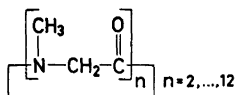


# Crystal Conformation of Cyclotrisar-cosyl at $-160^{\circ}\text{C}$

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To account for the relatively high observed resistance to ring inversion in cyclic oligopeptides of sarcosine with the general formula



transannular interactions between N and C (carbonyl) were suggested.<sup>1-4</sup> X-Ray crystallographic results for the cases  $n=4, 5, 7,$  and  $8^{5-8}$  do not support this assumption, and the explanation should be sought in the intrinsic conformation of the peptide chain itself.<sup>9</sup> The NMR-spectrum for cyclotrisarcosyl,<sup>1</sup> consisting of one singlet for *N*-methyl and one quartet for  $\text{CH}_2$  (intensity 9:6), shows that all amide groups have the same configuration. Since they cannot all be *trans* in a nine-membered ring, they must all be *cis*. In order to confirm this clear conformational evidence an X-ray crystallographic investigation of cyclotrisarcosyl has been performed.

The crystals of  $\text{C}_9\text{H}_{15}\text{N}_3\text{O}_3$  belong to the monoclinic system, with cell dimensions  $a=12.902(6) \text{ \AA}, b=12.342(6) \text{ \AA}, c=13.213(6) \text{ \AA},$

**Table 1 A.** Final fractional coordinates and thermal parameters with estimated standard deviations for molecule A. The expression for anisotropic vibration is  $\exp[2\pi^2(h^2a^{*2}U_{11} + \dots + 2klb^*c^*U_{23})]$ . Hmn is bonded to Cm and HMmn to CMm.

ATOM	X	Y	Z	U11	U22	U33	U12	U13	U23
O1	1.06361(19)	.79235(20)	.06711(18)	.0300(15)	.0274(15)	.0336(14)	-.0041(13)	.0081(12)	-.0005(12)
O2	.74135(25)	.54818(24)	.15767(24)	.0483(23)	.0154(19)	.0383(24)	-.0079(18)	-.0001(19)	-.0043(17)
O3	.60231(19)	.93343(19)	.1529(18)	.0352(17)	.0203(14)	.0455(15)	.0047(13)	-.0001(12)	.0049(12)
N1	.85337(22)	.92012(21)	.14911(21)	.0263(18)	.0183(15)	.0253(16)	.0041(14)	.0030(13)	.0027(13)
N2	.94627(23)	.07447(23)	.15594(24)	.0313(18)	.0168(17)	.0258(20)	.0031(15)	.0020(15)	.0020(15)
N3	.69913(29)	.71224(28)	.21858(25)	.0275(26)	.0155(21)	.0062(21)	-.0024(19)	-.0019(17)	-.0019(17)
C1	.94346(25)	.07060(27)	.14917(24)	.0234(20)	.0182(19)	.0264(19)	-.0029(17)	-.0005(16)	.0037(18)
C2	.87093(30)	.64475(28)	.23947(29)	.0379(25)	.0126(19)	.0256(25)	.0017(19)	.0013(20)	.0002(18)
C3	.72767(31)	.82108(33)	.25547(28)	.0264(26)	.0181(24)	.0284(21)	-.0009(22)	.0023(19)	.0015(19)
CM1	.98269(28)	.77536(27)	.13679(26)	.0194(21)	.0248(19)	.0219(20)	.0033(17)	-.0034(17)	.0014(17)
CC2	.76777(33)	.63184(35)	.20242(33)	.0370(28)	.0184(25)	.0209(28)	-.0056(23)	-.0031(23)	.0076(23)
CC3	.70440(27)	.89590(28)	.16683(27)	.0315(22)	.0150(19)	.0275(22)	.0017(18)	-.0024(18)	.0002(17)
CM1	.87478(28)	.99957(28)	.06997(27)	.0408(24)	.0318(20)	.0302(22)	.0055(18)	.0037(18)	.0009(17)
CM2	.97682(32)	.58506(32)	.08937(33)	.0378(27)	.0209(24)	.0410(32)	.0004(21)	.0050(23)	-.0004(22)
CM3	.59247(45)	.69752(42)	.10222(36)	.0269(45)	.0266(36)	.0597(30)	-.0052(34)	-.0005(29)	-.0021(28)

ATOM	X	Y	Z	B	ATOM	X	Y	Z	B
HM1	.9272(1)	.8585(1)	.2723(1)	.9(5)	HM2	1.0004(1)	.9239(1)	.2043(1)	1.2(6)
HM2	.9867(1)	.6995(1)	.2952(1)	1.2(6)	HM3	.6644(2)	.854(2)	.2662(2)	2.3(7)
HM3	.7829(2)	.8144(2)	.3069(2)	1.1(6)	HM12	.8177(2)	1.0551(2)	.0678(2)	2.0(6)
HM11	.9421(2)	1.0365(2)	.0845(2)	2.0(11)	HM21	1.0049(2)	.6136(2)	.0200(2)	3.4(8)
HM13	.8716(2)	.9702(2)	.0832(2)	3.2(8)	HM23	1.0428(2)	.5508(2)	.1191(2)	2.0(9)
HM22	.9216(2)	.5293(2)	.0057(2)	2.0(9)	HM32	.5805(2)	.6984(2)	.1077(2)	2.0(9)
HM31	.5641(2)	.6268(2)	.2086(2)	2.0(9)					
HM33	.5432(2)	.7535(2)	.2103(3)	3.0(8)					

**Table 1 B.** Final fractional coordinates etc. for molecule B.

ATOM	X	Y	Z	U11	U22	U33	U12	U13	U23
O1	.91929(19)	.81499(20)	.44378(18)	.0351(15)	.0367(15)	.0200(14)	.0017(13)	.0069(12)	-.0002(12)
O2	.80377(25)	.50271(24)	.76469(24)	.0716(23)	.0488(19)	.0761(24)	-.0118(18)	-.0340(19)	.0342(17)
O3	.85084(19)	.96538(19)	.78431(18)	.0429(17)	.0383(14)	.0200(15)	-.0116(13)	.0002(12)	.0067(12)
N1	.81848(22)	.93420(21)	.61935(21)	.0327(18)	.0204(15)	.0230(16)	.0042(14)	.0002(13)	.0003(13)
N2	.86085(23)	.68816(23)	.55272(24)	.0323(18)	.0207(17)	.0409(20)	.0023(15)	-.0077(15)	-.0014(15)
N3	.70767(29)	.73363(28)	.79199(25)	.0724(26)	.0370(21)	.0346(21)	-.0245(21)	.0024(19)	.0142(17)
C1	.77140(25)	.86000(27)	.53713(24)	.0272(20)	.0211(19)	.0218(19)	.0025(17)	.0013(16)	.0004(15)
C2	.78448(30)	.64413(28)	.62265(29)	.0445(25)	.0168(19)	.0456(25)	.0009(19)	.0019(20)	.0009(18)
C3	.72070(31)	.82051(33)	.75479(28)	.0453(26)	.0449(24)	.0230(21)	.0197(22)	.0013(19)	.0020(19)
CM1	.85586(29)	.78601(27)	.58089(26)	.0296(21)	.0233(19)	.0224(20)	-.0022(17)	.0006(17)	.0005(17)
CC2	.82244(33)	.65166(35)	.73208(33)	.0508(28)	.0338(25)	.0462(28)	.0003(20)	.0182(23)	.0236(23)
CC3	.80142(27)	.91427(28)	.71980(27)	.0299(22)	.0224(19)	.0295(22)	.0022(18)	.0042(18)	-.0021(17)
CM1	.80186(28)	1.02075(28)	.58957(27)	.0403(24)	.0219(20)	.0295(22)	.0061(18)	.0060(18)	-.0004(17)
CM2	.94540(32)	.61441(32)	.52778(33)	.0455(27)	.0274(24)	.0644(32)	.0134(21)	.0230(23)	.0152(22)
CM3	.82815(45)	.73785(42)	.80694(36)	.1111(45)	.0640(36)	.0410(30)	-.0358(34)	-.0330(29)	.0150(26)

ATOM	X	Y	Z	B	ATOM	X	Y	Z	B
HM1	.7856(1)	.9008(1)	.4751(1)	1.7(5)	HM2	.7057(1)	.8200(1)	.5559(1)	.9(6)
HM2	.7777(1)	.5659(1)	.0077(1)	2.4(6)	HM3	.6778(2)	.6101(2)	.6101(2)	1.3(6)
HM3	.6864(2)	.8608(2)	.8147(2)	4.3(6)	HM12	.6789(2)	.8022(2)	.6961(2)	2.4(7)
HM11	.8063(2)	1.0063(2)	.6318(2)	2.0(11)	HM21	.9524(2)	1.0027(2)	.5952(2)	2.2(8)
HM13	.8680(2)	1.1103(2)	.5166(2)	2.0(8)	HM23	.9168(2)	.5473(2)	.4836(2)	2.0(8)
HM22	.9845(2)	.5875(2)	.5880(2)	2.0(9)	HM32	.9974(2)	.6520(2)	.4785(2)	3.2(9)
HM31	.80186(28)	.7868(2)	.5408(2)	2.0(7)	HM33	.8266(2)	.6596(2)	.9285(2)	8.3(9)
HM33	.9004(2)	.7740(2)	.8991(3)	2.0(8)					

Table 2 A. Bond distances, bond angles and dihedral angles with estimated standard deviations for molecule A.

DISTANCE (Å)			DISTANCE (Å)		
O1 = CC1	1,237(4)	O2 = CC2	1,235(4)		
O3 = CC3	1,235(4)	N1 = CM1	1,471(4)		
N2 = CM2	1,469(4)	N3 = CM3	1,462(5)		
N1 = C1	1,463(4)	N2 = C2	1,460(4)		
N3 = C3	1,474(4)	N1 = CC3	1,335(4)		
N2 = CC1	1,356(4)	N3 = CC2	1,349(4)		
C1 = CC1	1,526(4)	C2 = CC2	1,516(5)		
C3 = CC3	1,535(5)				

ANGLE (°)		ANGLE (°)	
O1 = CC1 = C1	119.4(3)	O2 = CC2 = C2	119.7(3)
O3 = CC3 = C3	118.1(3)	O1 = CC1 = N2	121.3(3)
O2 = CC2 = N3	126.9(3)	O3 = CC3 = N1	122.3(3)
C1 = CC1 = N2	119.6(3)	C2 = CC2 = N3	119.4(3)
C3 = CC3 = N1	119.6(3)	CM1 = N1 = C1	116.0(3)
CM2 = N2 = C2	115.6(3)	CM3 = N3 = C3	116.0(3)
CM1 = N1 = CC3	117.7(3)	CM2 = N2 = CC1	118.0(3)
CM3 = N3 = CC2	118.3(3)	CC3 = N1 = C1	125.7(3)
CC1 = N2 = C2	125.7(3)	CC2 = N3 = C3	124.1(3)
N1 = C1 = CC1	110.2(3)	N2 = C2 = CC2	110.6(3)
N3 = C3 = CC3	110.7(3)		

DIHEDRAL ANGLE (°)			
N1 = C1 = CC1 = N2	-91.7(4)		
C1 = CC1 = N2 = C2	-6.7(5)		
CC1 = N2 = C2 = CC2	102.1(4)		
N2 = C2 = CC2 = N3	-101.3(3)		
C2 = CC2 = N3 = C3	10.5(5)		
CC2 = N3 = C3 = CC3	87.7(4)		
N3 = C3 = CC3 = N1	-104.6(3)		
C3 = CC3 = N1 = C1	8.3(5)		
CC3 = N1 = C1 = CC1	93.9(4)		

Table 2 B. Bond distances etc. for molecule B.

DISTANCE (Å)			DISTANCE (Å)		
O1 = CC1	1,233(4)	O2 = CC2	1,232(5)		
O3 = CC3	1,232(4)	N1 = CM1	1,465(4)		
N2 = CM2	1,466(5)	N3 = CM3	1,476(5)		
N1 = C1	1,466(4)	N2 = C2	1,462(5)		
N3 = C3	1,448(5)	N1 = CC3	1,357(4)		
N2 = CC1	1,358(5)	N2 = CC1	1,352(4)		
C1 = CC1	1,516(5)	C2 = CC2	1,533(5)		
C3 = CC3	1,516(5)				

ANGLE (°)		ANGLE (°)	
O1 = CC1 = C1	118.6(3)	O2 = CC2 = C2	118.5(4)
O3 = CC3 = C3	118.3(3)	O1 = CC1 = N2	122.3(3)
O2 = CC2 = N3	122.3(4)	O3 = CC3 = N1	122.0(3)
C1 = CC1 = N2	119.1(3)	C2 = CC2 = N3	119.2(4)
C3 = CC3 = N1	119.6(3)	CM1 = N1 = C1	115.0(3)
CM2 = N2 = C2	115.9(3)	CM3 = N3 = C3	117.9(4)
CM1 = N1 = CC3	117.4(3)	CM2 = N2 = CC1	119.0(3)
CM3 = N3 = CC2	116.4(4)	CC3 = N1 = C1	125.7(3)
CC1 = N2 = C2	125.9(3)	CC2 = N3 = C3	124.4(3)
N1 = C1 = CC1	109.3(3)	N2 = C2 = CC2	111.7(3)
N3 = C3 = CC3	110.3(3)		

DIHEDRAL ANGLE (°)			
N1 = C1 = CC1 = N2	91.0(4)		
C1 = CC1 = N2 = C2	7.3(5)		
CC1 = N2 = C2 = CC2	-102.0(4)		
N2 = C2 = CC2 = N3	99.7(4)		
C2 = CC2 = N3 = C3	-9.9(6)		
CC2 = N3 = C3 = CC3	-86.8(4)		
N3 = C3 = CC3 = N1	107.8(4)		
C3 = CC3 = N1 = C1	-11.9(5)		
CC3 = N1 = C1 = CC1	-91.7(4)		

$\beta = 90.82(4)^\circ$ , space group  $P2_1/n$ , and eight molecules in the unit cell ( $D_m = 1.33 \text{ g cm}^{-3}$ ,  $D_x = 1.34 \text{ g cm}^{-3}$ ). At room temperature the crystals are to some extent destroyed by the radiation and data were therefore collected at  $-160^\circ\text{C}$  (automatic four circle diffractometer,  $\text{MoK}\alpha$ -radiation, 2439 observed reflections). No corrections for absorption or secondary extinc-

tion were applied (crystal size  $0.5 \times 0.3 \times 0.3 \text{ mm}^3$ ).

The structure was solved by direct methods<sup>9</sup> and refined by full-matrix least-squares technique.<sup>10</sup> \* Methylene hydrogen positions were calculated. Methyl hydrogens were localized in a difference Fourier map. Anisotropic temperature factors were introduced for O, N, and C atoms, and weights in least-squares were calculated from the standard deviations in intensities,  $\sigma(I)$ , taken as

$$\sigma(I) = [C_T + (0.02C_N)^2]^{1/2}$$

where  $C_T$  is the total number of counts and  $C_N$  the net count. The final weighted  $R$ -value was 4.5% (conventional  $R = 5.0\%$ ) for 2439 observed reflections. The form factors used were those of Hanson *et al.*<sup>11</sup> except for hydrogen.<sup>12</sup>

Final fractional coordinates and thermal parameters for the two independent molecules (A and B) are given in Table 1 A and Table 1 B. From the temperature parameters of these tables the principal axes of thermal vibration ellipsoids were calculated. Maximum r.m.s. amplitudes range from 0.17 Å to 0.38 Å. No rigid-body analyses have been carried out.

Bond distances and angles and dihedral angles are listed in Tables 2 A and 2 B. The standard deviations (in parentheses) are estimated from the correlation matrix of the final least-squares refinement cycle. The two independent molecules have the same "crown" conformation shown in Fig. 1, which is the only conformation consistent with NMR-data.<sup>4</sup>

Average values of bond distances and two of the bond angles at nitrogen in the  $N$ -methyl amide groups are compared with earlier findings<sup>6-8,13</sup> in Table 3. It may be seen that the average (C-N-CC) *cis* angle of tricyclo-

\* All programs used (except those for phase determination) are included in this reference.

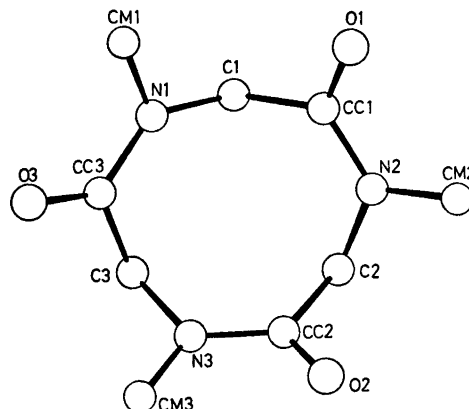


Fig. 1. Schematic drawing showing the molecular conformation.

Table 3. Average bond distances and angles for the cases  $n = 3, 4, 5, 7, 8$ .

$n =$	3	4	5	7	8
Distance (Å)					
CC—C	1.524	1.525	1.527	1.534	1.530
CC—N	1.351	1.346	1.344	1.343	1.345
CC—O	1.234	1.224	1.228	1.221	1.232
C—N	1.462	1.454	1.456	1.449	1.453
CM—N	1.468	1.466	1.483	1.446	1.487
Angle (°)					
(CM—N—CC) <i>cis</i>	118.0	117.9	118.7	118.6	118.6
(CM—N—CC) <i>trans</i>	—	123.8	123.8	122.8	123.5
(C—N—CC) <i>cis</i>	125.3	123.5	123.8	123.7	122.8
(C—N—CC) <i>trans</i>	—	116.1	117.2	118.4	117.5

<sup>a</sup> Due to the more accurate data, the values are taken from the cycloalanyl tetrasarcosyl structure.<sup>13</sup>

sarcosyl is somewhat greater than those of the larger rings. It should also be pointed out that the significantly longer CM—N bonds of cyclopenta- and cyclooctasarcosyl are possibly connected with the fact that for these compounds methyl hydrogens were not included in the calculations.

There are no short inter-molecular contacts. A list of observed and calculated structure factors is available from the author.

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- Dale, J. and Titlestad, K. *Chem. Commun.* (1969) 656.
- Titlestad, K., Groth, P. and Dale, J. *Chem. Commun.* (1973) 346.
- Titlestad, K., Groth, P. and Dale, J. *Chem. Commun.* (1973) 646.
- Titlestad, K. *Acta Chem. Scand. B* 29 (1975) 153.
- Groth, P. *Acta Chem. Scand.* 24 (1970) 780.
- Groth, P. *Acta Chem. Scand.* 27 (1973) 3117.
- Groth, P. *Acta Chem. Scand.* 27 (1973) 3419.
- Groth, P. *Acta Chem. Scand. A* 29 (1975) 38.
- Germain, G., Main, P. and Woolfson, M. M. *Acta Crystallogr. A* 27 (1971) 368.
- Groth, P. *Acta Chem. Scand.* 27 (1973) 1837.
- Hanson, H. P., Herman, F., Lea, J. D. and Skillman, S. *Acta Crystallogr.* 17 (1964) 1040.
- Stewart, R. F., Davidson, E. R. and Simpson, W. T. *J. Chem. Phys.* 43 (1965) 3175.
- Groth, P. *Acta Chem. Scand. A* 28 (1974) 449.

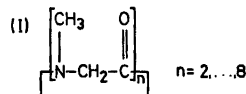
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## Crystal Conformation of Cyclodeca-sarcosyl. $4\text{CH}_3\text{OH}$ at $-160^\circ\text{C}$

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With exception for the case  $n = 6$ , the crystal structures of cyclic oligopeptides of sarcosine with the general formula I are known.<sup>1a-f</sup> For



$n = 2, 3, 4$  and  $8$  the conformations could be predicted on the basis of NMR data.<sup>2</sup> For  $n = 5$ ,

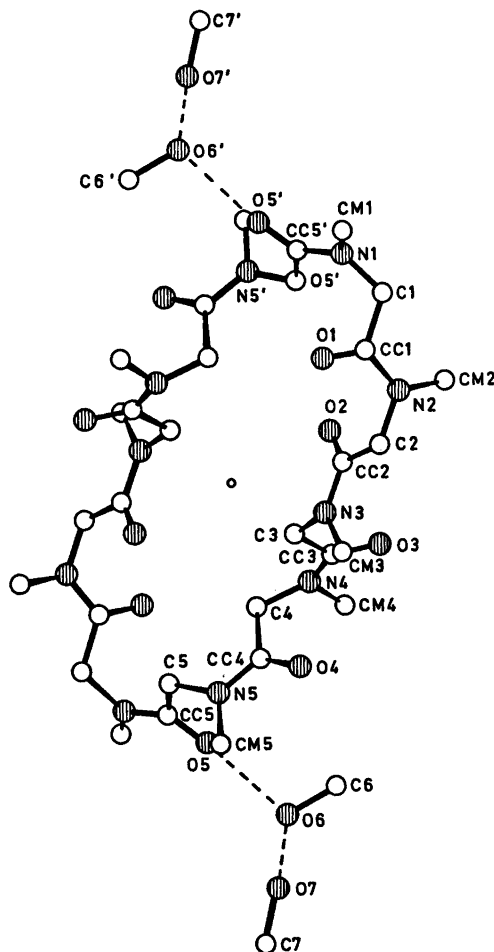


Fig. 1. Schematic drawing of the molecule.