Synthesis and Characterization of Furanose and Pyranose Derivatives of 3-Deoxy-D-*glycero*-D-*galacto*-2-nonulosonic Acid (KDN)[1,2]

Mitsunobu NAKAMURA, Hiroaki TAKAYANAGI, Kimio FURUHATA and Haruo OGURA*

School of Pharmaceutical Sciences, Kitasato University, Shirokane, Minato-ku, Tokyo 108, Japan. *Received September 25, 1991*

The products of Fischer's methyl glycosylation of 3-deoxy-D-*glycero*-D-*galacto*-2-nonulosonic acid (KDN) revealed existence of an the anomeric equilibrium between α,β-furanose and α,β-pyranose of KDN. In spite of the anomeric equilibrium, peracetylation of KDN and its derivatives by acetic anhydride with pyridine gave only α- and β-pyranose derivatives. The obtained methyl glycosides and hexa-*O*-acetyl derivatives were characterized by X-ray, nuclear magnetic resonance and circular dichroism spectral analyses.

Keywords KDN; anomeric equilibrium; furanose; X-ray crystal analysis; ^{1}H-NMR

An anomeric equilibrium among possible structural isomers of monosaccharides is widely recognized as being important in monosaccharide chemistry. Three types of ulosonic acid occur in nature (Fig. 1), and the anomeric equilibria of *N*-acetylneuraminic acid (Neu5Ac) and 3-deoxy-D-*manno*-2-octulosonic acid (KDO) have been revealed. Neu5Ac in solution comes to equilibrium between α-pyranose and β-pyranose,[3] but the furanose type of Neu5Ac is absent owing to the acetamide moiety substituted at the C-5 position. KDO equilibrates between α,β-furanose and α,β-pyranose in solution. Stereoselective syntheses of furanose or pyranose derivatives of KDO have been achieved under various reaction conditions.[4,5] Since 3-deoxy-D-*glycero*-D-*galacto*-2-nonulosonic acid (KDN, **1**) was isolated from rainbow trout egg,[6] several *O*- and *N*-pyranosides of **1** have been synthesized.[7-10] Further study of the biological functions of **1** and Neu5Ac requires more complex derivatives of **1** and its isomers.

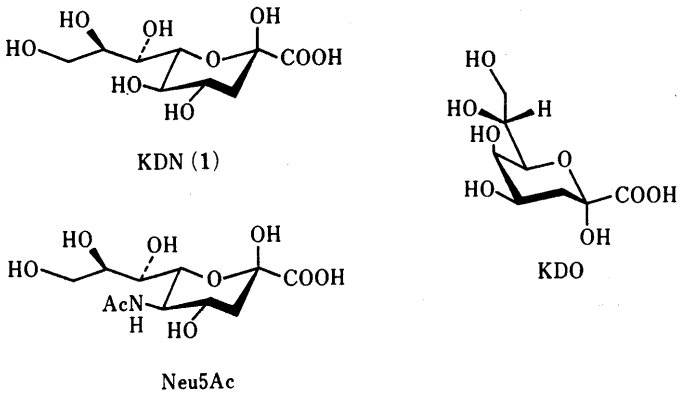


Fig. 1. Structures of KDN, Neu5Ac and KDO

Synthesis of such derivatives requires a knowledge of the anomeric equilibrium of **1**. In this paper, we wish to report the anomeric equilibrium between α,β-furanose and α,β-pyranose of **1**, as determined by examination of the products of Fischer's methyl glycosylation of the methyl ester of **1**. Peracetylation of **1** and its derivatives gave only α- and β-pyranose derivatives. These furanose and pyranose derivatives were characterized by X-ray, nuclear magnetic resonance (^{1}H-NMR) and circular dichroism (CD) spectral analyses.

^{1}H-NMR Spectrum of 1 ^{1}H-NMR measurement is a direct method for detecting the structural isomers of a monosaccharide in solution. We attempted to detect the furanose signal of **1** in the ^{1}H-NMR spectrum. Figure 2 shows the ^{1}H-NMR spectrum (1—3 ppm) of **1** in D_2O. Only the signals of α- and β-pyranose of **1** were observed ($\alpha:\beta=1:10$), and even when the ^{1}H-NMR spectrum of **1** was measured in acidic solution (DCl–D_2O) and basic solution (pyridine-d_5–D_2O), no furanose signal was observed.

Fischer's Methyl Glycosylation We chose Fischer's methyl glycosylation to reveal the anomeric equilibrium of **1** because it is a simple and poorly stereoselective reaction. Treatment of methyl 3-deoxy-D-*glycero*-D-*galacto*-2-nonulosonate (**3**) with the strong cation exchange resin Dowex-50 (H^+) in methanol afforded a mixture of methyl glycosides of **1**. We could not isolate each product from this mixture, so the mixture was acetylated, and methyl (methyl 4,6,7,8,9-penta-*O*-acetyl-3-deoxy-D-*glycero*-α- and -β-D-*galacto*-2-nonulofuranosid)onates (**4**, **5**) and methyl (methyl 4,5,7,8,9-penta-*O*-acetyl-3-deoxy-D-*glycero*-α- and -β-D-*galacto*-2-nonulopyranosid)onates (**6**, **7**) were isolated by chromatography (Chart 1). The ratio among these

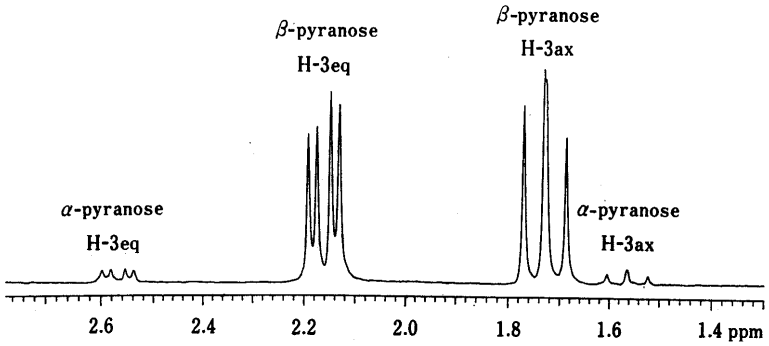


Fig. 2. ^{1}H-NMR Spectrum of **1**

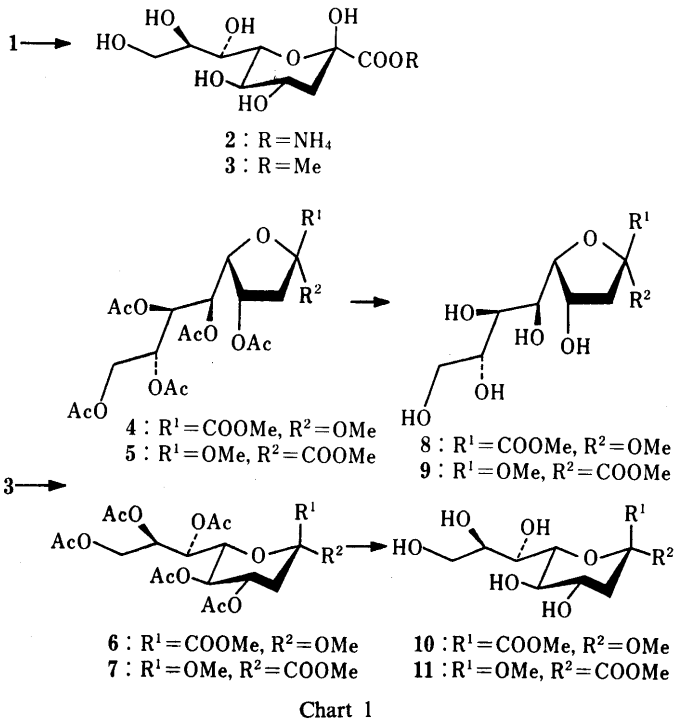


Chart 1

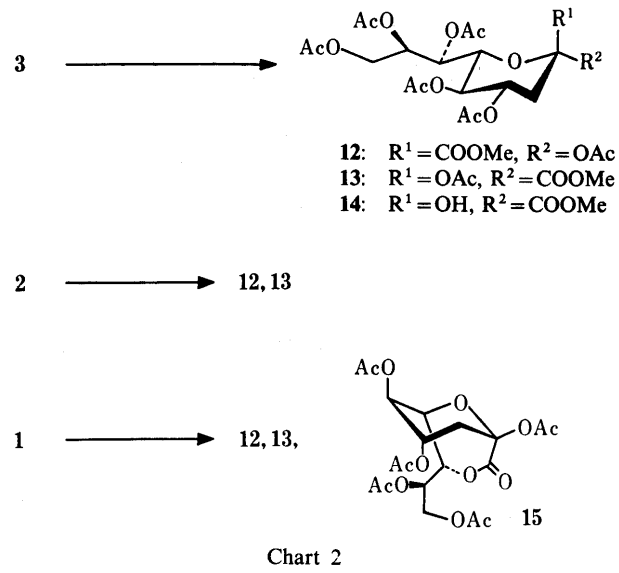


Chart 2

TABLE I

Run	Temp. (°C)	Time (h)	Yield (%) 4	5	6	7
1	20	240	32	48	0	5
2	70	1	21	39	1	16
3	70	3	15	33	2	27
4	70	5	2	4	5	67
5	70	15	0	0	4	74

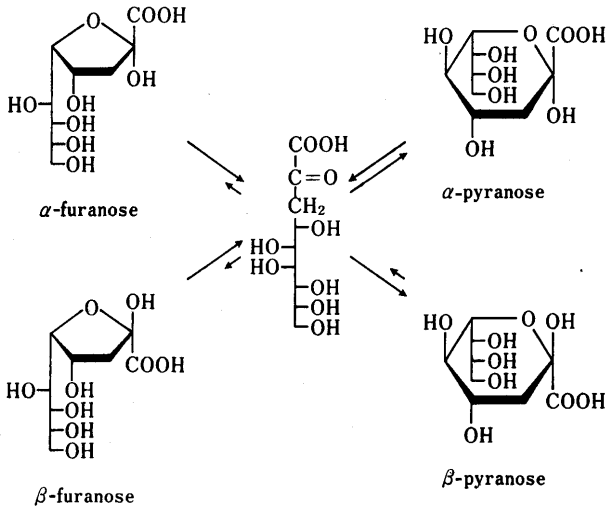


Fig. 3. Anomeric Equilibrium of **1**

glycosides varied depending upon the glycosylation conditions, as shown in Table I. When the glycosylation was run at 20 °C, α- and β-furanosides (**4, 5**) were mainly obtained (run 1). When the glycosylation was run at 70 °C for 15 h, β-pyranoside (**7**) was mainly obtained (run 5). These results indicated that the furanosides are formed by kinetic control and the pyranosides are formed by thermodynamic control. The anomeric equilibrium of **1** can be expressed as shown in Fig. 3.

TABLE II

Run	Temp. (°C)	Time (h)	Yield (%) 12	13	14
1	0	1	4	42	35
2	20	1	7	68	0
3	50	1	6	60	0
4	70	1	6	52	0

The obtained acetylated methyl glycosides **4**, **5**, **6** and **7** were deacetylated by K_2CO_3 in methanol to give methyl (methyl 3-deoxy-D-*glycero*-α- and -β-D-*galacto*-2-nonulofuranosid)onates (**8**, **9**) and methyl (methyl 3-deoxy-D-*glycero*-α- and -β-D-*galacto*-2-nonulopyranosid)onates (**10**, **11**) in quantitative yields, respectively.

Peracetylation of 1 and its Derivatives The hexa-*O*-acetylated pyranose derivatives of **1** were synthesized previously.[7,10] We attempted to synthesize hexa-*O*-acetylated derivatives of α- and β-furanose of **1** from three starting materials (Chart 2). Treatment of **3** with acetic anhydride and pyridine at various temperature (0—70 °C) afforded methyl 2,4,5,7,8,9-hexa-*O*-acetyl-3-deoxy-D-*glycero*-α- and -β-D-*galacto*-2-nonulopyranosonates (**12, 13**) and methyl 4,5,7,8,9-penta-*O*-acetyl-3-deoxy-D-*glycero*-D-*galacto*-2-nonulopyranosonate (**14**). The desired furanose derivatives were not obtained. The reaction conditions and yields are summarized in Table II. The acetylation and subsequent esterification of KDN ammonium salt (**2**) also gave **12** and **13**; this method was employed in our previous study.[7] On the other hand, the acetylation and subsequent esterification of **1** gave **12**, **13** and 2,4,5,8,9-penta-*O*-acetyl-3-deoxy-D-*glycero*-β-D-*galacto*-2-nonulopyranosono-1,7-lactone (**15**). In this reaction, many spots were detected on thin layer chromatography and we could not isolate another product. The structure of **15** was elucidated by ^{1}H-NMR comparison with the corresponding Neu5Ac derivative.[11]

Characterization of Furanose and Pyranose Derivatives of 1 The structures of crystalline compounds were elucidated by X-ray diffraction analysis. Figure 4 shows the crystal structures of the penta-*O*-acetylated methyl glycosides (**4**—**7**), and Fig. 5 shows those of the hexa-*O*-

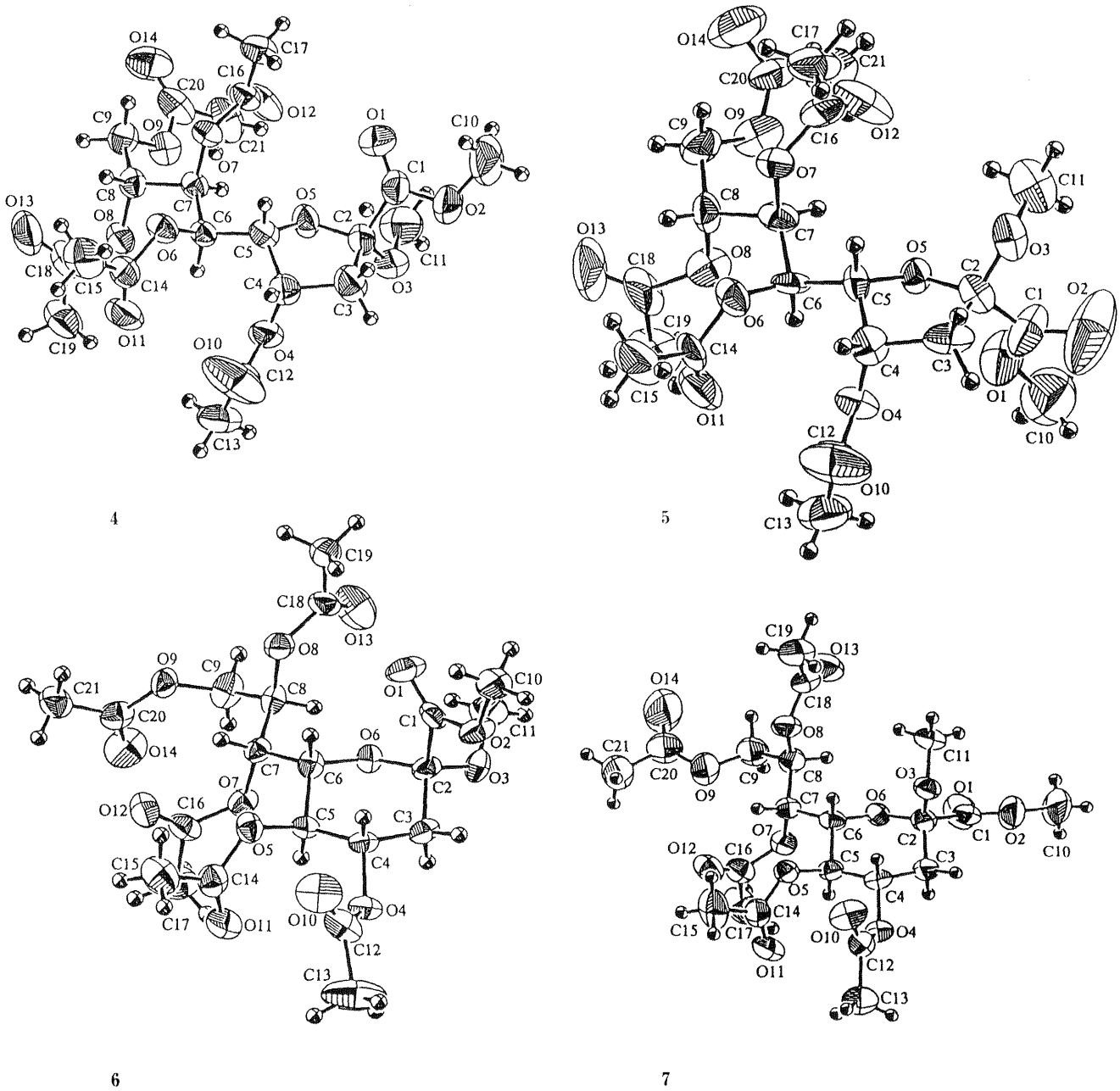


Fig. 4. Crystal Structures of **4**—**7**

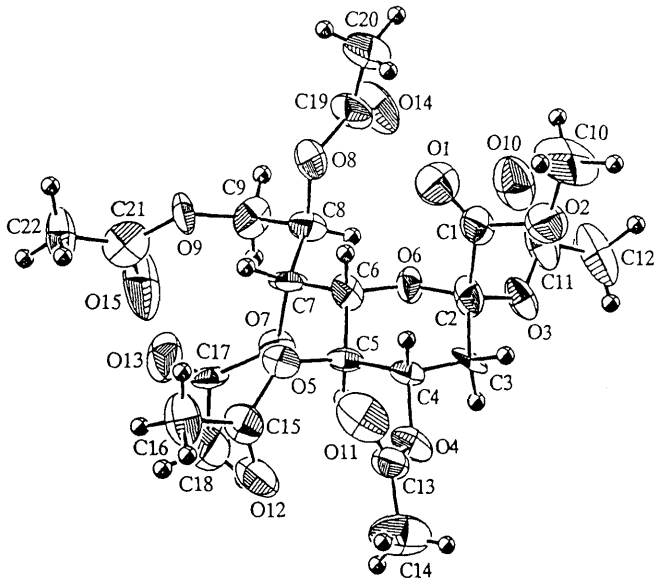
acetylated derivatives (**12**, **13**). The crystal structure of the deacetylated methyl glycosides (**8**, **9**, **11**) have been reported previously.[2,12] These crystal structures indicated that the conformations of the pyranose derivatives were $^1C_4$ form, and those of the furanose derivatives were E^4 form. The positional parameters and B_{eq} for **4**, **5**, **6**, **7**, **12** and **13** are listed in Table III—VIII.

Table IX shows the ^{1}H-NMR data for the methyl glycosides (**4**—**11**), the hexa-*O*-acetyl derivatives (**12**, **13**) and **14**. The H-3 signals of the furanosides are observed at lower fields than those of the pyranosides. The H-5 signals of **6**, **7** and the H-6 signals of **4**, **5** are observed at lower field than those of its deacetylated derivatives owing to acetylation shifts. The coupling constants $J_{3,4}$ and $J_{4,5}$ of the furanosides are smaller than those of the pyranosides. The configuration at the C-2 position of the pyranose derivatives was evaluated by applying the empirical rule that the H-3′(eq) signal of an α-anomer is usually observed at lower field than that of a β-anomer,[7] but those of the furanose derivatives could not be elucidated by this approach.

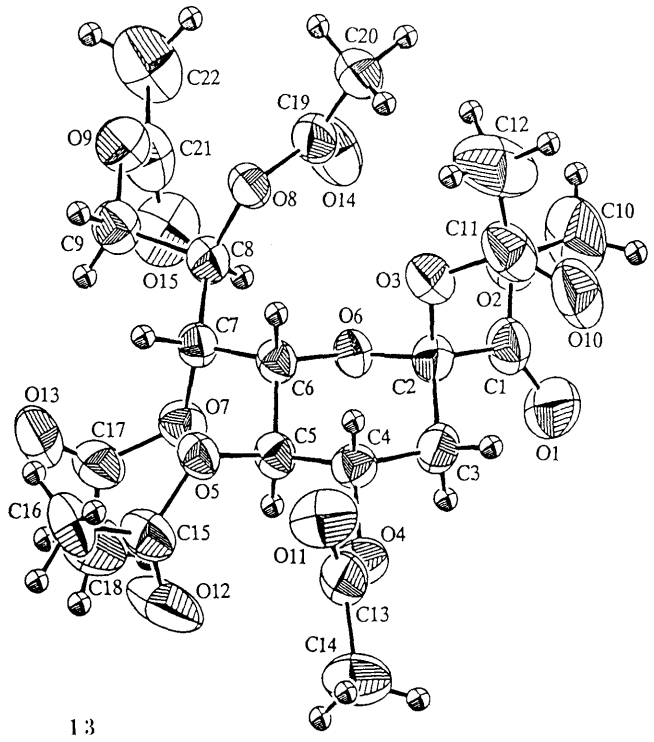
Figure 6 shows the CD spectra of the deacetylated methyl glycosides (**8**—**11**). The previous study of **1** indicated that the peak around 220—230 nm is due to the n–π* Cotton effect of the carboxyl group and the negative Cotton effect was assigned to the α-anomer and the positive one to the β-anomer.[7] In Fig. 6, the spectra of the methyl pyranosides (**10**, **11**) are in accordance with the above results, but no characteristic peak was observed in the spectra of the methyl furanosides (**8**, **9**).

Conclusion

The products of Fischer's methyl glycosylation of **1** revealed the anomeric equilibrium between α,β-furanose and α,β-pyranose of **1**. These results indicate that the furanosides were formed by kinetic control and the



1 2



1 3

Fig. 5. Crystal Structures of **12** and **13**

pyranosides by thermodynamic control. In spite of the anomeric equilibrium, peracetylation of **1**, **2** and **3** by acetic anhydride with pyridine gave only α- and β-pyranose derivatives. The obtained methyl glycosides and hexa-*O*-acetyl derivatives of **1** were characterized by X-ray, ^{1}H-NMR and CD spectral analyses. The X-ray crystal analysis showed that the conformations of the furanosides were E^4 form and those of the pyranosides were $^1C_4$ form. The ^{1}H-NMR spectra provided many characteristic data to distinguish the furanose and the pyranose derivatives of **1**. The ^{1}H-NMR and CD spectral analyses failed to elucidate the configurations at the C-2 position of the furanose derivatives.

Experimental

Melting points were measured with a Yamato melting point apparatus and the results are uncorrected. Optical rotations were measured with a JASCO JIP-4 digital polarimeter. Thin layer chromatography (TLC) was performed on silica gel (Merck) plates, and spots were detected by spraying with 5% sulfuric acid solution. Fast atom bombardment mass spectra (FAB-MS), and infrared (IR) spectra were measured with JEOL JMS-DX300 and JASCO FT/IR-7300 instruments, respectively. CD spectra were measured in a 0.1 cm cell with a JASCO J-720 spectropolarimeter. The ^{1}H-NMR spectra were measured with a Varian VXR-300 spectrometer. Trimethylsilane (TMS) in $CDCl_3$ or sodium 3-(trimethylsilyl)-1-propanesulfonate (DDS) in D_2O was used as an internal reference. Column chromatography was conducted on Silica gel 60 (70—230 mesh).

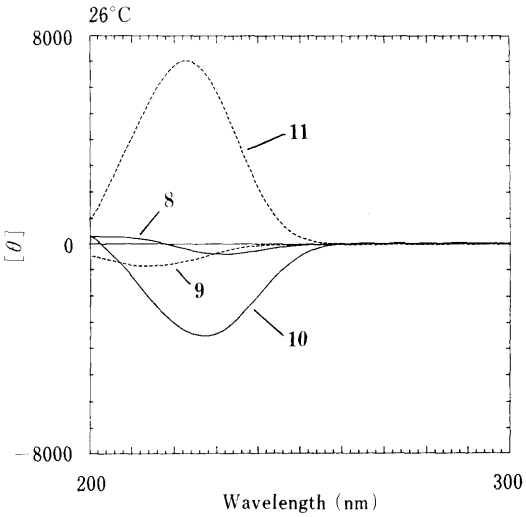


Fig. 6. CD Curves of **8**—**11** in MeOH

Methyl Esterification of 1 A solution of **1** (5.00 g, 18.6 mmol) and dry Dowex-50 (H^+) resin (5.00 g) in dry MeOH (100 ml) was stirred for 48 h at room temperature, then filtered, and the filtrate was evaporated to dryness. The residual syrup was purified on a column of silica gel with $CHCl_3$–MeOH (10 : 1) to yield **3** (4.04 g, 77%) as an amorphous powder. $[\alpha]_D^{26}$ −13.0° (c=0.55, MeOH). FAB-MS m/z: 283 (M^++1). *Anal.* Calcd for $C_{10}H_{18}O_9$: C, 42.55; H, 6.43. Found: C, 42.29; H, 6.51. IR ν_{max}^{KBr} cm^{-1}: 3385, 1744, 1067, 1033. ^{1}H-NMR (300 MHz, D_2O) δ: 1.53 (1H, dd, J=13.0, 11.8 Hz, 3-H_{ax}), 1.93 (1H, dd, J=13.0, 5.0 Hz, 3-H_{eq}), 3.25 (1H, dd, J=10.2, 9.2 Hz, 5-H), 3.32 (1H, dd, J=11.9, 6.4 Hz, 9-H), 3.40 (1H, ddd, J=9.4, 6.4, 2.3 Hz, 8-H), 3.49 (3H, s, $COOCH_3$), 3.53 (1H, dd, J=9.4, 0.8 Hz, 7-H), 3.66 (1H, ddd, J=11.8, 9.2, 5.0 Hz, 4-H), 3.67 (1H, dd, J=10.2, 0.8 Hz, 6-H).

Methyl Glycosylation of 3 by Fischer's Method A typical experimental procedure was as follows. A solution of **3** (1.00 g, 3.54 mmol) and dry Dowex-50 (H^+) (2.0 g) in dry-MeOH was stirred for 3 h at 70 °C. The solution was filtered and the filtrate was evaporated to dryness. The residual syrup was dissolved in pyridine (7.00 g, 88.5 mmol), and acetic anhydride (9.03 g, 88.5 mmol) was added dropwise to the solution at 5 °C. The mixture was stirred for 8 h at room temperature, poured into 0.5 N HCl (180 ml) and extracted with ethyl acetate (50 ml × 3). The extract was washed with sodium hydrogen carbonate solution and brine, dried and concentrated. The residual syrup was purified on a column of silica gel with ether–hexane (1 : 1—3 : 1) to yield **4**, **5**, **6** and **7**.

4: Colorless prisms, mp 96—98 °C (ether–hexane). $[\alpha]_D^{22}$ +70.3° (c=0.25, $CHCl_3$). FAB-MS m/z: 507 (M^++1). *Anal.* Calcd for $C_{21}H_{30}O_{14}$: C, 49.80; H, 5.79. Found: C, 49.88; H, 5.81. IR ν_{max}^{KBr} cm^{-1}: 1748, 1373, 1240, 1213.

5: Colorless prisms, mp 114—115 °C (ether). $[\alpha]_D^{26}$ +4.7° (c=0.21, $CHCl_3$). FAB-MS m/z: 507 (M^++1). *Anal.* Calcd for $C_{21}H_{30}O_{14}$: C, 49.80; H, 5.79. Found: C, 49.82; H, 6.08. IR ν_{max}^{KBr} cm^{-1}: 1747, 1373, 1238, 1216, 1038.

6: Colorless prisms, mp 115—116 °C (ether). $[\alpha]_D^{26}$ −17.0° (c=0.15, $CHCl_3$). FAB-MS m/z: 507 (M^++1). *Anal.* Calcd for $C_{21}H_{30}O_{14}$: C, 49.80; H, 5.79. Found: C, 49.72; H, 6.04. IR ν_{max}^{KBr} cm^{-1}: 1755, 1371, 1221, 1058.

7: Colorless needles, mp 117—118 °C (ether–hexane). $[\alpha]_D^{26}$ −6.3° (c=0.13, $CHCl_3$). FAB-MS m/z: 507 (M^++1). *Anal.* Calcd for $C_{21}H_{30}O_{14}$: C, 49.80; H, 5.79. Found: C, 49.90; H, 6.05. IR ν_{max}^{KBr} cm^{-1}: 1751, 1373, 1244, 1058.

TABLE III. Positional Parameters and B_{eq} for **4**

Atom	x	y	z	B_{eq}
O1	0.2005 (5)	0.4991	1.1145 (4)	6.0 (2)
O2	−0.0526 (5)	0.5294 (4)	1.0881 (5)	8.0 (3)
O3	−0.0893 (4)	0.3569 (4)	1.0063 (4)	5.7 (2)
O4	−0.0653 (4)	0.3417 (4)	0.6512 (3)	5.2 (2)
O5	0.1342 (4)	0.3685 (4)	0.9303 (3)	4.7 (2)
O6	0.3304 (4)	0.3775 (3)	0.6523 (3)	4.1 (1)
O7	0.4832 (3)	0.3630 (3)	0.9352 (3)	3.6 (1)
O8	0.3871 (4)	0.1724 (3)	0.7232 (3)	4.1 (1)
O9	0.5296 (4)	0.1442 (3)	1.0053 (3)	4.4 (1)
O10	−0.1304 (9)	0.4054 (5)	0.4471 (5)	12.4 (4)
O11	0.1969 (5)	0.2960 (4)	0.4765 (4)	6.6 (2)
O12	0.4769 (5)	0.3077 (4)	1.1425 (4)	6.0 (2)
O13	0.5401 (6)	0.1591 (5)	0.5778 (5)	9.6 (3)
O14	0.7537 (6)	0.1282 (4)	1.1654 (4)	7.3 (2)
C1	0.0682 (7)	0.4846 (5)	1.0644 (6)	4.8 (3)
C2	0.0042 (6)	0.4133 (5)	0.9571 (5)	4.8 (2)
C3	−0.0819 (7)	0.4526 (5)	0.8173 (6)	6.2 (3)
C4	0.0048 (6)	0.4202 (5)	0.7134 (5)	4.7 (2)
C5	0.1648 (6)	0.4004 (4)	0.8043 (5)	3.9 (2)
C6	0.2609 (5)	0.3330 (4)	0.7507 (4)	3.2 (2)
C7	0.3884 (5)	0.2944 (4)	0.8637 (4)	3.2 (2)
C8	0.4915 (6)	0.2338 (4)	0.8065 (5)	3.7 (2)
C9	0.6115 (6)	0.1880 (4)	0.9164 (5)	4.3 (2)
C10	−0.015 (1)	0.5996 (7)	1.187 (1)	11.7 (6)
C11	−0.0142 (8)	0.3159 (6)	1.1340 (7)	7.3 (4)
C12	−0.1314 (7)	0.3423 (6)	0.5155 (6)	6.5 (3)
C13	−0.1861 (8)	0.2570 (6)	0.4621 (7)	8.0 (4)
C14	0.2891 (7)	0.3531 (5)	0.5171 (5)	4.8 (2)
C15	0.3765 (9)	0.4024 (6)	0.4343 (6)	7.8 (4)
C16	0.5127 (6)	0.3638 (5)	1.0777 (5)	3.9 (2)
C17	0.5954 (6)	0.4441 (5)	1.1340 (5)	5.0 (2)
C18	0.4216 (8)	0.1432 (5)	0.6079 (6)	5.5 (3)
C19	0.2933 (9)	0.0901 (5)	0.5235 (6)	7.0 (3)
C20	0.6139 (9)	0.1208 (4)	1.1307 (6)	5.3 (3)
C21	0.511 (1)	0.0864 (5)	1.2172 (7)	7.4 (4)

TABLE IV. Positional Parameters and B_{eq} for **5**

Atom	x	y	z	B_{eq}
O1	0.4169 (7)	1.0279 (5)	0.149 (1)	7.5 (7)
O2	0.2848 (7)	0.9942 (6)	0.059 (2)	15 (1)
O3	0.3588 (5)	0.8573 (5)	0.025 (1)	4.7 (5)
O4	0.4640 (6)	0.9105 (5)	0.4140 (9)	4.3 (5)
O5	0.4927 (5)	0.8977 (4)	0.1398 (8)	3.7 (4)
O6	0.6342 (6)	0.7988 (4)	0.3760 (8)	4.2 (5)
O7	0.6720 (6)	0.7631 (5)	0.1142 (8)	4.1 (5)
O8	0.8070 (6)	0.9120 (5)	0.2641 (9)	5.0 (5)
O9	0.8447 (6)	0.8875 (5)	−0.006 (1)	5.5 (5)
O10	0.386 (1)	0.8606 (6)	0.578 (1)	9.5 (8)
O11	0.6784 (8)	0.8889 (5)	0.512 (1)	6.7 (6)
O12	0.648 (1)	0.8033 (7)	−0.091 (1)	9.5 (8)
O13	0.9249 (8)	0.8628 (7)	0.385 (1)	12 (1)
O14	0.9164 (8)	0.8205 (6)	−0.156 (1)	9.6 (8)
C1	0.361 (1)	0.9802 (9)	0.110 (2)	7 (1)
C2	0.392 (1)	0.9012 (7)	0.128 (1)	4.1 (8)
C3	0.354 (1)	0.8652 (7)	0.255 (1)	4.7 (7)
C4	0.4416 (9)	0.8476 (8)	0.337 (1)	4.5 (8)
C5	0.5134 (8)	0.8395 (6)	0.233 (1)	3.3 (7)
C6	0.6158 (9)	0.8504 (6)	0.274 (1)	3.5 (7)
C7	0.687 (1)	0.8385 (6)	0.166 (1)	3.8 (7)
C8	0.7960 (8)	0.8422 (8)	0.206 (1)	4.4 (8)
C9	0.862 (1)	0.8314 (8)	0.091 (1)	5.1 (8)
C10	0.387 (1)	1.103 (1)	0.140 (2)	11 (1)
C11	0.396 (1)	0.8780 (8)	−0.100 (1)	7 (1)
C12	0.436 (1)	0.910 (1)	0.535 (2)	7 (1)
C13	0.466 (1)	0.9768 (7)	0.604 (1)	7 (1)
C14	0.665 (1)	0.8259 (8)	0.491 (1)	4.8 (9)
C15	0.673 (1)	0.7667 (9)	0.586 (1)	10 (1)
C16	0.649 (1)	0.755 (1)	−0.013 (2)	6 (1)
C17	0.6284 (9)	0.674 (1)	−0.044 (1)	8 (1)
C18	0.877 (1)	0.913 (1)	0.355 (2)	7 (1)
C19	0.877 (1)	0.9878 (7)	0.417 (1)	8 (1)
C20	0.875 (1)	0.8763 (8)	−0.127 (2)	5 (1)
C21	0.856 (1)	0.9373 (7)	−0.216 (1)	7 (1)

TABLE V. Positional Parameters and B_{eq} for **6**

Atom	x	y	z	B_{eq}
O1	0.693 (1)	0.4353 (2)	0.486 (1)	5.3 (5)
O2	0.9411 (8)	0.4271 (2)	0.5722 (8)	3.9 (4)
O3	0.9714 (8)	0.4531 (2)	0.2171 (8)	3.4 (3)
O4	1.0617 (8)	0.3292 (2)	0.2531 (8)	3.4 (3)
O5	0.7137 (8)	0.3184 (2)	0.2168 (8)	3.0 (3)
O6	0.7706 (7)	0.4145 (2)	0.1572 (7)	2.7 (3)
O7	0.6167 (7)	0.3678 (2)	−0.1126 (8)	3.0 (3)
O8	0.4031 (8)	0.4254 (2)	0.1805 (8)	3.4 (3)
O9	0.2496 (8)	0.3908 (2)	−0.1118 (8)	3.3 (3)
O10	0.981 (1)	0.2903 (2)	0.455 (1)	5.6 (5)
O11	0.827 (1)	0.2878 (2)	0.004 (1)	5.2 (5)
O12	0.470 (1)	0.3178 (2)	−0.1038 (9)	4.1 (4)
O13	0.451 (1)	0.4839 (2)	0.140 (1)	6.4 (5)
O14	0.282 (1)	0.3739 (2)	−0.384 (1)	6.2 (5)
C1	0.826 (2)	0.4285 (3)	0.458 (1)	3.0 (5)
C2	0.898 (1)	0.4219 (3)	0.273 (1)	3.2 (5)
C3	1.015 (1)	0.3909 (3)	0.267 (1)	3.0 (5)
C4	0.940 (1)	0.3546 (3)	0.293 (1)	2.7 (5)
C5	0.800 (1)	0.3498 (2)	0.172 (1)	2.6 (5)
C6	0.688 (1)	0.3814 (3)	0.184 (1)	2.9 (5)
C7	0.557 (1)	0.3802 (2)	0.051 (1)	2.7 (5)
C8	0.479 (1)	0.4164 (3)	0.022 (1)	3.1 (5)
C9	0.366 (1)	0.4179 (3)	−0.128 (1)	4.1 (6)
C10	0.897 (1)	0.4368 (3)	0.748 (1)	4.5 (6)
C11	0.880 (1)	0.4854 (3)	0.220 (2)	4.9 (6)
C12	1.069 (2)	0.2991 (3)	0.348 (2)	4.4 (7)
C13	1.214 (2)	0.2777 (4)	0.294 (2)	9 (1)
C14	0.742 (1)	0.2881 (3)	0.123 (2)	3.7 (6)
C15	0.653 (2)	0.2574 (3)	0.194 (2)	5.5 (7)
C16	0.559 (1)	0.3370 (3)	−0.176 (1)	3.3 (6)
C17	0.630 (1)	0.3283 (3)	−0.349 (1)	5.7 (7)
C18	0.403 (1)	0.4606 (3)	0.227 (2)	4.2 (6)
C19	0.328 (1)	0.4642 (3)	0.402 (2)	4.7 (6)
C20	0.219 (1)	0.3699 (3)	−0.251 (2)	3.7 (6)
C21	0.097 (1)	0.3433 (3)	−0.210 (1)	4.4 (6)

TABLE VI. Positional Parameters and B_{eq} for **7**

Atom	x	y	z	B_{eq}
O1	0.9859 (6)	0.1434 (2)	1.1651 (8)	6.6 (4)
O2	1.0446 (6)	0.1158 (2)	0.9257 (9)	6.9 (4)
O3	0.7781 (5)	0.1202 (2)	0.8482 (6)	4.1 (2)
O4	0.6842 (5)	−0.0070 (1)	1.0203 (5)	3.7 (2)
O5	0.4489 (5)	0.0497 (1)	1.0852 (6)	3.7 (2)
O6	0.7323 (5)	0.1241 (1)	1.1202 (6)	3.5 (2)
O7	0.5518 (5)	0.1192 (1)	1.3799 (6)	3.9 (2)
O8	0.4645 (6)	0.1955 (1)	1.0726 (6)	4.7 (3)
O9	0.3433 (7)	0.1880 (2)	1.401 (1)	7.9 (4)
O10	0.5301 (6)	−0.0206 (2)	0.8335 (7)	5.7 (3)
O11	0.4532 (7)	−0.0028 (2)	1.2686 (8)	6.9 (4)
O12	0.3461 (6)	0.0890 (2)	1.4171 (7)	5.2 (3)
O13	0.5814 (7)	0.2584 (2)	1.070 (1)	7.7 (4)
O14	0.251 (1)	0.2480 (3)	1.454 (2)	14.9 (8)
C1	0.960 (1)	0.1247 (3)	1.046 (1)	5.1 (4)
C2	0.8191 (8)	0.1072 (2)	1.000 (1)	3.9 (4)
C3	0.8196 (8)	0.0570 (2)	1.001 (1)	3.9 (4)
C4	0.6765 (7)	0.0393 (2)	0.9894 (8)	3.5 (3)
C5	0.5874 (7)	0.0604 (2)	1.114 (1)	3.5 (3)
C6	0.5959 (7)	0.1103 (2)	1.105 (1)	3.4 (3)
C7	0.5118 (7)	0.1336 (2)	1.2253 (8)	3.5 (3)
C8	0.5299 (8)	0.1830 (2)	1.224 (1)	4.4 (4)
C9	0.471 (1)	0.2067 (2)	1.366 (1)	6.0 (5)
C10	0.7825 (8)	0.1663 (2)	0.818 (1)	5.7 (5)
C11	0.7825 (8)	0.1663 (2)	0.818 (1)	5.7 (5)
C12	0.6009 (8)	−0.0333 (2)	0.935 (1)	4.0 (4)
C13	0.610 (1)	−0.0797 (2)	0.992 (1)	5.6 (4)
C14	0.3927 (8)	0.0170 (3)	1.173 (1)	4.7 (4)
C15	0.251 (1)	0.0099 (3)	1.129 (1)	7.2 (5)
C16	0.454 (1)	0.0970 (2)	1.466 (1)	4.5 (4)
C17	0.510 (1)	0.0836 (3)	1.623 (1)	7.1 (5)
C18	0.501 (1)	0.2338 (3)	1.008 (1)	5.7 (5)
C19	0.429 (1)	0.2421 (3)	0.870 (1)	7.6 (6)
C20	0.246 (1)	0.2096 (3)	1.442 (1)	6.8 (6)
C21	0.125 (1)	0.1857 (3)	1.491 (1)	7.4 (6)

Deacetylation of 4, 5, 6 and 7 A typical experimental procedure was as follows. Anhydrous potassium carbonate (68.2 mg, 0.494 mmol) was added to a solution of **4** (500 mg, 0.987 mmol) in MeOH (50 ml) at room temperature. The mixture was stirred for 1 h at room temperature, neutralized with acetic acid (100 mg) and evaporated to dryness. The residual syrup was purified on a column of silica gel with $CHCl_3$–MeOH (10 : 1) to give **8** in quantitative yield.

8: Colorless plates, mp 80—82 °C (MeOH–ether). $[\alpha]_D^{26}$ +43.0° (c = 0.15, MeOH). FAB-MS m/z: 297 ($M^+ + 1$). *Anal.* Calcd for $C_{11}H_{20}O_9$: C, 44.59; H, 6.80. Found: C, 44.40; H, 6.86. IR ν_{max}^{KBr} cm^{-1}: 3367, 1744, 1082, 1040.

9: Colorless plates, mp 121—122 °C (iso-PrOH). $[\alpha]_D^{26}$ −46.8° (c = 0.27, MeOH). FAB-MS m/z: 297 ($M^+ + 1$). *Anal.* Calcd for $C_{11}H_{20}O_9$: C, 44.59; H, 6.80. Found: C, 44.65; H, 6.81. IR ν_{max}^{KBr} cm^{-1}: 3345, 1743, 1296, 1102, 1033.

10: $[\alpha]_D^{26}$ −28.2° (c = 1.13, MeOH). FAB-MS m/z: 297 ($M^+ + 1$). *Anal.* Calcd for $C_{11}H_{20}O_9 \cdot 1/3H_2O$: C, 43.71; H, 7.11. Found: C, 43.69; H, 7.21. IR ν_{max}^{KBr} cm^{-1}: 3406, 1736, 1071, 1039.

11: Colorless needles, mp 123—125 °C (MeOH–ether). $[\alpha]_D^{26}$ −54.5° (c = 0.25, MeOH). FAB-MS m/z: 297 ($M^+ + 1$). *Anal.* Calcd for $C_{11}H_{20}O_9 \cdot H_2O$: C, 42.04; H, 7.06. Found: C, 41.91; H, 6.93. IR ν_{max}^{KBr} cm^{-1}: 3491, 1734, 1293, 1165, 1040.

Acetylation of 3 A typical experimental procedure was as follows. The methyl ester **3** (1.00 g, 3.54 mmol) was added slowly to a mixture of pyridine (5.04 g, 63.8 mmol) and acetic anhydride (6.51 g, 63.8 mmol) at 0 °C. The mixture was stirred for 1 h at 0 °C, poured into 0.5 N HCl (130 ml) and extracted with ethyl acetate (50 ml × 3). The extract was washed with sodium hydrogen carbonate solution and brine, dried and

TABLE VII. Positional Parameters and B_{eq} for **12**

Atom	x	y	z	B_{eq}
O1	0.469 (2)	0.1017	0.1794 (8)	6.1 (9)
O2	0.432 (2)	0.347 (3)	0.1318 (7)	7 (1)
O3	0.765 (1)	0.371 (3)	0.1234 (6)	4.0 (7)
O4	0.726 (1)	0.454 (3)	0.3528 (7)	3.9 (7)
O5	0.779 (1)	0.103 (3)	0.3740 (5)	3.1 (6)
O6	0.814 (1)	0.162 (2)	0.1924 (6)	3.2 (7)
O7	1.090 (1)	0.010 (2)	0.2772 (6)	3.8 (7)
O8	0.782 (1)	−0.200 (2)	0.1741 (6)	3.5 (7)
O9	1.075 (1)	−0.360 (3)	0.2389 (6)	4.0 (7)
O10	0.685 (2)	0.178 (3)	0.0527 (8)	7 (1)
O11	0.536 (2)	0.371 (3)	0.4239 (7)	7 (1)
O12	0.989 (2)	0.218 (3)	0.4320 (6)	6.0 (9)
O13	1.097 (2)	−0.145 (3)	0.3726 (8)	6 (1)
O14	0.829 (2)	−0.196 (3)	0.0625 (6)	6.1 (9)
O15	1.346 (2)	−0.357 (3)	0.2554 (7)	9 (1)
C1	0.522 (3)	0.227 (3)	0.166 (1)	4 (1)
C2	0.712 (2)	0.296 (3)	0.181 (1)	4 (1)
C3	0.707 (1)	0.410 (3)	0.2377 (8)	3.1 (9)
C4	0.692 (2)	0.335 (3)	0.3053 (9)	2.7 (9)
C5	0.806 (2)	0.192 (3)	0.3130 (8)	3 (1)
C6	0.793 (2)	0.081 (3)	0.2559 (8)	3 (1)
C7	0.922 (2)	−0.055 (3)	0.2573 (7)	4 (1)
C8	0.946 (2)	−0.124 (3)	0.1878 (9)	4 (1)
C9	1.085 (2)	−0.251 (3)	0.186 (1)	4 (1)
C10	0.258 (2)	0.308 (4)	0.113 (1)	10 (2)
C11	0.755 (3)	0.309 (4)	0.060 (1)	6 (2)
C12	0.821 (2)	0.401 (4)	0.007 (1)	7 (1)
C13	0.647 (3)	0.469 (4)	0.409 (1)	4 (2)
C14	0.692 (2)	0.599 (4)	0.451 (1)	8 (2)
C15	0.870 (3)	0.132 (3)	0.431 (1)	4 (1)
C16	0.818 (2)	0.043 (4)	0.490 (1)	5 (1)
C17	1.153 (2)	−0.055 (3)	0.339 (1)	4 (1)
C18	1.331 (2)	0.020 (4)	0.348 (1)	8 (2)
C19	0.749 (3)	−0.214 (3)	0.109 (1)	5 (1)
C20	0.556 (2)	−0.256 (4)	0.099 (1)	6 (1)
C21	1.213 (3)	−0.421 (4)	0.271 (1)	5 (1)
C22	1.186 (2)	−0.525 (3)	0.322 (1)	5 (1)

TABLE VIII. Positional Parameters and B_{eq} for **13**

Atom	x	y	z	B_{eq}
O1	0.7018 (4)	0.28797 (8)	0.3339 (5)	7.2 (2)
O2	0.4569 (4)	0.27845 (7)	0.2619 (4)	5.9 (2)
O3	0.4767 (3)	0.32791 (6)	0.0280 (3)	4.4 (1)
O4	0.8455 (3)	0.40476 (7)	0.0816 (3)	4.5 (1)
O5	0.5460 (3)	0.44133 (5)	0.1239 (3)	3.6 (1)
O6	0.4743 (3)	0.35251 (5)	0.2802 (3)	3.5 (1)
O7	0.4047 (3)	0.41573 (6)	0.4810 (3)	4.2 (1)
O8	0.1446 (3)	0.36098 (6)	0.2455 (3)	3.8 (1)
O9	−0.0733 (3)	0.38167 (7)	0.4863 (3)	4.9 (1)
O10	0.6314 (4)	0.28371 (8)	−0.0555 (4)	7.0 (2)
O11	0.8062 (4)	0.42777 (8)	−0.1663 (4)	6.5 (2)
O12	0.7088 (5)	0.47127 (8)	0.2840 (5)	9.1 (2)
O13	0.3193 (4)	0.47177 (7)	0.4492 (4)	6.9 (2)
O14	0.1213 (5)	0.31210 (8)	0.3983 (5)	7.3 (2)
O15	0.0384 (5)	0.3664 (1)	0.7240 (4)	7.6 (2)
C1	0.5869 (6)	0.2965 (1)	0.2652 (6)	4.7 (2)
C2	0.5674 (5)	0.3322 (1)	0.1762 (5)	3.8 (2)
C3	0.7196 (4)	0.3507 (1)	0.1421 (5)	4.1 (2)
C4	0.6949 (4)	0.38826 (9)	0.0833 (5)	3.7 (2)
C5	0.5894 (4)	0.40800 (9)	0.1964 (4)	3.4 (2)
C6	0.4396 (4)	0.38730 (8)	0.2186 (4)	3.3 (2)
C7	0.3260 (4)	0.40490 (9)	0.3336 (4)	3.4 (2)
C8	0.1935 (5)	0.38076 (9)	0.3855 (5)	3.6 (2)
C9	0.0588 (5)	0.4031 (1)	0.4463 (5)	4.4 (2)
C10	0.4528 (7)	0.2447 (1)	0.3476 (7)	8.5 (3)
C11	0.5204 (6)	0.3018 (1)	−0.0775 (6)	5.6 (3)
C12	0.4104 (7)	0.3002 (2)	−0.2174 (7)	9.4 (4)
C13	0.8874 (5)	0.4238 (1)	−0.0517 (6)	4.7 (2)
C14	1.0490 (6)	0.4379 (1)	−0.0299 (6)	6.5 (3)
C15	0.6148 (6)	0.4713 (1)	0.1782 (5)	4.8 (2)
C16	0.5599 (5)	0.5031 (1)	0.0867 (5)	5.4 (2)
C17	0.3914 (5)	0.4503 (1)	0.5257 (6)	5.1 (2)
C18	0.4761 (7)	0.4569 (1)	0.6793 (7)	8.4 (3)
C19	0.1179 (5)	0.3257 (1)	0.2688 (6)	5.0 (2)
C20	0.0885 (6)	0.3073 (1)	0.1125 (7)	6.3 (3)
C21	−0.0665 (7)	0.3649 (1)	0.6327 (6)	6.0 (3)
C22	−0.2152 (7)	0.3449 (1)	0.6556 (6)	8.2 (3)

TABLE IX. Proton Chemical-Shift and Spin-Coupling Data at 300 MHz for **4**—**14**

Compound	Solvent	Chemical shift (ppm)												Coupling constant (Hz)									
		3	3′	4	5	6	7	8	9	9′	OCH_3	CO_2CH_3	$OCOCH_3$	$J_{3,3}$	$J_{3,4}$	$J_{3',4}$	$J_{4,5}$	$J_{5,6}$	$J_{6,7}$	$J_{7,8}$	$J_{8,9}$	$J_{8,9'}$	$J_{9,9'}$
4	$CDCl_3$	2.19	2.51	5.27	4.18	5.51	5.48	5.10	4.06	4.25	3.33	3.73	1.96—2.10	15.3	0.5	5.8	3.6	9.1	2.4	7.8	6.0	2.9	12.5
5	$CDCl_3$	2.37	2.52	5.37	4.14	5.56	5.60	5.12	4.13	4.30	3.25	3.82	1.99—2.13	15.5	1.1	5.9	3.6	9.3	2.8	7.8	5.9	2.9	12.4
6	$CDCl_3$	1.91	2.65	4.91	4.86	4.18	5.36	5.45	4.14	4.28	3.32	3.82	2.00—2.18	13.0	11.8	4.5	9.5	10.0	2.2	9.3	5.0	2.5	12.5
7	$CDCl_3$	1.83	2.51	5.30	4.88	4.05	5.40	5.29	4.14	4.70	3.25	3.80	1.97—2.12	13.0	11.4	5.3	10.0	10.0	2.2	5.4	6.8	2.2	12.5
8	D_2O	2.25	2.45	4.49	4.20	4.12	3.70	3.72	3.60	3.81	3.18	3.76		14.6	0.5	5.2	3.7	9.6	0.5	0.0	5.5	2.1	11.4
9	D_2O	2.36	2.46	4.47	4.07	4.14	3.69	3.70	3.58	3.80	3.18	3.76		15.0	1.1	5.2	3.0	9.2	1.0	0.0	5.4	2.4	11.4
10	D_2O	1.67	2.55	—	3.46	3.67	—	—	3.56	—	3.29	3.80		12.9	11.4	4.8	9.3	9.7	0.5	—	4.5	—	11.8
11	D_2O	1.65	2.26	3.89	3.49	3.73	3.79	—	3.63	—	3.19	3.77		13.5	11.5	5.2	9.0	10.0	0.8	—	—	2.1	—
12	$CDCl_3$	—	2.65	5.23	4.92	4.71	5.37	5.23	4.10	4.30		3.76	2.00—2.11	13.2	11.2	5.0	9.2	10.2	2.2	8.0	4.8	2.5	12.6
13	$CDCl_3$	2.06	2.60	5.24	4.95	4.17	5.37	5.13	4.12	4.42		3.77	1.99—2.14	13.6	11.6	5.1	9.8	10.2	2.3	6.3	5.8	2.4	12.5
14	Pyridine-d_5	2.24	2.64	5.78	5.36	4.84	5.78	5.45	4.32	4.76		3.53	1.81—1.96	12.9	11.4	5.1	9.6	10.0	2.0	5.2	7.0	2.5	12.2

concentrated. The residual syrup was purified on a column of silica gel with ether–hexane (1 : 1—3 : 1) to yield **12**, **13** and **14**.

12: Colorless needles, mp 96—97 °C (ether–hexane). $[\alpha]_D^{26}$ +10.5° (c=0.44, $CHCl_3$). FAB-MS m/z: 535 (M^++1). *Anal.* Calcd for $C_{22}H_{30}O_{15}$: C, 49.44; H, 5.66. Found: C, 49.66; H, 5.75. IR ν_{max}^{KBr} cm^{-1}: 1765, 1372, 1237, 1058.

13: Colorless needles, mp 104—105 °C (ether). $[\alpha]_D^{26}$ −24.3° (c=0.31, $CHCl_3$). EI-MS m/z: 534 (M^+). *Anal.* Calcd for $C_{22}H_{30}O_{15}$: C, 49.44; H, 5.66. Found: C, 49.49; H, 5.70. IR ν_{max}^{KBr} cm^{-1}: 1752, 1372, 1238, 1056.

14: Colorless prisms, mp 106—107 °C (ether–hexane). $[\alpha]_D^{26}$ +0.7° (c=0.28, $CHCl_3$). FAB-MS m/z: 493 (M^++1). *Anal.* Calcd for $C_{20}H_{28}O_{14}$: C, 48.78; H, 5.73. Found: C, 49.07; H, 5.87. IR ν_{max}^{KBr} cm^{-1}: 3413, 1752, 1240, 1214, 1050.

Acetylation and Esterification of 2 The ammonium salt **2** (1.00 g, 3.51 mmol) was added slowly to a mixture of pyridine (4.99 g, 63.1 mmol) and acetic anhydride (6.44 g, 63.1 mmol) at room temperature. The mixture was stirred for 5 h at room temperature, then MeOH (3 ml) was added to the solution at 5 °C, and the whole was evaporated to dryness. The amorphous residue was dissolved in *N*,*N*-dimethylformamide (10 ml), and anhydrous cesium carbonate (571 mg, 1.75 mmol) and iodomethane (2.49 g, 17.5 mmol) were added at room temperature. The whole was stirred for 24 h at room temperature, poured into water (100 ml) and extracted with ethyl acetate (50 ml × 3). The extract was washed with sodium hydrogen carbonate solution and brine, dried and concentrated. The residual syrup was purified on a column of silica gel with ether–hexane (3 : 1—1 : 1) to yield **12** (75 mg, 4%) and **13** (863 mg, 46%).

Acetylation and Esterification of 1 KDN **1** (1.00 g, 3.73 mmol) was added slowly to a mixture of pyridine (5.31 g, 67.1 mmol) and acetic anhydride (6.85 g, 67.1 mmol) at room temperature. The mixture was stirred for 1 h at room temperature, then MeOH (3 ml) was added at 5 °C, and the whole was evaporated to dryness. The amorphous residue was dissolved in *N*,*N*-dimethylformamide (10 ml), and anhydrous cesium carbonate (608 mg, 1.87 mmol) and iodomethane (2.65 g, 18.7 mmol) were added at room temperature. The whole was stirred for 24 h at room temperature, poured into water (100 ml) and extracted with ethyl acetate (50 ml × 3). The extract was washed with sodium hydrogen carbonate solution and brine, dried and concentrated. The residual syrup was purified on a column of silica gel with ether–hexane (1 : 1—3 : 1) to yield **12** (20 mg, 1%), **13** (159 mg, 8%) and **15** (172 mg, 10%).

15: Colorless prisms, mp 216—217 °C (dec.) (ether). $[\alpha]_D^{27}$ +6.8° (c=1.00, MeOH). FAB-MS m/z: 461 (M^++1). *Anal.* Calcd for $C_{19}H_{24}O_{13}$: C, 49.57; H, 5.22. Found: C, 49.81; H, 5.34. IR ν_{max}^{KBr} cm^{-1}: 1740, 1375, 1220, 1129, 1051. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 2.07, 2.08, 2.10, 2.12, 2.16 (each 3H, s, OAc), 2.31 (2H, d, J=3.0 Hz, 3-H_{ax} and 3-H_{eq}), 4.30 (1H, dd, J=12.5, 4.0 Hz, 9-H), 4.31 (1H, d, J=1.3 Hz, 6-H), 4.59 (1H, d, J=8.8 Hz, 7-H), 4.74 (1H, dd, J=12.5, 3.3 Hz, 9′-H), 4.82 (1H, dd, J=2.2, 1.3 Hz, 5-H), 5.17 (1H, m, 4-H), 5.49 (1H, ddd, J=8.8, 4.0, 2.3 Hz, 8-H).

X-Ray Diffraction Analysis The cell dimensions and diffraction intensities were measured on a Rigaku four-circle diffractometer (AFC-5R). The collected reflection intensities were corrected for Lorentz and polarization factors, but not for absorption. The structures were solved by direct methods using the program MITHRIL.[13] The positions of all hydrogen atoms were calculated. Atomic scattering factors were taken from the International Tables for X-Ray Crystallography.[14] All calculations were performed using the TEXSAN[15] crystallographic software package of Molecular Structure Corporation.

Crystal Data for **4**: Monoclinic space group $P2_1$, a=8.827(2) Å, b=15.573(5) Å, c=9.937(2) Å, β=103.95 (2)°, Z=2, D_{calcd}= 1.269 g/cm^3, Cu radiation. The final residuals for 315 variables refined against 1872 data with $|F| \geqq 3\sigma(F)$ ($3° < 2\theta < 140°$) were R=4.6 and 5.0%.

Crystal Data for **5**: Orthorhombic space group $P2_12_12_1$, a=13.976(1) Å, b=18.146(2) Å, c=10.286(1) Å, Z=4, D_{calcd}=1.289 g/cm^3, Mo radiation. The final residuals for 316 variables refined against 1120 data with $|F| \geqq 3\sigma(F)$ ($3° < 2\theta < 55°$) were R=6.2 and 4.6%.

Crystal Data for **6**: Orthorhombic space group $P2_12_12_1$, a=8.502(5) Å, b=37.29(2) Å, c=7.764(7) Å, Z=4, D_{calcd}=1.971 g/cm^3, Mo radiation. The final residuals for 316 variables refined against 1975 data with $|F| \geqq 3\sigma(F)$ ($3° < 2\theta < 55°$) were R=9.0 and 9.8%.

Crystal Data for **7**: Orthorhombic space group $P2_12_12_1$, a=9.936(2) Å, b=30.457(5) Å, c=8.492(2) Å, Z=4, D_{calcd}=1.309 g/cm^3, Cu radiation. The final residuals for 316 variables refined against 1891 data with $|F| \geqq 3\sigma(F)$ ($3° < 2\theta < 140°$) were R=6.7 and 7.4%.

Crystal Data for **12**: Monoclinic space group $P2_1$, a=8.022(2) Å, b=8.416(2) Å, c=19.769(2) Å, β=92.38(1)°, Z=2, D_{calcd}=1.331 g/cm^3, Cu radiation. The final residuals for 333 variables refined against 1115 data with $|F| \geqq 3\sigma(F)$ ($3° < 2\theta < 140°$) were R=7.9 and 6.4%.

Crystal Data for **13**: Orthorhombic space group $P2_12_12_1$, a= 8.6423(8) Å, b=37.623(3) Å, c=8.246(1) Å, Z=4, D_{calcd}=0.632/cm^3, Cu radiation. The final residuals for 334 variables refined against 2343 data with $|F| \geqq 3\sigma(F)$ ($3° < 2\theta < 140°$) were R=4.2 and 4.1%.

Acknowledgement This work was supported in part by a Grant-in-Aid for Scientific Research (63470129) from the Ministry of Education, Science and Culture, and by a grant from Suzuken Memorial Foundation.

References

1) Part XXVII of the series "Studies on Sialic Acid."
2) M. Nakamura, H. Takayanagi, K. Furuhata, and H. Ogura, in preparation.
3) H. Friebolin, P. Kunzelmann, M. Supp, R. Brossmer, G. Keilich, and D. Ziegler, *Tetrahedron Lett.*, **22**, 1383 (1981).
4) D. Charon and L. Szabó, *J. Chem. Soc. Perkin Trans. 1*, **1979**, 2369.
5) S. Nakamoto and K. Achiwa, *Chem. Pharm. Bull.*, **36**, 202 (1988).
6) D. Nadano, M. Iwasaki, S. Endo, K. Kitajima, S. Inoue, and Y. Inoue, *J. Biol. Chem.*, **261**, 11550 (1986).
7) M. Nakamura, K. Furuhata, and H. Ogura, *Chem. Pharm. Bull.*, **36**, 4807 (1988).
8) M. Nakamura, K. Furuhata, and H. Ogura, *Chem. Pharm. Bull.*, **37**, 821 (1989).
9) K. Ikeda, K. Kawai, and K. Achiwa, *Chem. Pharm. Bull.*, **39**, 1305 (1991).
10) M. Nakamura, K. Furuhata, T. Yamasaki, and H. Ogura, *Chem. Pharm. Bull.*, **39**, 3140 (1991).
11) N. Sugiyama, K. Sugai, N. Yamada, M. Goto, C. Ban, K. Furuhata, H. Takayanagi, and H. Ogura, *Chem. Pharm. Bull.*, **36**, 1147 (1988).
12) R. Shirai, M. Nakamura, S. Hara, H. Takayanagi, and H. Ogura, *Tetrahedron Lett.*, **29**, 4449 (1988).
13) C. J. Gilmore, MITHRIL, an integrated direct methods computer program, *J. Appl. Cryst.*, **17**, 42, Univ. of Glasgow, Scotland, 1984.
14) International Tables for X-Ray crystallography," Vol. IV, Kynoch Press, Birmingham, 1974, pp. 72—149.
15) TEXSAN, TEXRAY Structure Analysis Package, Molecular Structure Corporation, 1985.