(7)–N	1.470	1.477	C(6)–C(7)–N	113.7 (113.0)	C(7)–N—C(1)–O	–178.8
			C(7)–N—C(1)	125.3 (125.3)		
C–H	0.94–1.05 (3)		H—C–H	106–109 (3)	H(N)–N–C(1)–O	0
N–H	0.89		H(N)–N–C(7)	119	H(N)–N–C(1)–C(2)	–176
O–H	0.96		H(N)–N–C(1)	116		
			H(O)–O–C(1)	116		

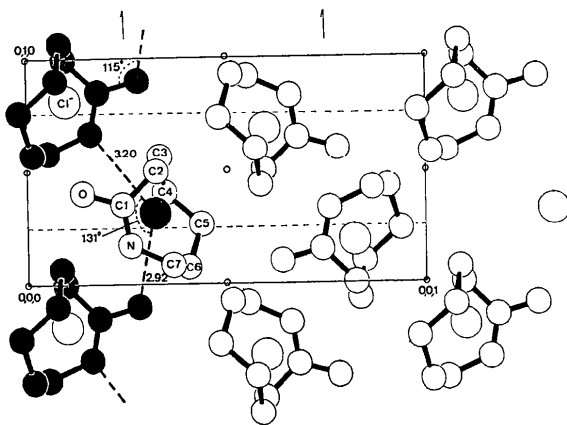


Fig. 2. Enantholactam hydrochloride structure projected perpendicular to (100). The atoms marked by black circles form part of a hydrogen-bonded chain along [010].

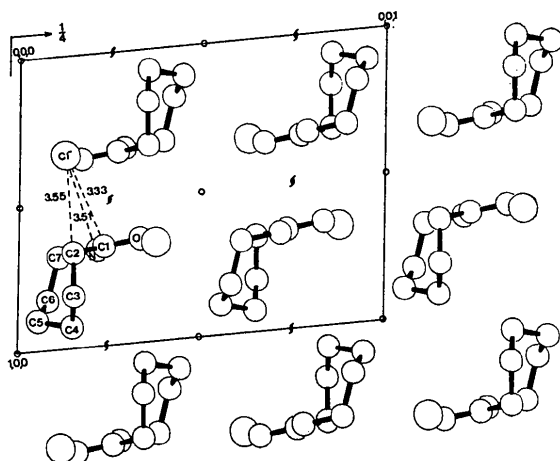


Fig. 3. The enantholactam hydrochloride structure projected down [010].

linked by hydrogen bonds ($N-H \cdots Cl$, 3.20; $Cl \cdots H-O$, 2.92 Å). These chains run in the [010] direction, as shown in Fig. 2, with the atoms of the protonated amide groups and the chloride ions lying in layers at $x = \frac{1}{3}$ (and $x = \frac{2}{3}$), as shown in Fig. 3. Each chloride ion is thus linked by hydrogen bonds to amide groups in its own layer, and is also directly above or below an amide group of the other layer. The shortest distance between atoms in different layers is 3.34 Å, between the amide carbon C(1) and Cl. This distance is some-

what less than the sum of the corresponding van der Waals radii, and it is noteworthy that the small but significant out-of-plane deformation at C(1) is such that this atom is displaced from the plane of its three neighbours [N, O, C(2)] towards the Cl⁻ ion. The displacement is small [0.031 (3) Å] but highly significant and its direction is a clear indication that the interaction in question is attractive. Analogous interactions between nucleophilic centres and carbonyl groups in crystals have been interpreted in terms of incipient addition reactions (Bürgi, Dunitz & Shefter, 1973, 1974). The amide groups interact with chloride ions only on one side of the layer; the other side is shielded by the hydrocarbon part of the ring. The methylene groups on the far sides of rings belonging to different layers pack together (Fig. 3), and this packing must be tight enough to inhibit the thermal motion that might otherwise be expected to occur in such a flexible molecule.

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