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The crystal and molecular structures of 1,2,3,4,5,6,7,8-octa-*O*-acetyl-L-*threo*-L-*altro*- and -L-*threo*-L-*galacto*-octitol

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ABSTRACT

The molecular structures of the title octitol octa-acetates were determined by X-ray crystallography, using direct methods, and refined to final residual parameters of $R = 0.076$ and 0.047, respectively. The L-*threo*-L-*altro* isomer adopts a bent conformation in which a 1,3-parallel interaction between O-3 and C-6 is tolerated. For the L-*threo*-L-*galacto* isomer, a planar zigzag conformation is observed, in which four pairs of oxygen atoms are aligned 1,3 parallel.

INTRODUCTION

The conformational behaviour of the 20 diastereomeric octitols in solution as well as in the crystalline state is almost unknown. Until now, the only X-ray structure published is that of L-*threo*-D-*galacto*-octitol octa-acetate[1]. In connection with a C_2-extension of hexose derivatives[2], a number of other isomeric octitol octa-acetates became available for investigation. Two of them, the title compounds **1** and **2**, yielded crystals suitable for X-ray analysis; the results are given below.

Contrary to previous assumptions[3], recent investigations[4–6] have shown that the avoidance of 1,3-parallel interactions between the heavy atoms O and C, designated as O//O and C//O interactions, is not a dominating factor in determining the conformations of higher alditols in the solid state. Acetylated alditols in particular are able to adopt "unexpected" conformations, as is evident from the structures of the pentitol penta-acetates[7,8], the hexitol hexa-acetates[7,9,10], the four hepitol hepta-acetates investigated so far[11], and one decitol deca-acetate[12].

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TABLE I

Crystallographic data [a,b] for the octitol octa-acetates **1** and **2** ($C_{24}H_{34}O_{16}$, mol wt 578.52)

Data	**1**	**2**
Mp (degrees)	96–97	115–118
Crystal dimensions (mm)	0.5×0.4×0.2	0.2×0.2×0.1
Space group	$P2_1$	$P2_1$
Cell parameters (pm, degrees)		
a	865.7(1)	1211.6(1)
b	1105.6(2)	822.9(1)
c	1598.4(2)	1378.0(1)
β	105.48(1)	93.70(1)
Volume V (pm)	$1474.4(2)\times10^6$	$1371.0(1)\times10^6$
Z	2	2
$F(000)$	612	612
Calculated density D_x ($g\times cm^{-3}$)	1.303	1.401
λ, CuK_{α_1} (pm)	154.051	154.051
$\mu(cm^{-1})$	9.1	9.8
$2\theta_{max}$ (degrees)	153	153
Reflections measured	3542	3265
(symmetry independent)	3234	2999
Reflections with $F_o > n\sigma(F_o)$	3100 ($n = 4$)	2817 ($n = 3$)
Number of refined parameters	490	360
Ratio of valued reflections to parameters	6.3	7.8
Final residual factors		
R	0.076	0.046
R_w	0.083	0.045

[a] Enraf–Nonius CAD4 diffractometer. [b] Standard deviations in parentheses.

Therefore, until further insights develop, each of the higher alditols should be studied individually.

RESULTS AND DISCUSSION

1,2,3,4,5,6,7,8-Octa-*O*-acetyl-L-*threo*-L-*altro*-octitol[2] (**1**) and 1,2,3,4,5,6,7,8-octa-*O*-acetyl-L-*threo*-L-*galacto*-octitol[2] (**2**) were crystallized from ethanol and suitable crystals subjected to X-ray analysis. Relevant crystallographic data are given in Table I. The structures were solved by direct methods in the usual way with the help of the programs SHELXS90[13] and SHELX76[14].

The heavy atoms O and C were refined first. Hydrogen atoms were introduced at calculated positions. The final fractional co-ordinates of C and O atoms in **1** and **2**, together with equivalent thermal parameters, are listed in Table II *. A perspective view (SCHAKAL88[15] plot) of compounds **1** and **2** is presented in Figs.

* Lists of observed and calculated structure amplitudes, anisotropic thermal parameters, fractional co-ordinates of hydrogen atoms with isotropic thermal parameters, tables of bond distances and angles, and further information have been deposited with, and can be obtained from, Elsevier Science Publishers B.V., BBA Data Deposition, P.O. Box 1527, Amsterdam, The Netherlands. Reference should be made to No. BBA/DD/527/*Carbohydr. Res.*, 242 (1993) 21–28.

TABLE II

Fractional positional parameters [a] of C and O atoms ($\times 10^4$) and the equivalent temperature factors U_{eq} [b] for the octitol octa-acetates **1** and **2**

Atom	**1**				**2**			
	x	y	z	$U_{eq}(\times 10^3)$	x	y	z	$U_{eq}(\times 10^3)$
O-1	2605(5)	7632(5)	652(3)	61(1)	3289(2)	3715(4)	10527(2)	46(1)
O-2	4005(4)	4590(5)	1242(2)	47(1)	2210(2)	6199(5)	9367(2)	42(1)
O-3	3971(4)	5847(4)	2695(2)	36(1)	3744(2)	4036(5)	8527(2)	38(1)
O-4	7285(4)	7132(4)	2123(2)	40(1)	1064(2)	4575(5)	7281(2)	41(1)
O-5	6951(4)	6904 [c]	3828(2)	39(1)	2547(2)	2321(4)	6531(2)	34(1)
O-6	8019(4)	4775(4)	4663(2)	42(1)	1433(2)	4793(5)	5303(2)	35(1)
O-7	8767(4)	3546(4)	3209(2)	45(1)	3057(2)	2571(4)	4550(2)	36(1)
O-8	6886(5)	1392(5)	3426(3)	61(1)	2092(2)	4989 [c]	3377(2)	44(1)
O-11	108(5)	7719(6)	−184(3)	87(1)	2928(3)	1994(7)	11706(3)	98(2)
O-21	4097(7)	4485(6)	−135(3)	91(1)	447(2)	6674(6)	9696(3)	65(1)
O-31	3076(5)	7673(5)	2932(3)	68(1)	3876(3)	1390(5)	8948(3)	63(1)
O-41	9445(5)	6091(5)	1995(3)	61(1)	837(3)	7271(6)	7200(3)	71(1)
O-51	9494(5)	7551(6)	4169(4)	100(1)	4345(2)	1648(5)	6544(2)	56(1)
O-61	5899(5)	4927(8)	5235(3)	106(1)	1468(2)	7396(5)	4815(2)	51(1)
O-71	7710(6)	3031(6)	1801(3)	90(1)	4830(2)	2187(5)	4186(2)	53(1)
O-81	4281(6)	1736(6)	2857(4)	99(1)	2460(3)	6802(7)	2239(3)	95(2)
C-1	2381(6)	6382(6)	780(4)	51(1)	2156(3)	3575(6)	10158(3)	45(1)
C-2	4079(6)	5885(6)	1195(3)	43(1)	1959(3)	4488(6)	9224(3)	38(1)
C-3	4796(5)	6354(5)	2103(3)	35(1)	2560(3)	3876(6)	8361(3)	36(1)
C-4	6595(5)	6063(5)	2401(3)	34(1)	2250(2)	4747(6)	7419(2)	33(1)
C-5	7370(5)	5886(5)	3366(3)	33(1)	2825(3)	4027(5)	6561(3)	32(1)
C-6	6962(5)	4763(5)	3791(3)	38(1)	2600(2)	4853(5)	5585(2)	32(1)
C-7	7164(6)	3582(6)	3355(3)	42(1)	3302(3)	4262(6)	4768(3)	37(1)
C-8	7008(7)	2509(6)	3900(4)	55(1)	3187(3)	5230(6)	3833(3)	41(1)
C-11	1336(7)	8245(7)	146(4)	68(1)	3573(4)	2823(7)	11312(3)	52(2)
C-12	1690(9)	9507(8)	52(5)	89(1)	4767(4)	2956(8)	11615(3)	66(2)
C-21	4034(7)	3964(7)	523(4)	63(1)	1367(3)	7178(7)	9610(3)	45(1)
C-22	3927(8)	2641(8)	662(5)	76(1)	1735(4)	8871(7)	9752(4)	70(2)
C-31	3220(6)	6649(6)	3103(3)	45(1)	4317(3)	2679(7)	8825(3)	47(1)
C-32	2597(7)	6014(7)	3769(4)	64(1)	5514(3)	3055(9)	8972(4)	69(2)
C-41	8755(5)	7044(6)	1956(3)	42(1)	445(3)	5959(7)	7237(3)	47(1)
C-42	9279(7)	8256(7)	1747(4)	61(1)	−757(3)	5557(8)	7236(4)	68(2)
C-51	8110(7)	7656(6)	4247(4)	54(1)	3395(3)	1237(6)	6553(3)	39(1)
C-52	7595(8)	8582(7)	4772(5)	74(1)	2982(3)	−452(6)	6627(3)	53(1)
C-61	7353(7)	4935(7)	5330(3)	54(1)	958(3)	6168(6)	4933(3)	38(1)
C-62	8560(8)	5106(7)	6174(4)	67(1)	−239(3)	5927(7)	4682(3)	57(2)
C-71	8833(7)	3220(6)	2398(4)	56(1)	3905(3)	1658(6)	4231(3)	38(1)
C-72	10578(7)	3138(8)	2358(4)	71(1)	3540(3)	−3(6)	3961(3)	52(1)
C-81	5447(8)	1078(7)	2902(5)	74(1)	1823(3)	5885(7)	2585(3)	51(1)
C-82	5454(10)	−4(7)	2405(6)	106(1)	646(4)	5681(8)	2223(3)	63(2)

[a] Standard deviations in parentheses. [b] $U_{eq} = 1/3\ \Sigma_i\Sigma_j U_{ij} a_i^* a_j^* \mathbf{a}_i \mathbf{a}_j$. [c] This co-ordinate was fixed.

1 and 2, respectively, together with the numbering schemes. Selected torsion angles are given in Table III.

L-*threo*-L-*altro*-Octitol octa-acetate[2] (**1**) has a bent (sickle) conformation (Fig. 1) with each of the chain segments C-1 to C-5 and C-5 to C-8 in a planar zigzag

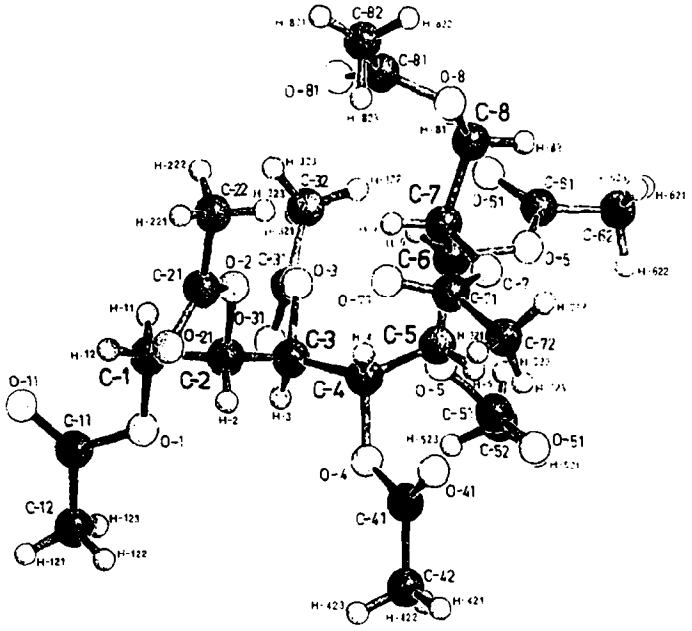

Fig. 1. A SCHAKAL88[15] drawing of a molecule of 1,2,3,4,5,6,7,8-octa-*O*-acetyl-L-*threo*-L-*altro*-octitol (**1**) showing atom numbering.

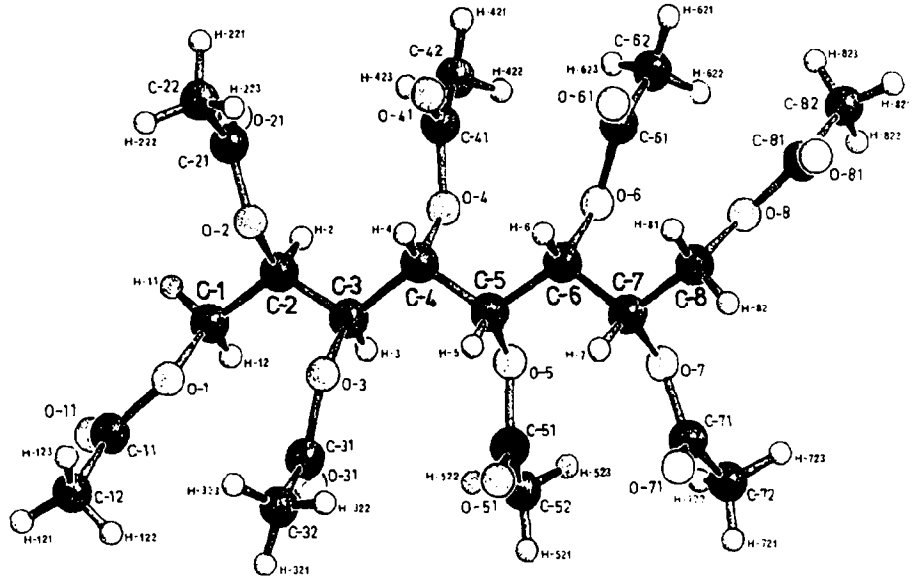

Fig. 2. A SCHAKAL88[15] drawing of a molecule of 1,2,3,4,5,6,7,8-octa-*O*-acetyl-L-*threo*-L-*galacto*-octitol (**2**) showing atom numbering.

TABLE III

Selected torsion angles (degrees) in **1** and **2** [a]

Angle	1	2
Angles in the central chain		
O-1–C-1–C-2–C-3	68.0(6)	64.8(5)
C-1–C-2–C-3–C-4	−167.4(5)	174.8(4)
C-2–C-3–C-4–C-5	−151.1(5)	−176.7(3)
C-3–C-4–C-5–C-6	70.9(6)	−177.9(3)
C-4–C-5–C-6–C-7	52.1(6)	172.1(3)
C-5–C-6–C-7–C-8	170.1(4)	−172.3(4)
C-6–C-7–C-8–O-8	168.7(4)	−68.194)
Angles between vicinal oxygens		
O-1–C-1–C-2–O-2	−172.2(4)	−60.0(4)
O-2–C-2–C-3–O-3	−50.7(5)	61.2(4)
O-3–C-3–C-4–O-4	−146.6(4)	−179.3(3)
O-4–C-4–C-5–O-5	63.9(5)	−61.6(4)
O-5–C-5–C-6–O-6	−64.6(4)	63.1(4)
O-6–C-6–C-7–O-7	−67.9(5)	−63.0(4)
O-7–C-7–C-8–O-8	−71.2(6)	56.3(4)
Angles between vicinal hydrogens		
H-11–C-1–C-2–H-2	−172(2)	−59.2(5)
H-12–C-1–C-2–H-2	65(2)	60.3(5)
H-2–C-2–C-3–H-3	71(2)	−58.3(5)
H-3–C-3–C-4–H-4	−153(2)	−178.3(3)
H-4–C-4–C-5–H-5	66(2)	55.0(5)
H-5–C-5–C-6–H-6	−180(2)	−58.9(4)
H-6–C-6–C-7–H-7	48(2)	59.3(4)
H-7–C-7–C-8–H-81	−72(2)	−63.8(5)
H-7–C-7–C-8–H-82	170(2)	56.5(5)

[a] Standard deviations in parentheses.

arrangement. Bending occurs by rotations around the C-4–C-5 and C-5–C-6 bonds, thereby avoiding parallel 1,3-interactions between O-3 and O-5, and O-5 and O-7, respectively, in an overall planar conformation but at the expense of introducing a C//O interaction between O-3 and C-6. The distance between these atoms is 296.5(6) pm. Alternative conformations would have been sickles involving one O//O interaction. However, like other alditol derivatives with the structural element of three contiguous stereogenic centres of the same configuration ("*ribo*"), it prefers the conformation which involves a C//O interaction. Thus, **1** resembles the behaviour of D-*glycero*-L-*allo*-heptitol[16]. Even more dramatic is this effect in D-*glycero*-D-*manno*-heptitol[5], D-altritol[4], DL-altritol hexa-acetate[10], 1-deoxy-1-nitro-D-altritol[17], and allitol hexa-acetate[10], which circumvent one or, in the case of allitol hexa-acetate[10], two O//O interactions in the planar zigzag conformation by bending, but at the expense of establishing one C//O interaction (in the case of allitol hexa-acetate, two such interactions). In these cases, contrary to the situation in **1** and D-*glycero*-L-*allo*-heptitol[16], O//O and C//O interactions could easily have been avoided. To our knowledge, only the following compounds that involve

an element of *ribo* configuration are found in the crystalline state in bent conformations totally free of any C//O and O//O interactions: ribitol[18], ribitol penta-acetate[8], allitol[19], and D-*glycero*-D-*gluco*-heptitol[5]. So far, only D-*glycero*-D-*manno*-heptitol hepta-acetate[11] has been found in a conformation that differs from all the other cited ones, because an O//O interaction is established, in this case in a sickle.

Based on the aforementioned investigations, we formulate the following generalisations:

If in an open-chain alditol or its peracetate three contiguous carbons are of *ribo* configuration, a bent conformation will be adopted in the crystalline state. In these conformations, a high preference for establishing C//O interactions, even if not a necessity, is observed.

1,2,3,4,5,6,7,8-Octa-*O*-acetyl-L-*threo*-L-*galacto*-octitol[2] (**2**) should avoid, if following the so-called Hassel–Ottar rule[3], two O//O interactions in the planar carbon chain conformation by bending. However, as can be seen from Fig. 2, this compound, contrary to compound **1**, adopts just this zigzag conformation, tolerating the 1,3-parallel interactions O-4//O-6 and O-5//O-7. Furthermore, two other such interactions are observed, namely, between O-1 and O-3, and O-6 and O-8, respectively. The distances are: O-1–O-3 285.6(4), O-4–O-6 282.4(4), O-5–O-7 284.6(3), and O-6–O-8 282.3(3) pm.

The behaviour of **2** is not without precedent. In all reported molecular structures of alditols and alditol derivatives that contain three contiguous stereogenic centres of alternating opposite configurations ("*xylo*") and **do not** contain an element of *ribo* configuration (see above), O//O interactions in planar zigzag conformations can be tolerated, and bending to sickle conformations free of such interactions is observed in only a fraction of reported cases. Xylitol[20], D-glucitol[21], D-iditol[19] and DL-iditol[22], *meso*-*glycero*-*gulo*-heptitol[23], D-*glycero*-L-*galacto*-heptitol[24], and 7-deoxy-7-nitro-D-*glycero*-L-*gulo*-heptitol[25] are found in bent conformations, thus circumventing any O//O without adopting C//O interactions. However, 6-deoxy-6-nitro-D-glucitol[26], 7-deoxy-7-nitro-D-*glycero*-D-*gulo*-heptitol[25], and 1-deoxy-nitro-D-*glycero*-L-*galacto*-heptitol[25] exist in planar zigzag conformations involving one O//O interaction each; 1-deoxy-1-nitro-D-iditol[26] even tolerates two such interactions, and this also occurs with D-*galacto*-L-*galacto*-decitol[6]. As far as the structure determination of xylitol is concerned, it should be mentioned that another metastable form exists[27], which has not been investigated. In the case of D-glucitol also, other modifications are known; the investigated form[21] is not the usual one, as can be seen from the reported melting point[21]. Recently[10], we summarized the literature on the many glucitol derivatives which have been found in zigzag conformations and thus are tolerating at least one 1,3-parallel interaction between O-2 and O-4.

The corresponding alditol acetates are especially prone to crystallize in the planar zigzag conformation. Reported examples are xylitol penta-acetate (stable form)[7], D-glucitol hexa-acetate[7,9], DL-glucitol hexa-acetate[10], and *meso*-*glycero*-

gulo-heptitol hepta-acetate[11]. The title compound **2**, therefore, is just another example. The tolerance of O//O interactions in alditol acetates extends to the involvement of primary oxygens, which could easily avoid such a relationship. The same orientations have been observed previously, for instance, in xylitol penta-acetate (stable form)[7], D-glucitol hexa-acetate[7,9], DL-glucitol hexa-acetate[10], and galactitol hexa-acetate[10].

In summarizing these results, we conclude that, where an element of *xylo* configuration is present in a crystalline alditol or alditol derivative (but only in the absence of three contiguous carbons of *ribo* configuration), planar zigzag conformations involving O//O interactions compete with bent conformations free of such interactions. Considering all the cases reported till now, the planar conformation is more common, with a higher tendency for this behaviour with increasing molecular weight.

Obviously, former generalisations with regard to the conformational behaviour of open-chain carbohydrates in the solid state[3] were premature. Despite the fact that our investigations have yielded some new insights, the investigation of many other compounds will be necessary in order to understand the overall situation, which is much more complicated than was assumed previously[3].

EXPERIMENTAL

The compounds were prepared by the procedures cited[2]. The X-ray structure determinations were performed at ~ 20°C, and the methods and results are given in Table 1 or have been deposited. Calculations of geometries were executed by using the PLATON program[28].

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