Synthesis and Nuclear Magnetic Resonance Studies of Some *N*-Acylated Methyl 4-Amino-4,6-dideoxy-α-D-mannopyranosides

Lennart Kenne, Per Unger, and Thomas Wehler
Department of Organic Chemistry, University of Stockholm, Arrhenius Laboratory, S-106 91 Stockholm, Sweden

The methyl α-glycosides of 4-amino-4,6-dideoxy-D-mannopyranose (perosamine), *N*-acylated with either formic, acetic, or (*S*)-2,4-dihydroxybutanoic acid, have been synthesized. The ^1H and ^{13}C n.m.r. spectra of these substances and the parent, non-*N*-acylated glycoside, demonstrated how the chemical shifts are influenced by the *N*-acylation. The *N*-formyl derivative occurred in two conformations, s-*cis* and s-*trans*, and the free-energy barrier between these, 86.9 kJ mol^{-1}, was defined by dynamic n.m.r. spectroscopy.

The O-specific side-chains in the lipopolysaccharides from *Vibrio cholerae* 0:1,[1] *Brucella abortus* 1119–3,[2] and *Yersinia enterocolitica* serotype 0:9[3] are homopolysaccharides, composed of 4-amino-4,6-dideoxy-D-mannose (perosamine) residues. These are linked through O-2 and connected by α-pyranosidic linkages. They are further *N*-acylated with (*S*)-2,4-dihydroxybutanoic acid in the *V. cholerae* polysaccharide and with formic acid in the two others. In structural studies of these polysaccharides, n.m.r. spectroscopy was the main tool. In order to take full advantage of this method, chemical shifts for differently substituted sugars and rules for substituent effects should be available. We have now synthesized these *N*-acylated methyl 4-amino-4,6-dideoxy-α-D-mannopyranosides and studied them by ^1H and ^{13}C n.m.r. spectroscopy.

Results and Discussion

Methyl 4-amino-4,6-dideoxy-α-D-mannopyranoside (**3**) has been prepared from methyl 3,4-anhydro-6-deoxy-α-D-talopyranoside *via* the 4-azido-4,6-dideoxy-α-D-mannopyranoside (**2**).[4] We have now prepared it from methyl α-D-rhamnopyranoside, which was transformed into the 4-bromo-4,6-dideoxy-α-D-talopyranoside (**1**) by the method of Classon *et al.*[5] Treatment with sodium azide gave the 4-azido-4,6-dideoxy-α-D-mannoside (**2**), which on hydrogenation yielded the amine (**3**). This glycoside was *N*-acylated to the *N*-formyl, *N*-acetyl, and *N*-[(*S*)-2,4-dihydroxybutanoyl] derivatives, the latter by reaction with the γ-lactone of the corresponding acid. This acid, previously prepared by other methods,[6,7] was prepared by deamination of L-homoserine, a type of reaction known to proceed with retention of configuration.[8]

It was evident from the ^1H and ^{13}C n.m.r. spectra of the *N*-formyl derivative that it was a mixture of the s-*cis*-(**4a**) and s-*trans*-(**4b**) conformers in the ratio 7:3. In the s-*trans*-conformer, the formyl proton is always close to at least one of the ring protons or 6-H_3, resulting in a short relaxation time, 1.6 s. In the s-*cis*-conformation, the formyl proton is directed away from the ring, resulting in a longer relaxation time, 4.7 s. A long-range coupling (^4J 0.6 Hz) between the formyl proton and 4-H in the s-*cis*-form may indicate a W-arrangement and the occurrence of conformer (**4a'**) in addition to (**4a**).

^{13}C N.m.r. studies of *N*-formylneuraminic acid have indicated a ratio of 85:15 between the s-*cis*- and the s-*trans*-forms.[9]

Calculation of the free-energy barrier between rotamers (**4a**) and (**4b**) was performed using a two-site-exchange bandshape analysis and Eyring's equation as described by Sandström.[10] The bandshape was adjusted for signals obtained in the temperature interval 115—145 °C, in which coalescence of the signals for the formyl proton occurred. Values for the free-energy barrier ($\Delta G^{\ddagger}$) of 86.9 ± 0.8 kJ mol^{-1} (130 °C) and differences in Gibbs' free energy ($\Delta G°$) of 2.6 ± 0.2 kJ mol^{-1} (115 °C) were obtained from the calculations. Extrapolation by an Arrhenius plot gave a rate constant of *ca.* 2 × 10^{-2} s^{-1} at

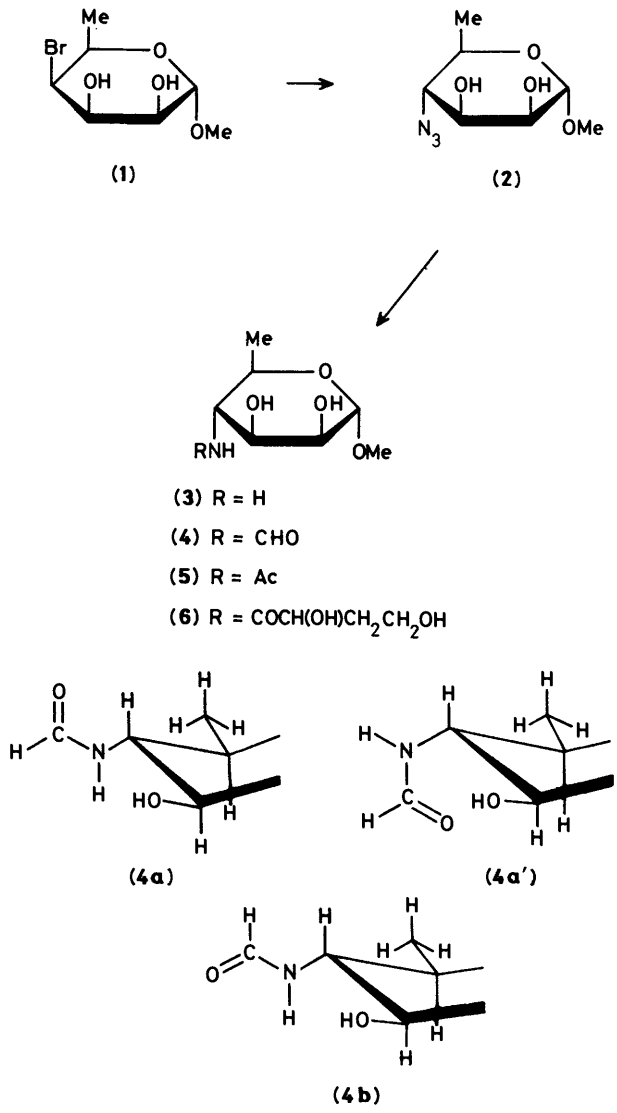

Table 1. ^{13}C N.m.r. chemical shifts[a] of methyl 4-amino-4,6-dideoxy-α-D-mannopyranoside (**3**) and the glycoside *N*-acylated with formic (**4a**), (**4b**), acetic (**5**), and (*S*)-2,4-dihydroxybutanoic acid (**6**). Chemical-shift differences[b] are given in parentheses

Compound	C-1	C-2	C-3	C-4	C-5	C-6	OMe	C-1′[c]	C-2′	C-3′	C-4′
(**3**)[d]	101.92	70.96	70.02	54.62	69.48	17.78	55.51				
(**4a**)	101.70	69.94	69.05	52.79	67.70	17.69	55.60	165.60			
	(−0.22)	(−1.02)	(−0.97)	(−1.83)	(−1.78)	(−0.09)	(0.09)				
(**4b**)	101.70	69.64	68.86	57.49	67.58	17.52	55.64	168.52			
	(−0.22)	(−1.32)	(−1.16)	(2.87)	(−1.90)	(−0.26)	(0.13)				
(**5**)	101.71	69.99	69.31	53.89	68.26	17.65	55.60	175.33	23.05		
	(−0.21)	(−0.97)	(−0.71)	(−0.73)	(−1.22)	(−0.13)	(0.09)				
(**6**)	101.75	70.14	68.97	53.81	68.05	17.67	55.59	177.81	70.09	36.81	58.88
	(−0.17)	(−0.82)	(−1.05)	(−0.81)	(−1.43)	(−0.11)	(0.08)				

[a] Chemical shifts are given in p.p.m. relative to internal dioxane (δ_C 67.40). Spectra are obtained at 70 °C. [b] Chemical-shift differences were calculated by subtraction of chemical shifts of (**3**) from those of *N*-acylated derivative; a positive difference indicates a downfield shift. [c] Primed labels refer to the acyl group. [d] Spectra obtained at pD 8.7.

Table 2. ^{13}C N.m.r. chemical-shift differences from variation in temperature[a] ($\Delta\delta_C$ in p.p.m.)

Compound	C-1	C-2	C-3	C-4	C-5	C-6	OMe	C-1′	C-2′	C-3′	C-4′
(**3**)[d]	0.02	0.19	0.07	0.13	0.10	0.01	0.02				
(**4a**)	0.05	0.14	0.13	0.17	−0.01	0.04	0.01	−0.04			
(**4b**)	0.05	0.14	0.13	−0.04	0.08	0.01	*b*	−0.09			
(**5**)	0.04	0.12	0.12	0.10	0.01	0.03	0.01	−0.09	0.02		
(**6**)	0.05	0.16	0.20	0.14	0.03	0.05	0.03	−0.25	0.25	0.04	0.20

[a] $\Delta\delta_C = \delta_C$ (70 °C) − δ_C (30 °C). Dioxane was taken as δ_C 67.40 for both temperatures. [b] Signal could not be observed in the spectrum obtained at 70 °C.

30 °C, which corresponds to a half-life of 30 s, indicating that the rate of exchange between the *N*-formyl conformations could be of relevance for the immunological properties of polysaccharides containing such groups.

^{13}C N.m.r. Chemical Shifts.—^{13}C N.m.r. data for compounds (**3**)—(**6**) are given in Table 1. This Table also contains the chemical-shift differences obtained by comparing values for the acylated derivatives (**4**)—(**6**) with those for compound (**3**). The shift differences show that *N*-acylation has a large influence on the chemical shifts of the carbon substituted with the nitrogen, C-4, and the two neighbouring carbons, C-3 and C-5. In addition to this, the axially hydroxylated C-2, being in a 1,3-position to the substitution, is shielded by *ca.* 1 p.p.m. The shifts are similar for compounds (**4a**), (**5**), and (**6**) but differ for (**4b**), due to the different conformation of the acyl group. The largest variation of the substituent shifts is observed for the *N*-substituted C-4, with deshielding of C-4 in (**4b**) but shielding in the others, the strongest effect being observed for (**4a**). C-5 Is somewhat more shielded than C-3 in all of these compounds.

N-Acylation of compound (**3**) causes shielding of the adjacent carbons by 0.7—1.9 p.p.m. in all compounds. For the substituted carbons a shielding by 0.7—1.8 p.p.m. is obtained for all compounds but (**4b**), where a large deshielding by 2.9 p.p.m. is observed. This downfield shift is in agreement with the effects shown for *O*-acetylation,[11] where the substituted carbons are deshielded by 0.7—3.5 p.p.m.

Differences in chemical shift of the carbonyl carbon are observed with the most deshielded carbon for the largest acyl group. A difference of 3 p.p.m. is observed for the signals of the carbonyl carbon of the two different formyl conformations. The shielding of the carbonyl carbon and C-4 in (**4a**) in comparison with (**4b**) is probably caused by the steric interaction between the carbonyl oxygen and 4-H, which have a *syn* relationship. Czarniecki and Thornton[9] showed that the chemical-shift difference between the s-*cis*- and s-*trans*-conformers of *N*-formylneuraminic acid was 4.6 p.p.m. for C-5, 0.2 p.p.m. for the adjacent carbons, and 2.9 p.p.m. for the carbonyl carbon. Similar chemical-shift differences were also observed for rotamers (**4a**) and (**4b**).

The coupling constants, $^1J_{CH}$, for the carbonyl carbon also differ and are 196.6 and 200.2 Hz for (**4a**) and (**4b**), respectively.

Chemical-shift Differences on Variation of Temperature.—Temperature shifts have been used for the assignment of signals in ^{13}C n.m.r. spectra of oligosaccharides[12] and for information on conformation and hydrogen bonds.[13] Temperature shifts for compounds (**3**)—(**6**) are given in Table 2. Increasing the temperature from 30 to 70 °C caused deshielding of all carbons carrying an OH or NH_2 group. The magnitude of the shifts was 0.07—0.20 p.p.m., with the majority being *ca.* 0.15 p.p.m. For the other carbons the temperature-induced shift differences varied from an upfield shift of 0.01 to a downfield shift of 0.10 p.p.m. Both extremes were observed for C-5. In the 2,4-dihydroxybutanoyl group the same general pattern was observed but the numerical values were somewhat higher, which could be due to the enhanced mobility of this acyl group at higher temperature.

^1H N.m.r. Chemical Shifts.—^1H N.m.r. data of compounds (**3**)—(**6**) are given in Table 3. Acylation or increased temperature did not change the *J*-values, indicating that the conformation of the sugars was not significantly altered.

N-Acylation caused deshielding of almost all ring protons of the methyl 4-amino-4,6-dideoxy-α-D-mannopyranosides. The largest effect was observed for 4-H. The adjacent 3-H and 5-H were deshielded 0.10—0.25 p.p.m., with the strongest effect on 3-H in all compounds but (**4b**). The exocyclic 6-protons were slightly shielded by the substituents. The results are in agreement with the substituent shifts reported for *O*-acetylated methyl gluco- and galacto-pyranosides.[11]

The formyl proton and 4-H in the s-*cis*-form (**4a**) were more deshielded (0.13 and 0.55 p.p.m., respectively) than the corresponding protons in the s-*trans*-form (**4b**). Interaction of the *syn*-

Table 3. ^{1}H N.m.r. chemical shifts[a] of methyl 4-amino-4,6-dideoxy-α-D-mannopyranoside (**3**) and the *N*-acylated glycoside with formic (**4a**), (**4b**), acetic (**5**), and (*S*)-2,4-dihydroxybutanoic acid (**6**). Coupling constants[b] are given in brackets and chemical-shift differences[c] in parentheses

Compound	1-H	2-H	3-H	4-H	5-H	6-H_3	OMe	1′-H[d]	2′-H	3′-H_2	4′-H_2
(**3**)[e]	4.716 [1.7]	3.874 [3.4]	3.635 [10.3]	2.774 [9.8]	3.644 [6.2]	1.292	3.401				
(**4a**)	4.753 [1.8]	3.945 [3.4]	3.83[f] [10.5]	3.90[f] [10.3]	3.79[f] (6.2)	1.234	3.405	8.200 [0.6]			
	(0.037)	(0.071)	(0.19)	(1.13)	(0.15)	(−0.058)	(0.004)				
(**4b**)	4.748 [1.8]	3.963 [3.3]	3.799[g] [10.3]	3.356 [10.3]	3.822[g] [6.3]	1.282	3.409	8.031			
	(0.032)	(0.089)	(0.164)	(0.582)	(0.178)	(−0.010)	(0.008)				
(**5**)	4.730 [1.6]	3.928 [3.6]	3.799[f] [10.5]	3.83[f] [10.5]	3.74[f] [6.2]	1.203	3.404		2.035		
	(0.014)	(0.054)	(0.15)	(1.06)	(0.10)	(−0.089)	(0.003)				
(**6**)	4.743 [1.9]	3.93[f] [3.1]	3.89[f] [10.4]	3.86[f] [10.1]	3.83[f] [6.2]	1.202[h]	3.409		4.284 [4.3, 8.3]	2.039 [7.2, 14.3]	3.743
	(0.027)	(0.06)	(0.25)	(1.09)	(0.19)	(−0.090)	(0.008)			1.887 [5.9]	

[a] Chemical shifts are given in p.p.m. relative to internal sodium 4,4-dimethyl-4-silapentane-1-sulphonate (δ_H 0.000). Spectra were obtained at 30 °C. [b] Digital resolution was 0.1 Hz. [c] Chemical-shift differences were calculated by subtraction of chemical shifts of (**3**) from those of *N*-acylated derivative; a positive difference indicates a downfield shift. [d] Primed labels refer to the acyl group. [e] Spectra obtained at pD 8.7. [f] Chemical shifts and coupling constants were calculated by a spin simulation/iteration program and are given to two decimal places. [g] Chemical shifts were obtained from the cross-peaks in the COSY spectrum. [h] This signal was distorted due to virtual coupling.

oriented carbonyl oxygen and the axially oriented 4-H in (**4a**) could be a possible explanation for this result.

Comparison of substituent shifts for the signals of 3-H and 5-H with those for signals of C-3 and C-5 in (**4a**), (**5**), and (**6**) shows that an upfield shift of carbon signals is accompanied by a downfield shift of the corresponding proton signals. This could be due to enhanced bond polarization that has been described by Koch and Perlin.[14]

Experimental

General Methods.—Concentrations were performed under reduced pressure at a bath temperature < 50 °C. I.r. spectra were obtained for chloroform solutions on a Perkin-Elmer 257 spectrometer. N.m.r. spectra were recorded at 400 MHz (^{1}H) and 100 MHz (^{13}C) on a JEOL GX-400 instrument. Spectra were obtained for solutions in D_2O, with sodium 4,4-dimethyl-4-silapentane-1-sulphonate (δ_H 0.000) and dioxane (δ_C 67.40) as internal references for all temperatures. The digital resolution for ^{1}H and ^{13}C spectra was 0.1 Hz and 0.6 Hz, respectively. Light petroleum refers to the fraction boiling in the range 60—71 °C.

N.m.r. Experiments.—For complete assignment of ^{13}C-signals two-dimensional C–H shift-correlation spectroscopy was performed using a 1 024 × 256 data matrix, where the t_1 dimension was zero-filled once before the Fourier transformation. The frequency range was 1.3 kHz and 5.5 kHz in the f_1 and f_2 dimensions, respectively. The delays Δ_1 and Δ_2 were 3.6 ms and 1.8 ms, respectively. Resolution enhancement was performed by a trapezoidal function in both dimensions.

A COSY spectrum was used for the assignment of the overlapping resonances in compound (**4**). A total of 128 experiments, each consisting of 512 data points, was accumulated and zero-filled into 256 data points, with a frequency range of 700 Hz, containing resonances of the ring protons. The FIDs were multiplied by a non-shifted sinebell function.

Spin–lattice relaxation times (T_1) were measured by the inversion-recovery method and calculated with a three-parameter non-linear fit. The sample was not degassed.

Dynamic ^{1}H n.m.r. spectroscopy of methyl 4,6-dideoxy-4-formamido-α-D-mannopyranoside (**4**) was performed for solutions in $(CD_3)_2SO$ in the temperature range 25—180 °C. Spectra were obtained for the *N*-formyl protons at ten different temperatures. For calculation for the free-energy barrier a computer program for two-site-exchange bandshape analysis was used.[10]

The chemical shifts and coupling constants of the signals in the strongly coupled spin-systems, 3-H, 4-H, 5-H in (**4**) and (**5**), and 2-H, 3-H, 4-H, 5-H in (**6**), were analysed by spin-simulation and iteration of the signals, using the INMGX-COMIC-2 program, available in the GX software. The results were compared with ^{1}H n.m.r. spectra obtained with decoupling of the 6-protons at 30 °C.

Methyl 4-*Bromo*-4,6-*dideoxy*-α-D-*talopyranoside* (**1**).—2,4,5-Tribromoimidazole (8.6 g, 28.1 mmol) and triphenylphosphine (7.4 g, 28.1 mmol) were added to a solution of methyl 6-deoxy-α-D-mannopyranoside (2.0 g, 11.2 mmol) in a mixture of acetonitrile (40 ml) and toluene (80 ml). The reaction mixture was kept at 70 °C for 1 h and then at 90 °C for 5 h. After cooling to room temperature the mixture was filtered, the filtrate was concentrated to dryness, and the product was purified by chromatography on a column of silica gel (37 × 6.5 cm) eluted with ethyl acetate–toluene (1:2). Crystallization of the residue from toluene–light petroleum gave compound (**1**) (1.4 g, 52%), m.p. 83—85 °C; $[\alpha]_D^{22}$ +56° (*c* 0.11 in water); $\delta_H(D_2O$; 50 °C) 4.811 (1-H, $J_{1,2}$ 1.5 Hz), 3.819 (2-H, $J_{2,3}$ 4.0 Hz), 4.057 (3-H, $J_{3,4}$ 4.1 Hz), 4.384 (4-H, $J_{4,5}$ 1.8 Hz), 4.076 (5-H, $J_{5,6}$ 6.3 Hz), 1.357 (6-H_3), and 3.402 (OMe); $\delta_C(D_2O$; 70 °C) 102.42 (C-1), 69.60 (C-2), 66.21 (C-3), 59.46 (C-4), 65.96 (C-5), 19.79 (C-6), and 55.68 (OMe).

Methyl 4-*Azido*-4,6-*dideoxy*-α-D-*mannopyranoside* (**2**).—15-Crown-5 (0.41 g, 1.9 mmol) and sodium azide (0.12 g, 1.8 mmol) were dissolved in hot *N*,*N*-dimethylformamide (DMF) (15 ml). Methyl 4-bromo-4,6-dideoxy-α-D-talopyranoside (**1**) (0.23 g, 0.9 mmol) was added to the cooled mixture, which was kept at 60 °C overnight. After concentration to dryness, the mixture was separated on a column of silica gel (23 × 3 cm) eluted with ethyl acetate–toluene (2:1). Crystallization of the residue from toluene–light petroleum gave compound (**2**) (80 mg, 42%), which decomposed at 82—83 °C; $[\alpha]_D^{22}$ +85° (*c* 0.3 in water); $\nu_{max.}(CHCl_3)$ 2 117 cm^{-1}; $\delta_H(D_2O$; 50 °C) 4.723 (1-H, $J_{1,2}$ 1.7 Hz), 3.924 (2-H, $J_{2,3}$ 3.4 Hz), 3.816 (3-H, $J_{3,4}$ 10.0 Hz), 3.381 (4-H, $J_{4,5}$ 10.0 Hz), 3.664 (5-H, $J_{5,6}$ 6.2 Hz), 1.358 (6-H_3), and 3.390 (OMe); $\delta_C(D_2O$; 70 °C) 101.74 (C-1), 70.21 (C-2), 70.25 (C-3), 65.72 (C-4), 67.90 (C-5), 18.19 (C-6), and 55.62 (OMe).

Methyl 4-*Amino*-4,6-*dideoxy*-α-D-*mannopyranoside* (**3**).—The azido compound (**2**) (0.12 g) in ethanol (10 ml) was

hydrogenated under pressure (50 atm) in the presence of 10% Pd–carbon (50 mg) at 22 °C for 3 h. The catalyst was filtered off, the filtrate was concentrated to dryness, and the residue was crystallized from ethanol–diethyl ether to yield pure compound (**3**) (0.1 g, 96%), m.p. 142—143 °C; $[\alpha]_D^{23}$ +73° (*c* 0.2 in water).

Methyl 4,6-*Dideoxy*-4-*formamido*-α-D-*mannopyranoside* (**4**).—Acetic formic anhydride[15] (1 ml) was added to a solution of compound (**3**) (64.4 mg, 0.36 mmol) in a mixture of DMF (0.1 ml) and diethyl ether (1 ml). After 5 min at 22 °C the solution was made alkaline with aqueous 2M sodium hydroxide. The product was purified by concentration to dryness and chromatography on a column of silica gel (20 × 1 cm) eluted with ethyl acetate–methanol–water (85:10:5), to yield pure compound (**4**) (61.4 mg; 82%), $[\alpha]_D^{22}$ +52° (*c* 0.2 in water).

Methyl 4-*Acetamido*-4,6-*dideoxy*-α-D-*mannopyranoside* (**5**).—The free amine (**3**) (67 mg, 0.38 mmol) was treated with pyridine (2 ml) and acetic anhydride (2 ml) at 22 °C for 5 h. Aqueous sodium hydroxide (2 ml; 0.3M) was then added and the solution was left overnight to remove *O*-acetyl groups. The mixture was concentrated to dryness, and the product crystallized from toluene–iso-octane(2,2,4-trimethylpentane) to (**5**) (73 mg; 87%), m.p. 183—185 °C; $[\alpha]_D^{22}$ +66° (*c* 0.3 in water).

(S)-2-*Hydroxy*-γ-*butyrolactone*.—L-Homoserine (1.0 g, 9.5 mmol) was dissolved in aqueous 3M acetic acid (30 ml). The solution was cooled to 0 °C and a solution of sodium nitrite (1.7 g, 20 mmol) in water (10 ml) was added in small portions during 1 h. After a further 2 h the solution was degassed under reduced pressure for 30 min and then concentrated to dryness. The residue was dissolved in water, then passed through a Dowex 50 (H^+) column (30 × 2 cm). The eluate was concentrated to dryness, to afford a crude mixture of (*S*)-2,4-dihydroxybutanoic acid and the γ-lactone (0.93 g; 1:4). The optical purity of the product was established by g.l.c.–m.s. of the acetylated (−)-2-octanyl ester derivative.[16] $\delta_C(D_2O;$ 30 °C) (lactone) 178.6 (C-1), 68.0 (C-2), 67.2 (C-4), and 31.4 (C-3); $\delta_C(D_2O;$ 30 °C) (acid) 181.0 (C-1), 68.3 (C-2), 58.5 (C-4), and 36.5 (C-3).

Methyl 4,6-*Dideoxy*-4-[(S)-2,4-*dihydroxybutanamido*]-α-D-*mannopyranoside* (**6**).—Compound (3) (46 mg) was heated with pyridine (3 ml) and the lactone–acid mixture (100 mg) at 100 °C for 16 h. The reaction mixture was concentrated to dryness and separated on a column of silica gel (14 × 2.5 cm) eluted with ethyl acetate–methanol–water (85:10:5), to yield compound (**6**) (33 mg, 45%), $[\alpha]_D^{23}$ +34° (*c* 2.1 in water).

Acknowledgements

We thank Professor Jan Sandström and Docent Ulf Berg for valuable help and making the computer program for bandshape analysis available. This work was supported by grants from the Swedish Natural Science Research Council and the Swedish Technical Board for Development.

References

1 L. Kenne, B. Lindberg, P. Unger, B. Gustafsson, and T. Holme, *Carbohydr. Res.*, 1982, **100**, 341.
2 M. Caroff, D. R. Bundle, M. B. Perry, J. W. Cherwonogrodzky, and J. R. Duncan, *Infect. Immun.*, 1984, **46**, 384.
3 M. Caroff, D. R. Bundle, and M. B. Perry, *Eur. J. Biochem.*, 1984, **139**, 195.
4 C. L. Stevens, R. P. Glinski, K. G. Taylor, P. Blumbergs, and S. K. Gupta, *J. Am. Chem. Soc.*, 1970, **92**, 3160.
5 B. Classon, P. J. Garegg, and B. Samuelsson, *Can. J. Chem.*, 1981, **59**, 339.
6 J. W. E. Glattfeld and F. V. Sander, *J. Am. Chem. Soc.*, 1921, **43**, 2675.
7 L. J. Altman, C. Y. Han, A. Bertolino, G. Handy, D. Lanngani, W. Muller, S. Schwartz, D. Shanker, W. H. deWolt, and F. Yang, *J. Am. Chem. Soc.*, 1978, **100**, 3235.
8 P. Brewster, F. Hiron, E. D. Hughes, C. K. Ingold, and P. A. O. S. Rao, *Nature*, 1950, **166**, 179.
9 M. F. Czarniecki and E. R. Thornton, *J. Am. Chem. Soc.*, 1977, **99**, 8279.
10 J. Sandström, 'Dynamic NMR Spectroscopy,' Academic Press, London, 1982.
11 P. E. Jansson, L. Kenne, and E. Schweda, *J. Chem. Soc., Perkin Trans. 1*, 1987, 377.
12 M. Forsgren, P. E. Jansson, and L. Kenne, *J. Chem. Soc., Perkin Trans. 1*, 1985, 2383.
13 K. Bock and R. U. Lemieux, *Carbohydr. Res.*, 1982, **100**, 63.
14 H. J. Koch and A. S. Perlin, *Carbohydr. Res.*, 1970, **15**, 397.
15 L. I. Krimer, *Org. Synth.*, 1970, **50**, 1.
16 D. G. Streefkerk, M. J. A. deBie, and J. F. G. Vliegenthart, *Carbohydr. Res.*, 1974, **33**, 339.

Received 12*th June* 1987; *Paper* 7/1036