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# X-Ray and conformational investigations of a 4:1 mixture of 6-(*N*-benzyl-*N*-*tert*-butoxycarbonylamino)-2,3,6,7-tetradeoxy-*α*-DL-*erythro*- and -*β*-DL-*threo*-hept-2-enopyranos-4-uloses*

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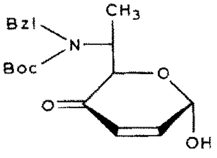
## ABSTRACT

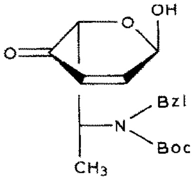
The crystals of a 4:1 mixture of 6-(*N*-benzyl-*N*-*tert*-butoxycarbonylamino)-2,3,6,7-tetradeoxy-*α*-DL-*erythro*- and -*β*-DL-*threo*-hept-2-enopyranos-4-ulose were monoclinic, space group $P2_1/c$, with cell dimensions: $a = 9.490(2)$, $b = 21.516(5)$, $c = 10.279(2)$ Å, $\beta = 115.31(1)°$, $Z = 4$. The ulose ring had a half-chair conformation deformed towards the sofa (envelope) form.

## INTRODUCTION

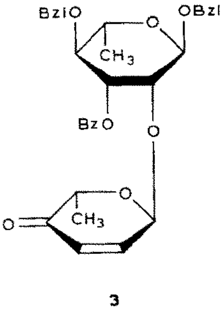
The amino sugar precursor[1] 6-(*N*-benzyl-*N*-*tert*-butoxycarbonylamino)-2,3,6,7-tetradeoxy-*α*-D-*erythro*-hept-2-enopyranos-4-ulose (**1**) contains a disubstituted 3,6-dihydro-2*H*-pyran-3-one ring. Based on $^1$H- and $^{13}$C-n.m.r. data, an *E* (envelope, sofa) conformation for *trans*-6-methoxy-2-methyl-3,6-dihydro-2*H*-pyran-3-one was postulated[2]. However, X-ray diffraction studies[3] of benzyl 3-*O*-benzoyl-4-*O*-benzyl-2-*O*-(2,3,6-trideoxy-*α*-L-*glycero*-hex-2-enopyranosyl-4-ulose)-*α*-L-rhamnoside (**3**) revealed that the 6-alkoxy-2-methyl-3,6-dihydro-2*H*-pyran-3-one ring adopted an *E* form deformed towards the half-chair (*H*) conformation. On the other hand, an *H* conformation deformed towards the *E* conformation was found for the 2-unsubstituted 6-alkoxy-3,6-dihydro-2*H*-pyran-3-one ring[4].



**1** (D form)



**2** (D form)



**3**

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* Dedicated to Professor A. Zamojski on the occasion of his 60th birthday.

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Since the n.m.r. data may be interpreted in terms of an *H* or *E* conformation, an X-ray structure investigation was undertaken of a mixture of the racemates of the *erythro* (**1**) and *threo* (**2**) derivatives.

## EXPERIMENTAL

A mixture of 6-(*N*-benzyl-*N*-*tert*-butoxycarbonylamino)-2,3,6,7-tetradeoxy-*α*-DL-*erythro*- (**1**) and -*β*-DL-*threo*-hept-2-enopyranos-4-ulose (**2**) was obtained by oxidation of 2-(*N*-benzyl-*N*-*tert*-butoxycarbonylamino)-1-(2-furyl)-propan-1-ol by bromine in acetonitrile–water[5].

Colourless crystals of the mixture of **1** and **2**, obtained from ethyl acetate–

TABLE I

Fractional coordinates (x$10^4$) and equivalent, isotropic temperature factors (Å$^2$)[a,b] for **1**

| *Atom* | x/a | y/b | z/c | $B_{eq}$ |
|---|---|---|---|---|
| C-1 | 5733(5) | 5593(2) | −3257(4) | 6.57(6) |
| C-2 | 5260(5) | 6053(2) | −4473(4) | 6.89(6) |
| C-3 | 4987(5) | 6632(2) | −4342(4) | 6.91(6) |
| C-4 | 5024(4) | 6868(2) | −2996(4) | 6.33(5) |
| C-5 | 5154(4) | 6384(2) | −1880(4) | 4.26(6) |
| C-6 | 5659(3) | 6614(1) | −377(3) | 4.55(5) |
| C-7 | 7248(4) | 6909(2) | 275(4) | 6.49(6) |
| O-1 | 4519(4) | 5225(1) | −3527(3) | 7.21(5) |
| O-4 | 4751(4) | 7415(2) | −2794(4) | 7.64(7) |
| O-5 | 6272(3) | 5913(1) | −1902(2) | 4.50(5) |
| O-1A[c] | 6694(9) | 5204(5) | −3100(9) | 6.1(1) |
| O-4A | 5316(10) | 7404(8) | −2756(11) | 6.6(1) |
| O-5A | 5030(12) | 5901(8) | −2184(11) | 10.9(1) |
| C-5A | 5736(13) | 6280(10) | −1803(13) | 7.5(1) |
| C-8 | 6718(4) | 5664(1) | 1195(3) | 5.26(5) |
| C-9 | 7987(3) | 5838(1) | 2657(3) | 5.01(5) |
| C-10 | 7759(4) | 6241(2) | 3584(4) | 6.46(6) |
| C-11 | 8940(4) | 6371(2) | 4924(4) | 7.85(6) |
| C-12 | 10381(4) | 6112(2) | 5339(4) | 7.57(6) |
| C-13 | 10634(4) | 5718(2) | 4434(5) | 7.50(6) |
| C-14 | 9443(4) | 5577(2) | 3078(4) | 6.55(6) |
| C-15 | 4168(3) | 6059(1) | 727(3) | 4.68(5) |
| C-16 | 1556(3) | 6494(2) | 36(3) | 5.02(5) |
| C-17 | 1810(4) | 6638(2) | 1561(4) | 6.78(6) |
| C-18 | 813(4) | 7040(2) | −932(4) | 6.68(6) |
| C-19 | 646(4) | 5909(2) | −545(4) | 6.92(6) |
| N-1 | 5490(2) | 6127(1) | 544(2) | 4.37(5) |
| O-6 | 3064(2) | 6452(1) | −79(2) | 4.77(4) |
| O-15 | 4027(2) | 5678(1) | 1543(2) | 6.21(5) |

[a] $B_{eq} = 8\pi^2 \cdot D_u^{1/3}$, where $D_u$ is the determinant of the *U* matrix in orthogonal space. [b] In this and subsequent Tables, the values in parentheses are estimated standard deviations. [c] Disordered atoms with population parameter 0.19 are designated A.

heptane, had m.p. 120–123°. A crystal 0.3 × 0.25 × 0.15 mm was used for measurements on a four-circle automated CAD-4 diffractometer. Graphite-monochromated Cu-$K_a$ radiation was applied with the $\omega/2\Theta$ scan technique up to $2\Theta_{max} = 139°$. Lattice parameters were refined against 25 reflections. Lorentz and polarisation, but no absorption, corrections were applied. Of a total of 3905 collected reflections, 2172 were of $I > 2\sigma(I)$.

Crystal data: $C_{19}H_{25}NO_5$, $M_r = 347.41$, monoclinic, space group $P2_1/c$, Z = 4, $a = 9.490(2)$, $b = 21.516(3)$, $c = 10.279(2)$ Å, $\beta = 115.31(1)°$, $V = 1897.3(3)$ Å$^3$, $F(000) = 744$, $D_c = 1.22$ Mg.m$^{-3}$, $\mu$(Cu-$K_a$) = 0.68 mm$^{-1}$.

The structure was solved by direct methods, using the SHELXS-86[6] program, and refined by full-matrix least-squares programs of the SHELX-76[7]. Only hydrogen atoms of the ulose ring were taken from the difference density maps. The positions of the other H atoms were calculated.

*Disorder in the ulose ring atoms.* — It was noted that C-5, O-5, O-4, and O-1 exhibited abnormally high temperature factors.

An examination of the Fourier $\Delta F$ map at $R = 0.16$ revealed four relatively high maxima in the area of the ulose ring. Their positional parameters were included in the parameter set as alternative positions of C-5, O-5, O-4, and O-1 (in Table I distinguished by letter A). The common population parameter for the disordered atoms, after refinement, was 0.81:0.19. Because of the marked inequality of this population ratio, the parameters of the atoms at the positions of lower population were then refined with isotropic temperature factors. The higher population atoms and the rest of the molecule were refined further in the anisotropic mode. The $R$ factor was decreased rapidly to below 0.1 and the temperature factors of the disordered atoms became more reasonable.

The final refinement step involved all of the positional and thermal parameters except the H temperature factors (set as $B_{eq}$ of the adjacent atom + 1 Å$^2$ and held invariant). The final $R$ value was 0.0573 (unit weights). The maximum, residual electron-density amplitude on the final $\Delta\rho$ maps was 0.13 e/Å$^3$. The refined positional parameters* and the $B_{eq}$ values are given in Table I.

## RESULTS AND DISCUSSION

The interatomic distances, valence angles, and selected torsion angles for **1** and **2** are given in Tables II–IV, respectively, and Fig. 1 presents the optimal projections.

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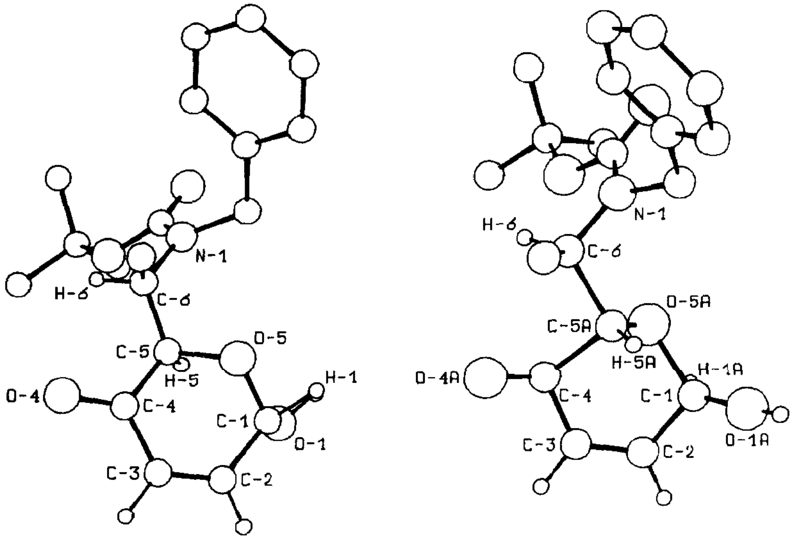
* Lists of structure factors, hydrogen coordinates, and anisotropic thermal parameters have been deposited with, and can be obtained from, Elsevier Science Publishers B.V., BBA Data Deposition, P. O. Box 1527, Amsterdam, The Netherlands. Reference should be made to No. BBA/DD/435/*Carbohydr. Res.*, 201 (1990) 153–159.



1 2

Fig. 1. Parellel projections of isomers **1** (81%) and **2** (19%). For purposes of clarity, only the ulose hydrogen atoms are shown and labelling of the amino substituents is omitted. The molecule orientations are those of optimal viewing.

TABLE II

Bond lengths (Å)

| | | | |
|---|---|---|---|
| C-2–C-1 | 1.505(6) | C-9–C-8 | 1.517(3) |
| O-1–C-1 | 1.326(6) | N-1–C-8 | 1.460(3) |
| O-5–C-1 | 1.438(4) | C-10–C-9 | 1.372(5) |
| O-1A[a]–C-1 | 1.197(11) | C-14–C-9 | 1.379(5) |
| O-5A–C-1 | 1.652(15) | C-11–C-10 | 1.383(4) |
| C-3–C-2 | 1.291(6) | C-12–C-11 | 1.365(5) |
| C-4–C-3 | 1.460(6) | C-13–C-12 | 1.354(7) |
| C-5–C-4 | 1.515(6) | C-14–C-13 | 1.402(5) |
| O-4–C-4 | 1.242(6) | N-1–C-15 | 1.354(4) |
| O-4A–C-4 | 1.187(17) | O-6–C-15 | 1.325(3) |
| C-5A–C-4 | 1.689(18) | O-15–C-15 | 1.220(4) |
| C-6–C-5 | 1.493(5) | C-17–C-16 | 1.513(5) |
| O-5–C-5 | 1.474(5) | C-18–C-16 | 1.506(5) |
| C-7–C-6 | 1.504(4) | C-19–C-16 | 1.499(6) |
| C-5A–C-6 | 1.662(16) | O-6–C-16 | 1.488(4) |
| N-1–C-6 | 1.466(4) | O-5A–C-5A | 1.021(24) |

[a] Disordered atoms are designated A.

TABLE III

Bond angles (degrees)

| | | | |
|---|---|---|---|
| C-1–C-2–C-3 | 123.4(4) | C-5–C-6–N-1 | 110.9(2) |
| C-2–C-1–O-1 | 107.2(3) | C-6–C-5–O-5 | 109.2(2) |
| C-2–C-1–O-5 | 110.2(3) | C-7–C-6–C-5A | 99.3(5) |
| C-2–C-1–O-1A[a] | 120.8(7) | C-7–C-6–N-1 | 112.3(2) |
| C-2–C-1–O-5A | 103.2(6) | C-5A–C-6–N-1 | 108.6(7) |
| O-1–C-1–O-5 | 114.0(4) | C-6–N-1–C-8 | 119.8(2) |
| O-1–C-1–O-1A | 98.9(6) | C-6–N-1–C-15 | 122.1(2) |
| O-1–C-1–O-5A | 79.4(6) | C-8–C-9–C-10 | 123.4(3) |
| C-1–O-5–C-5 | 112.6(3) | C-8–C-9–C-14 | 118.4(3) |
| O-5–C-1–O-1A | 105.6(5) | C-9–C-8–N-1 | 115.2(2) |
| O-5–C-1–O-5A | 40.5(4) | C-8–N-1–C-15 | 117.9(2) |
| O-1A–C-1–O-5A | 133.8(7) | C-9–C-10–C-11 | 121.2(3) |
| C-2–C-3–C-4 | 120.6(4) | C-10–C-9–C-14 | 118.3(3) |
| C-3–C-4–C-5 | 116.1(4) | C-9–C-14–C-13 | 119.9(4) |
| C-3–C-4–O-4 | 124.5(4) | C-10–C-11–C-12 | 120.4(4) |
| C-3–C-4–O-4A | 116.3(7) | C-11–C-12–C-13 | 119.3(3) |
| C-3–C-4–C-5A | 105.5(7) | C-12–C-13–C-14 | 120.9(4) |
| C-4–C-5–C-6 | 116.2(3) | N-1–C-15–O-6 | 112.1(2) |
| C-4–C-5–O-5 | 106.7(4) | N-1–C-15–O-15 | 123.3(2) |
| C-5–C-4–O-4 | 118.7(4) | C-15–O-6–C-16 | 121.3(3) |
| C-5–C-4–O-4A | 125.1(6) | O-6–C-15–O-15 | 124.6(3) |
| C-5–C-4–C-5A | 19.5(5) | C-17–C-16–C-18 | 110.3(3) |
| O-4–C-4–O-4A | 24.7(6) | C-17–C-16–C-19 | 113.2(3) |
| O-4–C-4–C-5A | 129.5(7) | C-17–C-16–O-6 | 111.2(2) |
| O-4A–C-4–C-5A | 126.3(8) | C-18–C-16–C-19 | 111.4(2) |
| C-4–C-5A–C-6 | 99.3(1.1) | C-18–C-16–O-6 | 100.9(3) |
| C-5–C-6–C-7 | 114.7(3) | C-19–C-16–O-6 | 109.1(3) |
| C-5–C-6–C-5A | 19.9(4) | | |

[a] Disordered atoms are designated A.

TABLE IV

Selected torsion angles (degrees)

| | | | |
|---|---|---|---|
| C-3–C-2–C-1–O-1 | −107.6(5) | C-6–C-5–C-4–O-4A | −1.3(8) |
| C-3–C-2–C-1–O-5 | 17.0(6) | O-5–C-5–C-4–O-4A | 120.7(7) |
| C-3 C-2 C-1 O-1A[a] | 140.6(7) | C-7–C-6–C-5–C-4 | 60.9(4) |
| C-3–C-2–C-1–O-5A | −24.7(7) | N-1–C-6–C-5–C-4 | −170.6(3) |
| C-5–O-5–C-1–C-2 | −52.0(5) | C-7–C-6–C-5–O-5 | −59.8(4) |
| C-5A–O-5A–C-1–C-2 | 69(1) | N-1–C-6–C-5–O-5 | 68.7(3) |
| C-5–O-5–C-1–O-1 | 68.5(4) | C-1–O-5–C-5–C-4 | 63.5(4) |
| C-5–O-5–C-1–O-1A | 176.0(6) | C-1–O-5A–C-5A–C-4 | −84(1) |
| C-4–C-3–C-2–C-1 | 4.2(7) | C-1–O-5–C-5–C-6 | −170.1(3) |
| C-5–C-4–C-3–C-2 | 8.8(6) | C-15–N-1–C-6–C-5 | 90.9(3) |
| O-4–C-4–C-3–C-2 | 178.8(4) | C-15–N-1–C-6–C-7 | −139.3(3) |
| O-4A–C-4–C-3–C-2 | −154.1(6) | C-15–N-1–C-6–C-5A | 111.9(5) |
| C-5A–C-4–C-3–C-2 | −8.7(7) | C-6–N-1–C-8–C-9 | −89.4(3) |
| C-6–C-5–C-4–C-3 | −162.6(3) | C-6–N-1–C-15–O-6 | −3.8(3) |
| O-5–C-5–C-4–C-3 | −40.5(4) | C-8–N-1–C-15–O-6 | 170.9(2) |
| O-5A–C-5A–C-4–C-3 | 58(1) | C-6–N-1–C-15–O-15 | 176.2(2) |
| O-5–C-5–C-4–O-4 | 148.9(3) | C-16–O-6–C-15–N-1 | 175.1(2) |

[a] Disordered atoms are designated A.

The positional disorder of a part of the sugar ring causes the ulose fragment to exist in two forms having a common part consisting of C-1,2,3,4 (see Fig. 2). HO-1 is pseudo-axial in **1** (higher population form) and pseudo-equatorial in **2** (lower population form) (see Table V), **1** (81%) exists in the *α*-1*S*:5*R*:6*R* (*α*-1*R*:5*S*:6*S*) form and **2** in the *β*-1*R*:5*S*:6*R*(*β*-1*S*:5*R*:6*S*) form.

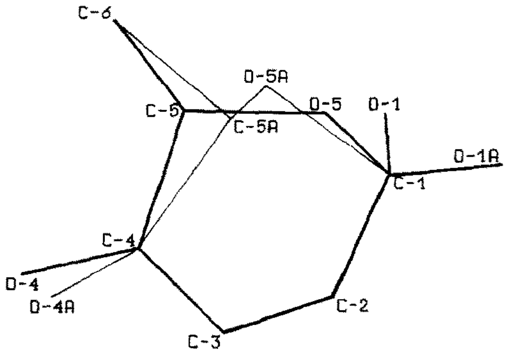


Fig. 2 A schematic design of the overlap of isomeric ulose rings (**1** and **2**). The isomer with the higher population is shown by heavy lines.

TABLE V

Conformational parameters of ulose rings for **1–3**

| | **1** | **2** | **3**[3] |
|---|---|---|---|
| *Puckering parameters* | | | |
| Q (Å) | 0.496 | 0.549 | 0.415 |
| $\varphi$ (°) | 98.0 | 287.6 | 110.4 |
| $\theta$ (°) | 126.8 | 48.4 | 122.5 |
| $q_2$ (Å) | 0.397 | 0.410 | 0.349 |
| *Endocyclic torsion angles (degrees)* | | | |
| C-1–C-2 | 17.0 | −24.5 | 18.3 |
| C-2–C-3 | 4.2 | 4.2 | 6.2 |
| C-3–C-4 | 8.8 | −8.7 | 1.1 |
| C-4–C-5 | −40.5 | 58.0 | −27.3 |
| C-5–O-5 | 63.5 | −84.0 | 53.1 |
| O-5–C-1 | −52.0 | 69.0 | −48.8 |
| *Deviations from least-squares planes (Å)* | | | |
| | *5-atomic* | *4-atomic* | *5-atomic* |
| O-5 | 0.656 | −0.588 | −0.551 |
| C-5 | | 0.168 | |
| O-1 | −1.112 | 0.636 | |
| O-4 | 0.100 | 0.489 | 0.022 |
| *Asymmetry parameters (degrees)* | | | |
| $\Delta C_2$ | 10.0 | 13.5 | 9.9 |
| $\Delta C_s$ | 16.9 | | 6.5 |
| Conformation | ${}^{\circ}H_5+{}^{\circ}E$ | ${}^{5}H_{o}\rightarrow E_{o}$ | ${}^{\circ}E+{}^{\circ}H_5$ |

The bond lengths and valence angles in the disordered fragment of the lower population deviate strongly from the usual values. The highly unequal population ratio did not allow better results to be obtained.

*Conformation of the ulose ring.* — The conformational parameters (puckering[8], asymmetry[9], and deviations from least-squares planes) for the ulose rings of **1**, **2**, and **3** are given in Table V. The ulose ring in **1** adopts a hybrid ${}^{0}H_{5}+{}^{0}E$ conformation, despite the fact that the $sp^2$ atoms C-2,3,4 would prefer an ($E$) conformation. A similar effect was observed for the ulose ring in **3**. In each of these rings, the five-atom least-squares planes may be distinguished, but the distribution of endocyclic torsion angles does not show the symmetry of a mirror plane. The asymmetry parameters indicate a deviation from both a symmetry plane and two-fold axis.

The ulose ring in **2** has the ${}^{5}H_{0}$ conformation deformed towards $E$. In spite of two torsion angles of $<10^\circ$, the ring has only a four-atom least-squares plane which is characteristic for the $H$ conformation. However, the above statements are affected by the lower accuracy of positions of C-5A and O-5A.

The conformational deviations of the rings discussed from an ideal $E$ conformation are due to the significant lability of the $E$ form, which has a relatively high strain energy and therefore is subject to various intra- or inter-molecular effects.

## ACKNOWLEDGMENTS

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## REFERENCES

1 J. Jurczak, J. Raczko, A. Gołebiowski, J. W. Krajewski, P. Gluziński, and Z. Urbańczyk-Lipkowska, *Angew. Chem.*, submitted for publication.
2 O. Achmatowicz, Jr., and M. H. Burzyńska, *Pol. J. Chem.*, 53 (1979) 265–276.
3 J. W. Krajewski, Z. Urbańczyk-Lipkowska, P. Gluziński, A. Zamojski, and K. Stadnicka, *Carbohydr. Res.*, 117 (1983) 13–22.
4 J. W. Krajewski, G. Grynkiewicz, P. Gluziński, Z. Urbańczyk-Lipkowska, A. Zamojski, and K. Stadnicka, *Acta Crystallogr., Sect. B*, 38 (1982) 1485–1489.
5 S. Pikul, J. Jurczak, and G. Grynkiewicz, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 35 (1987) 293–296.
6 G. M. Sheldrick, in G. M. Sheldrick, C. Krüger, and R. Goddard (Eds.), *Crystallographic Computing 3*, Oxford University Press, 1985, pp. 175–189.
7 G. M. Sheldrick, *SHELX-76*, Program for Crystal Structure Determination and Refinement (University of Cambridge, England); 400-Atomic Version (Ch. Weizman Institute of Science, Rehovot, Israel, 1979); implemented on IBM PC/AT (1987).
8 D. Cremer and J. A. Pople, *J. Am. Chem. Soc.*, 97 (1975) 1354–1358.
9 W. L. Duax, C. M. Weeks, and D. C. Rohrer, *Top. Stereochem.*, 9 (1976) 271–383.