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STEREOSELECTIVE ALDOL CONDENSATIONS WITH SUGAR ALDEHYDES. CONDENSATION OF 2-ACETAMIDO-2-DEOXY-D- AND -L-GLYCERALDEHYDE WITH DI-*tert*-BUTYL OXALOACETATE*

MOMČILO MILJKOVIĆ AND PETER HAGEL

Department of Biological Chemistry, The Milton S. Hershey Medical Center, The Pennsylvania State University, Hershey, Pennsylvania 17033 (U.S.A.)

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ABSTRACT

Aldol condensation of 2-acetamido-2-deoxy-D- and -L-glyceraldehyde with di-*tert*-butyl oxaloacetate at pH 12 yielded *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-D- and -L-*xylo*-hexulopyranosonate as the major, and *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-D- and -L-*arabino*-hexulopyranosonates as the minor products. The ratio of the corresponding *xylo* to *arabino* diastereomers was ~3:1.

INTRODUCTION

The suggestion of a chair-like, six-membered ring, pericyclic transition state for the observed diastereoselection in the Ivanov reaction[2], the observation[3] that the configuration of the aldol products obtained under conditions of kinetic control strongly depends upon the geometry of the starting enolate, and the observation[4,5] that a highly stereoselective aldol-condensation can readily be achieved if all aspects of the C–C bond formation are kinetically controlled have contributed, more than anything else, for the aldol condensation to become one of the most versatile methods for the stereoselective, sequential synthesis of 1,3-diol units. Numerous studies of the various factors that control the configuration of the products of aldol condensation[6] resulted, *inter alia*, in the stereoselective synthesis of 6-deoxyerythronolide B[7] and tylonolide[8].

An achiral enolate anion approaching an aldehyde group having a vicinal chiral carbon atom is usually directed preferentially to one of the diastereofaces (*re* or *si*) of the trigonal carbonyl carbon. The degree of this preference is commonly termed as diastereofacial selectivity (or Cram/anti Cram selectivity), and is determined by the ratio of the two diastereomers formed. In the course of our studies directed toward the synthesis of sialic acid and analogs from appropriately pro-

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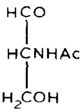
*Dedicated to Prof. Djordje Stefanović on the occasion of his 80th birthday. Taken in part from the Ph.D. thesis of P.H.

tected, acyclic 2-amino-2-deoxy-*aldehydo* sugar derivatives, the aldol condensation of 2-acetamido-2-deoxy-D- (**1**) and -L-glyceraldehyde (**2**) with di-*tert*-butyl oxaloacetate was investigated, and the results are reported herein.

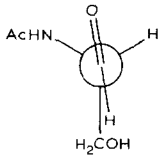
RESULTS AND DISCUSSION

2-Acetamido-2-deoxy-D- (**1**) and -L-glyceraldehyde (**2**) were synthesized by periodic acid oxidation of 2-acetamido-2-deoxy-D-mannitol (**3**) and 2-acetamido-2-deoxy-D-glucitol (**4**), respectively*.

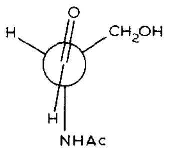


$$\begin{array}{c}\mathrm{HCO}\\ |\\ \mathrm{HCNHAc}\\ |\\ \mathrm{H_2COH}\end{array}$$

1



1a



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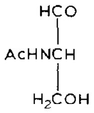
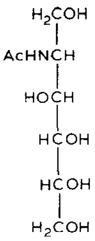


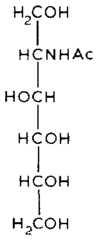
$$\begin{array}{c}\mathrm{HCO}\\ |\\ \mathrm{AcHNCH}\\ |\\ \mathrm{H_2COH}\end{array}$$

2



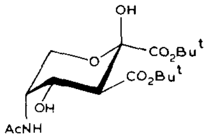
$$\begin{array}{c}\mathrm{H_2COH}\\ |\\ \mathrm{AcHNCH}\\ |\\ \mathrm{HOCH}\\ |\\ \mathrm{HCOH}\\ |\\ \mathrm{HCOH}\\ |\\ \mathrm{H_2COH}\end{array}$$

3



$$\begin{array}{c}\mathrm{H_2COH}\\ |\\ \mathrm{HCNHAc}\\ |\\ \mathrm{HOCH}\\ |\\ \mathrm{HCOH}\\ |\\ \mathrm{HCOH}\\ |\\ \mathrm{H_2COH}\end{array}$$

4



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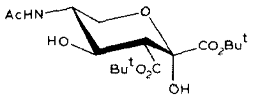

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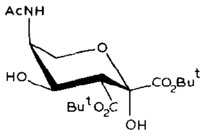

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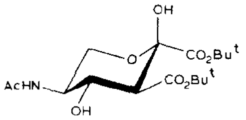

8

The aldol condensations were performed, at room temperature, by adjusting the pH of a methanolic solution containing **1** or **2** and di-*tert*-butyl oxaloacetate to 12.0 by adding 0.5M sodium methoxide in anhydrous methanol. The products were *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxyhexulopyranosonates having the D-*arabino* (**5**), D-*xylo* (**6**), L-*arabino* (**7**), and L-*xylo* (**8**) configurations, and a racemate of **6** and **8**; their yields are given in Table I. The structures of **5**–**8** were unequivocally determined from the corresponding ^{1}H-n.m.r. spectra, and

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*In none of the previously reported oxidations of 2-acetamido-2-deoxy-D-glucitol (**4**) with periodate[9-11] was 2-acetamido-2-deoxy-L-glyceraldehyde (**2**) isolated or characterized. Foster and Horton[9] immediately reduced **2** to 2-acetamidopropane-1,3-diol, whereas Barker *et al.*[10] and Honda *et al.*[11] only reported that the periodate oxidation of **4** was very rapid.

TABLE I

CONDENSATION OF **1** AND **2** WITH DI-*tert*-BUTYL OXALOACETATE

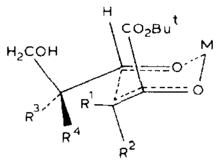
Product (%)	*Aldehyde*	
	1	**2**
5 (3*S*,4*S*,5*R*)	9	
6 (3*R*,4*R*,5*R*)	25	
7 (3*R*,4*R*,5*S*)		8
8 (3*S*,4*S*,5*S*)		17
6 + **8** (Racemate)	7	13

were further supported by high-resolution mass spectra and optical rotation values. The identity of the racemate (**6** + **8**) was also proven by mixing acetone solutions containing equimolar amounts of **6** (m.p. 85–87°; $[\alpha]_D^{27}$ +24°) and **8** (m.p. 83–85°; $[\alpha]_D^{27}$ −24°), which resulted in precipitation of the racemate (**6** + **8**), m.p. 168–170°; $[\alpha]_D^{27}$ 0°.

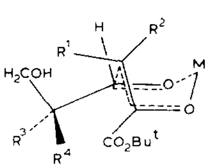
The ^{1}H-n.m.r. spectra of the less polar D- and L-*arabino*-hexulopyranosonates **5** and **7** were identical. Diequatorial orientation of substituents at C-3 and C-4 was evident from the large coupling constant, $J_{3,4}$ 10.74 Hz, whereas the axial orientation of the acetamido group at C-5 was evident from a relatively small coupling constant, $J_{4,5}$ 4.15 Hz. The equatorial orientation of H-5 was further supported by the absence of a large coupling between this proton and axially oriented H-6 ($J_{5,6}$ 1.95, and $J_{5,6'}$ 1.46 Hz). Chemical shifts and coupling constants of ring hydrogen atoms in the ^{1}H-n.m.r. spectra of **5** and **7** further suggested that **5** must exist in the $^1C_4$(D), and **7** in the $^4C_1$(L) conformation. This may be due to the absence of severe, 1,3-diaxial, nonbonding interaction between OH-4 and the substituent at C-2 (a hydroxyl or *tert*-butoxycarbonyl group, depending upon the anomeric configuration) that is present in the alternative chair conformations. Although the anomeric configurations were not determined, they are assumed to be as depicted owing to the anomeric effect.

The ^{1}H-n.m.r. spectra of the more polar D- and L-*xylo*-hexulopyranosonates **6** and **8** also were identical. The equatorial orientation of substituents of the pyranoside ring was evident from large coupling constants involving H-3, -4, and -5 ($J_{3,4}$ = $J_{4,5}$ 10.25 Hz). The axial orientation of H-5 was further supported by the presence of a large coupling with axially oriented H-6 ($J_{5,6a}$ 10.25; $J_{5,6e}$ 5.13 Hz). No conformational ambiguity exists for **6** and **8**, as the all-equatorial orientation of ring substituents requires **6** to be in $^4C_1$(D), and **8** in $^1C_4$(L) conformation. Again, the anomeric configurations were not determined but, in view of the anomeric effect, they are assumed to be as depicted.

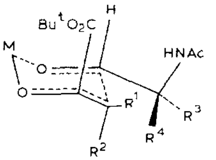
A total of eight possible (*β*, or *si*), six-membered ring, pericyclic, transition states can be envisioned for the aldol-condensation products of 2-acetamido-2-deoxy-D-glyceraldehyde (**1**) with di-*tert*-butyl oxaloacetate, namely four chair-like



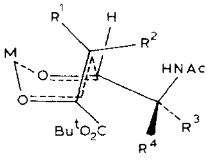
9 $R^1 = H, R^2 = CO_2Bu^t, R^3 = NHAc, R^4 = H$ (*Z*-enolate)
10 $R^1 = CO_2Bu^t, R^2 = R^4 = H, R^3 = NHAc$ (*E*-enolate)



11 $R^1 = R^4 = H, R^2 = CO_2Bu^t; R^3 = NHAc$ (*Z*-enolate)
12 $R^1 = CO_2Bu^t, R^2 = R^4 = H, R^3 = NHAc$ (*E*-enolate)



13 $R^1 = R^4 = H, R^2 = CO_2Bu^t, R^3 = CH_2OH$ (*Z*-enolate)
14 $R^1 = CO_2Bu^t, R^2 = R^4 = H, R^3 = CH_2OH$ (*E*-enolate)



15 $R^1 = CO_2Bu^t; R^2 = R^3 = H, R^4 = CH_2OH$ (*Z*-enolate)
16 $R^1 = R^3 = H, R^2 = CO_2Bu^t, R^4 = CH_2OH$ (*E*-enolate)

(**9, 10, 13,** and **14**) and four boat-like* (**11, 12, 15,** and **16**) transition states, depending upon the actual conformation of 2-acetamido-2-deoxy-D-glyceraldehyde (**1**) on one side, and upon the configuration of di-*tert*-butyl oxaloacetate enolate on the other side. Transition states **9–12** contain the rotamer **1a** of **1**, whereas **13–16** contain the rotamer **1b**. The di-*tert*-butyl oxaloacetate enolate is present in **9, 11, 13,** and **15** in its *Z* configuration (having the two *tert*-butoxycarbonyl groups in *trans* orientation), and in **10, 12, 14,** and **16** in the *E* configuration (having *cis tert*-butoxycarbonyl groups). For the reaction of the L enantiomer **2**, eight transition states energetically identical and enantiomeric with **9–16** can be written.

The condensation products **6** and **5** may arise from **1** either *via* the chair-like transition states **9** and **13**, respectively, or *via* the boat-like transition states **12** and **16**, respectively. The latter two transition states may most likely be excluded because (a) the *E* configuration for the enolate is certainly disfavored owing to strong, non-bonding, and electrostatic interactions between the *cis*-oriented *tert*-butyloxycarbonyl groups; and (b), **12** and **16** are encumbered by severe, 1,3-diaxial interaction between a *tert*-butoxycarbonyl group and the substituted vicinal carbon atom in **1**. This 1,3-diaxial interaction is also present in the boat-like transition states **11** and **15**, rendering them conformationally disadvantaged, although they do contain the enolate state in the favored, *Z* configuration; and conversely, the chair-like arrangements **10** and **14**, which are free from such 1,3-diaxial steric interaction, involve the high-energy, *E* enolate state. (It should be noted that **10, 11, 14,** and **15** would generate not **5** and **6**, but different diastereomers that were not encountered.) Consequently, the transition states **9** and **13**, which avoid the

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*Instead of the boat-like transition states **11, 12, 15,** and **16**, inverted, chair-like transition states may be written in which a chelated metal atom would lie below the plane containing two oxygen atoms, C-2 of **1** (or **2**), and C-2 of the di-*tert*-butyloxaloacetate group. However, this would have not changed this discussion.

destabilizing factors just discussed, would represent the pathways of choice for the reaction of **1** with di-*tert*-butyl oxaloacetate. From the observed preponderance of product **6** (Table I), one may conclude that the rotamer **1a** is favored over **1b** in the transition state by a factor of 2–3, which implies predominant attack on the *re* face of **1** (transition state **9**); the attack on the *si* face (transition state **13**) gives rise to the minor product **5**. Consequently, the conformation of 2-acetamido-2-deoxy-D- (and -L-)glyceraldehyde (**1a** and **1b**, respectively) seems to be the determining factor for the stereochemical outcome of this aldol condensation.

We did not adopt Felkin's model[12–14] to depict the six-membered, pericyclic, transition states **9** and **13**, because a rotation about the C-1–C-2 bond of **1** (**2**, or both) would be required in order for the C-1–Nu (Nu = nucleophile, C-3 of the *tert*-butyl oxaloacetate enolate) and the C-2–L (L = large group, *viz.* CH_2OH or NHAc) bonds to assume the antiperiplanar orientation that would lower the conformational energy of the transition state by $\sim$20–40 kJ mol due to the antiperiplanar effect[14]. This rotation would, however, place the *tert*-butyloxycarbonyl group at C-4 group and the chiral, vicinal carbon atom of **1** into such a proximity as to offset the gain of conformational energy from the antiperiplanar effect.

EXPERIMENTAL

General methods. — The melting points are uncorrected. Optical rotations were determined with a Cary 60 spectropolarimeter in a 1.0-cm cell. I.r. spectra were recorded with a Perkin–Elmer infrared spectrophotometer Model 267, and ^{1}H-n.m.r. spectra for solutions in (^{2}H)chloroform with Bruker WM-360 and Varian T-60 spectrometers and tetramethylsilane (Me_4Si) as the internal standard. The silica gel used for all column chromatography was obtained from E. Merck (Darmstadt, W. Germany; Silica gel 60, particle size <0.063 mm).

2-Acetamido-2-deoxy-D-glyceraldehyde (**1**). — To an aqueous solution (15 mL) of 2-acetamido-2-deoxy-D-mannitol[15] (**3**) (500 mg, 2.24 mmol) was added HIO_4 (1.5 g, 6.57 mmol), and the reaction was allowed to proceed for 10 min at room temperature. An excess of $BaCO_3$ was added and the mixture stirred at room temperature until neutral. The solids were filtered off and washed with ethanol (15 mL). The combined filtrate was evaporated *in vacuo* (bath temperature, 30°) to give a partly crystalline residue that was purified by rapid (short column) chromatography on silica gel (3 g) with 3:1 benzene–methanol as eluent. After being dried in a high vacuum for 2 h at room temperature, **1** was obtained as a chromatographically homogeneous, highly viscous, colorless syrup (241 mg, 84%); $[\alpha]_D^{27}$ +16° (*c* 1.06, methanol); ν_{max}^{Nujol} 3400 (br., hydrogen-bonded OH and NH), 1720 (weak, C=O stretch, CHO), and 1645 cm^{-1} (amide I band). Because of its instability, aldehyde **1** could not be characterized by microanalysis.

Condensation of 2-acetamido-2-deoxy-D-glyceraldehyde (**1**) *with di-*tert*-butyl oxaloacetate.* — To a solution of **1** (264 mg, 2.02 mmol) and di-*tert*-butyl oxaloacetate (274 mg, 1.12 mmol) in anhydrous methanol (2 mL) was added a 0.5M methanolic solution of sodium methoxide until the pH of the reaction mixture was ~12.0 (~2.1 mL). After being kept for 1 h at room temperature, the mixture was made neutral with Dowex-50W (H^+) cation-exchange resin. The resin was filtered off and washed with ethanol, and the combined filtrate was evaporated *in vacuo* (bath temperature, 30°). The faintly yellow syrup obtained contained two products, in addition to a large amount of unreacted **1** (t.l.c. in 6:1 benzene–methanol). The starting material (**1**) and other impurities were removed by sequential chromatography on silica gel (12 g each) with 6:1 benzene–methanol and 1:1 hexane–acetone as eluent, respectively. Separation of two condensation products was subsequently effected by chromatography on silica gel (25 g) with 15:1 chloroform–methanol. The less polar, *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-D-*arabino*-hexulopyranosonate (**5**) was isolated as a chromatographically homogeneous, colorless crystalline solid (35 mg, 9%). The analytical sample was obtained by recrystallization (twice) from diisopropyl ether; m.p. 134–135.5°, $[\alpha]_D^{27}$ −26° (*c* 0.46, chloroform); $\nu_{\max}^{\mathrm{CHCl_3}}$ 3420 (br., hydrogen-bonded OH and NH), 1725 (C=O stretch, ester), and 1670 cm^{-1} (C=O stretch, monosubstituted amide); ^{1}H-n.m.r.: δ 6.00 (d, 1 H, $J_{5,\mathrm{NH}}$ 7.3 Hz, NH), 4.44 (ddd, 1 H, $J_{4,\mathrm{OH}}$ 2.9, $J_{3,4}$ 10.7, $J_{4,5}$ 4.1 Hz, H-4), 4.41 (d, 1 H, $J_{3,\mathrm{OH}}$ 1.2 Hz, OH), 4.34 (dddd, 1 H, $J_{5,\mathrm{NH}}$ 7.3, $J_{4,5}$ 4.1, $J_{5,6}$ 1.5, $J_{5,6'}$ 1.9 Hz, H-5), 4.11 (dd, 1 H, $J_{5,6}$ 1.5, $J_{6,6'}$ 12.2 Hz, H-6), 3.78 (dd, 1 H, $J_{5,6'}$ 1.9, $J_{6,6'}$ 12.2 Hz,H-6'), 3.64 (d, 1 H, $J_{4,\mathrm{OH}}$ 2.9 Hz, OH), 3.07 (dd, 1 H, $J_{3,\mathrm{OH}}$ 1.2, $J_{3,4}$ 10.7 Hz, H-3), 2.08 (s, 3 H, N-Ac), 1.56, and 1.44 [2 s, 18 H, 2 $(CH_3)_3C$].

Anal. Calc. for $C_{17}H_{29}NO_8$: mol.wt. 375.1893. Found (m.s., *m/z*): 375.1900.

Further elution with 9:1 chloroform–methanol as eluent afforded a chromatographically homogeneous and partly crystalline, colorless material (129 mg; 32%). Trituration with acetone gave fine needles (27 mg, 7%) of racemic *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-D,L-*xylo*-hexulopyranosonate, m.p. 169–169.5°, $[\alpha]_D^{27}$ 0° (dimethyl sulfoxide); ^{1}H-n.m.r. spectrum identical with those of **6** and **8**. A mixed m.p. with the racemate obtained analogously from **2** showed no depression (m.p. 169–170°).

The acetone mother liquor from the crystallization of the racemate was evaporated to give *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-D-*xylo*-hexulopyranosonate (**6**) as a syrup (102 mg, 25%) that crystallized spontaneously, m.p. 85–87°, $[\alpha]_D^{27}$ +24° (*c* 0.52, dimethyl sulfoxide); $\nu_{\max}^{\mathrm{CHCl_3}}$ 3430 (br. hydrogen-bonded OH and NH), 1725 (C=O stretch, ester), and 1670 cm^{-1} (C=O stretch, monosubstituted amide); ^{1}H-n.m.r.: δ 7.82 (d, 1 H, $J_{5,\mathrm{NH}}$ 7.8 Hz, NH), 6.57 (d, 1 H, $J_{3,\mathrm{OH}}$ 1.7 Hz, OH), 4.90 (d, $J_{4,\mathrm{OH}}$ 6.8 Hz, OH), 3.91 (ddd, 1 H, $J_{3,4} = J_{4,5} = 10.2$, $J_{4,\mathrm{OH}}$ 6.8 Hz, H-4), 3.62 (dddd, 1 H, $J_{4,5} = J_{5,6'} = 10.2$, $J_{5,\mathrm{NH}}$ 7.8, $J_{5,6}$ 5.1 Hz, H-5), 3.46 (dd, 1 H, $J_{5,6}$ 5.1, $J_{6,6'}$ 10.5 Hz, H-6), 3.35 (dd, 1 H, $J_{5,6'}$ 10.2, $J_{6,6'}$ 10.5 Hz, H-6'), 2.74 (dd, 1 H, $J_{3,\mathrm{OH}}$ 1.7, $J_{3,4}$ 10.2 Hz, H-3), 1.81 (s, 3 H, N-Ac), 1.46 and 1.36 [2 s, 18 H, 2 $(CH_3)_3C)$].

Anal. Calc. for $C_{17}H_{29}NO_8$: mol.wt., 375.1893. Found: mol.wt. (m.s., *m/z*): 375.1907.

*2-Acetamido-2-deoxy-*L*-glyceraldehyde* (**2**). — An aqueous solution (15 mL) of 2-acetamido-2-deoxy-D-glucitol[16] (**4**) (500 mg, 2.24 mmol) was treated for 10 min at room temperature with HIO_4 (1.5 g, 6.57 mmol). After processing and purification as described for the D-enantiomer, **2** was obtained as a colorless, viscous syrup (241 mg, 84%); $[\alpha]_D^{27}$ −18° (*c* 1.0, methanol); i.r. and ^{1}H-n.m.r. spectra were identical with those of **1**. Because of its instability, this product was immediately used for aldol condensation, without further characterization.

Condensation of 2-acetamido-2-deoxy-L-glyceraldehyde (**2**) *with di-*tert*-butyl oxaloacetate*. — To a solution of **2** (241 mg, 1.84 mmol) in anhydrous methanol (2 mL) was added di-*tert*-butyl oxaloacetate (250 mg, 0.98 mmol), and the pH of the solution was adjusted to ~12.0 by adding 0.5M sodium methoxide in anhydrous methanol (~1.9 mL). After the reaction mixture had been kept for 1 h at room temperature, Dowex-50W (H^+) cation-exchange resin was added, and processing and purification were performed as described for the reaction of **1**. *tert*-Butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-L-*arabino*-hexulopyranosonate (**7**) was isolated as a colorless syrup (29 mg, 8%) which rapidly crystallized from diisopropyl ether to give colorless plates (21 mg, 6%), m.p. 129–131.5°, $[\alpha]_D^{27}$ +22° (*c* 0.3, chloroform); i.r. and ^{1}H-n.m.r. spectra were identical with those of **5**.

The semicrystalline mass (109 mg, 30%) obtained from the column by further elution gave, on trituration with acetone, racemic *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-D,L-*xylo*-hexulopyranosonate (46 mg, 13%) as white needles, m.p. 171–172°, $[\alpha]_D^{27}$ 0° (dimethyl sulfoxide); i.r. and ^{1}H-n.m.r. spectra were identical with those of **6** and **8**.

On evaporation, the mother liquor from the racemate gave a material (63 mg, 17%) that did not crystallize from diisopropyl ether but, after several days at room temperature, formed small plates of *tert*-butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-L-*xylo*-hexulopyranosonate (**8**), m.p. 83–85°, $[\alpha]_D^{27}$ −24° (*c* 0.4, dimethyl sulfoxide); i.r. and ^{1}H-n.m.r. spectra were identical with those of **6**.

Racemic tert-*butyl 5-acetamido-3-*tert*-butoxycarbonyl-3,5-dideoxy-*D,L-xylo-*hexulopyranosonate* (**6** + **8**). — When 10-mg samples of **6** and **8**, each dissolved in acetone (0.5 mL), were mixed, the racemate (18 mg) precipitated immediately. The analytical sample was obtained by recrystallization from acetone, m.p. 168–170°.

Anal. Calc. for $C_{17}H_{29}NO_8 \cdot H_2O$: C, 51.90; H, 7.94. Found: C, 52.22; H, 7.98.

The water of crystallization is apparently held by the sugar molecule very strongly as we were not able to remove it completely even after drying for one week in a high vacuum at 50°.

Anal. Calc. for $C_{17}H_{29}NO_8$: C, 54.39; H, 7.79. Found: C, 53.89; H, 7.45.

REFERENCES

1 H. E. Zimmerman and M. D. Traxler, *J. Am. Chem. Soc.*, 79 (1957) 1920–1923.
2 D. Ivanoff and A. Spassoff, *Bull. Soc. Chim. Fr.*, 49 (1931) 19–23; 371–375; 375–377; 377–379.
3 J. E. Dubois and P. Fellmann, *Tetrahedron Lett.*, (1975) 1225–1228.

4 J. E. Dubois and P. Fellmann, *C.R. Acad. Sci.*, 274 (1972) 1307–1309.
5 J. Mulzer, J. Segner, and G. Bruntrup, *Tetrahedron Lett.*, (1977) 4651–4654.
6 D. A. Evans, J. V. Nelson, and T. R. Taber, *Top. Stereochem.*, 13 (1982) 1–115; S. Masamune and W. Choy, *Aldrichimica Acta*, 15 (1982) 47–63; T Mukaiyama, *Org. React.*, 28 (1982) 203–331; C. H. Heathcock, *Science*, 214 (1981) 395–400; Z. G. Hajos, in R. L. Augustine (Ed.), *Carbon–Carbon Bond Formation*, Vol. 1, Marcel Dekker, New York, 1979, pp 1–84; C. H Heathcock, in J A. Morrison (Ed.), *Asymmetric Synthesis*, Vol. 3, Academic Press, New York, 1984, pp. 111–212.
7 S. Masamune, M. Hirama, S. Mori, S. A. Ali, and D. S. Garvey, *J. Am. Chem. Soc.*, 103 (1981) 1568–1571.
8 S. Masamune, L D.-L. Lu, W. P. Jackson, T. Kaiho, and T. Toyoda, *J. Am. Chem. Soc.*, 104 (1982) 5523–5526.
9 A. B. Foster and D. Horton, *J. Chem. Soc.*, (1958) 1890–1894.
10 S. A. Barker, A. B. Foster, M. Stacey, and J. M. Webber, *J. Chem. Soc.*, (1958) 2218–2227.
11 S. Honda, K. Kakehi, and K. Mukai, *Anal. Chim Acta*, 111 (1979) 227–234.
12 M. Cherest, H. Felkin, and N. Prudent, *Tetrahedron Lett.*, (1968) 2199–2204.
13 M. Cherest and H. Felkin, *Tetrahedron Lett.*, (1968) 2205–2208.
14 N. T. Anh and O. Eisenstein, *Nouv. J. Chim.*, 1 (1977) 61–70.
15 W. Roth, W. Pigman, and I. Danishefsky, *Tetrahedron*, 20 (1964) 1675–1677
16 P. D Bragg and L. Hough, *J. Chem. Soc.*, (1957) 4347–4352.