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KINETICALLY CONTROLLED NUCLEOPHILIC ADDITION-REACTIONS TO METHYL 4,6-*O*-BENZYLIDENE-2,3-DIDEOXY-2-NITRO-α-D-*erythro*-HEX-2-ENOPYRANOSIDE*

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ABSTRACT

Axial attack mainly occurred in the reactions of methyl 4,6-*O*-benzylidene-2,3-dideoxy-2-nitro-α-D-*erythro*-hex-2-enopyranoside with sodium borodeuteride, hydrogen peroxide, hydrogen cyanide, and methanol, whereas equatorial attack predominated in the reaction with sodium methoxide and *tert*-butyl peroxide.

INTRODUCTION

On the basis of our studies and literature upon nucleophilic addition-reactions to pyranoside derivatives, we have recently proposed[1,5] that the kinetically favored direction of an approaching nucleophile† is predictable by the following factors: (*i*) regardless of substituent(s), axial attack predominates over equatorial attack, because the former yields a thermodynamically more stable, chair-like transition state, whereas the latter gives a less stable, boat-like transition state because of stereoelectronic reasons[2]; (*ii*) to a substituent at the β′-position, *cis*-addition prevails over *trans*-addition, if $A^{(1,3)}$ strain* is generated between the electron-withdrawing group and the β′-substituent in such a transition state because of stereoelectronic factors, (*iii*) concerning the substituent at the γ-position, *trans*-addition preponderates over *cis*-addition through steric and electrostatic repulsion between an approaching nucleophilic and the γ-substituent.

In nucleophilic addition-reactions to methyl 4,6-*O*-benzylidene-2,3-dideoxy-2-nitro-α-D-*erythro*-hex-2-enopyranoside (**1**), axial attack should predominate over equatorial attack owing to factors (*i*) and (*ii*), but equatorial attack should prevail from factor (*iii*). As axial attack is hindered by steric and electrostatic repulsion, not only from O-4, but also from the anomeric methoxyl group, the ratio of equato-

*Stereochemistry of Nucleophilic Addition Reactions. Part XIV. For Part XIII, see ref. 1.

†This proposal does not include the subsequent protonation.

*The original definition of $A^{(1,3)}$ strain[3] is based on steric hindrance; however, in this paper, it is modified to incorporate electrostatic repulsion. Baer and Kovář reported an important role of $A^{(1,3)}$ strain in nitroalkane cyclization[4].

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rial attack should increase, especially in the case of a sterically bulky and/or negatively charged nucleophile. On the basis of this prediction, we have investigated the reactions of the nitroalkene **1** with various nucleophiles and have found that, indeed, the bulky *tert*-butyl peroxide and (negatively charged) methoxide ions attack almost exclusively from the equatorial side of the molecule, in contrast to hydrogen peroxide, deuteride ion, and also methanol†.

RESULTS AND DISCUSSION

Reduction of **1** (refs. 6, 7) with sodium borohydride in acetonitrile for 9 h at room temperature afforded a mixture of two compounds, as judged from ^{1}H-n.m.r. spectroscopy and t.l.c., from which the *ribo* isomer **2** was isolated in 67% yield by recrystallization from ethanol. Assignment of the *ribo* configuration with the $^4C_1$(D) conformation to **2** was based on the coupling constants (benzene-d_6); $J_{1,2}$ 3.7, $J_{2,3a} = J_{3a,3e} = J_{3a,4} = 12$, $J_{2,3e}$ 4.5, and $J_{3e,4}$ 5.0 Hz*. When the *ribo* isomer **2** was treated with triethylamine in 1,4-dioxane, partial epimerization of **2** to **3** was observed by t.l.c. and ^{1}H-n.m.r. spectroscopy, indicating that the minor product **3** may be the 2-epimer of **2**. Attempts at isolation of **3** by fractional recrystallization or column chromatography on silica gel failed, because of partial epimerization of **3** to **2** during the procedure. When a similar reduction was performed in acetonitrile for 16 h at room temperature or in ethanol for 1.5 h at 0°, the ratios of **2** to **3** became 7:3 or 3:2, respectively, as estimated from ^{1}H-n.m.r. spectroscopy (on the basis of the signals for the benzylidene methine protons at δ 5.47 for **2** and 5.52 for **3** as well as the methoxyl groups at δ 3.36 for **2** and 3.39 for **4** in chloroform-*d*). Reduction of **1** with sodium borodeuteride in acetonitrile afforded the deuterio derivative **4**, the ^{1}H-n.m.r. spectrum of which showed that the H-3a signal (δ 2.48) had completely disappeared and the H-3e signal (δ 2.17) had become a broad triplet ($J_{2,3e} = J_{3e,4} = 5.0$ Hz), revealing that a deuteride ion had attacked exclusively from the axial side of **1**.

The reaction of **1** with an excess of hydrogen cyanide in 1,4-dioxane containing 1.5 equivs. of potassium cyanide provided a mixture of epimeric, 3-cyano derivatives having the *allo* (**5**) and *altro* (**6**) configurations in the ratio of 2:1, as estimated by ^{1}H-n.m.r. spectroscopy (Table I). The *allo* isomer **5** was isolated as crys-

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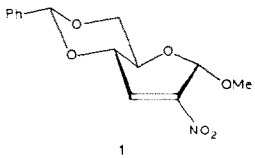
†Part of the present work has been reported in preliminary form[5], and for more-detailed studies on stereochemistry, see ref. 1.

*In chloroform-*d* (100 MHz), the signal of H-2 appeared at δ 4.50 as a multiplet, from which the coupling constants could be read as $J_{1,2}$ 4.0, $J_{2,3}$ 7.5, and $J_{2,3'}$ 9.5 Hz. These values suggested that compound **2** had the *ribo* configuration with a skew conformation. However, the chemical shifts of H-3a and H-3e in this solvent were so close that H-2, H-3a, and H-3e should be interpreted as an ABX, and not an AMX pattern; only $J_{2,3a} + J_{2,3e} = 17$ Hz could be determined from the H-2 signal. As the coupling constants, $J_{2,3e} = J_{3e,4} = 5.0$ Hz, were determined from the spectrum of **4**, the $J_{2,3a}$ value was calculated as 12 Hz (17 minus 5 Hz), indicating that compound **2** also exists in the chair conformation in chloroform-*d*.



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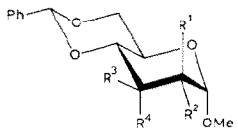
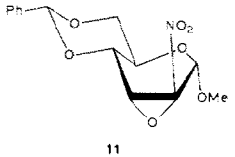


2 $R^1 = R^3 = R^4 = H, R^2 = NO_2$
3 $R^1 = NO_2, R^2 = R^3 = R^4 = H$
4 $R^1 = R^3 = H, R^2 = NO_2, R^4 = D$
5 $R^1 = R^3 = H, R^2 = NO_2, R^4 = CN$
6 $R^1 = NO_2, R^2 = R^3 = H, R^4 = CN$
7 $R^1 = R^4 = H, R^2 = NO_2, R^3 = OMe$
8 $R^1 = R^3 = H, R^2 = NO_2, R^4 = OMe$
9 $R^1 = NO_2, R^2 = R^3 = H, R^4 = OMe$



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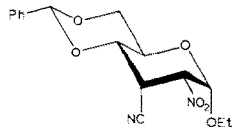

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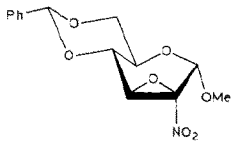

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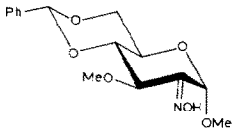

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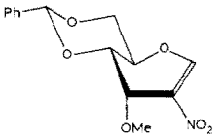

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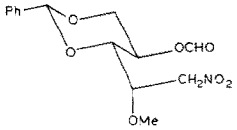

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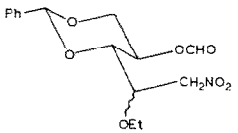

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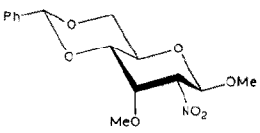

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tals by the addition of ethanol; its configuration was assigned by the coupling constants (Table II); $J_{1,2}$ 3.7, $J_{2,3}$ 5.1, and $J_{3,4}$ 4.9 Hz. Although the ^{1}H-n.m.r. spectrum of pure **5** was recorded just after dissolution in chloroform-*d*, gradual epimerization at C-2 was observed when the sample was kept at room temperature; the ratios of **5**:**6** became 9:1 and 1.6:1, after 29 h and 7 d, respectively. The epimerization occurred more readily in acetone-d_6; the ratios of **5** to **6** being 6:1 and 3.5:1, after 3 h and 43 h, respectively. Although the minor product **6** could not be isolated because of facile epimerization, the *altro* structure may be assigned for **6** on the basis of the coupling constants ($J_{1,2} \leq 1.0$ and $J_{2,3} \leq 1.0$ Hz) and the facile epimerization of **5** into **6**. When an ethanolic mixture containing **5** and **6** was heated until the crystals of **5** had dissolved and the solution was kept at room temperature, partial transglycosylation occurred to give ethyl 4,6-*O*-benzylidene-3-cyano-2,3-dideoxy-2-nitro-α-D-allopyranoside (**10**) as crystals. The *allo* configuration assigned to **10** was again based on the coupling constants; $J_{1,2}$ 3.8, $J_{2,3}$ 4.9, and $J_{3,4}$ ~4.0 Hz.

TABLE I

CHEMICAL SHIFTS (δ) AT 100 MHz OF THE PRODUCTS IN CHLOROFORM-d[a]

Compound	*H-1*	*H-2*	*H-3*	*H-4*	*H-5*	*H-6a*	*H-6e*	*PhCH*	*OMe*
2	5.18(d)	4.50(m)	[b]		←3.28–3.96→		4.23(m)	5.47(s)	3.36(s)
2[c]	4.95(d)	3.80(m)	[d]	~2.93(m)	3.62(m)	3.35(t)	4.00(q)	5.27(s)	2.85(s)
4[c]	4.95(d)	3.79(m)	[e]	2.92	3.62(m)	3.34(t)	4.01(q)	5.27(s)	2.85(s)
5	5.46(d)	4.62(q)	3.97(t)		→4.47–3.60→			5.62(s)	3.54(s)
6	5.48(s)	4.92(br[f]s)						5.66(s)	3.58(s)
7[g]	5.33(d)	4.85(q)			←4.40–3.70→			5.77(s)	3.49(s), 3.63(s)
8[c]	5.04(d)	3.47	4.11(t)	2.91(q)	4.35(sex)	3.40(t)	4.13(q)	5.27(s)	3.47(s), 3.11(s)
9[c]	5.01(s)	4.35(d)	4.07(q)	3.77(q)	4.37(sex)	3.39(t)	4.06(q)	5.16(s)	3.15(s), 2.91(s)
10	5.51(d)	4.56(t)	3.94(t)	3.85–3.60	~4.25(m)	3.85–3.60	4.32(q)	5.57(s)	3.73(q, OEt), 1.28 (t)
12	5.31(s)		4.35(s)	3.68(d)	4.04(m)	3.74(t)	4.29(q)	5.54(s)	3.55(s)
14	8.16(s)		4.77(d)	3.90(q)	~4.42(m)	3.89(t)	4.62(q)	5.60(s)	3.69(s)
15	4.62(d)	4.15(m)	4.04(m)	5.08(sex)		[h]		5.52(s)	3.44(s)
17[c]	5.10(d)	4.09(q)	3.95(q)	2.91(q)	3.83(sex)	3.35(t)	4.10(q)	5.12(s)	3.25(s), 3.20(s)

[a]Me_4Si as the internal standard. [b]2.30–2.70 (H-3a + H-3e). [c]Recorded in benzene-d_6. [d]H-3a, 2.48(q); H-3e, 2.18 (m). [e]H-3e, 2.17(br[f]t). [f]br denotes broad. [g]Recorded in acetone-d_6. [h]OCHO, 8.09(s); H-5a, 3.70(t); H-5e, 4.44(q).

TABLE II

FIRST-ORDER COUPLING CONSTANTS (Hz) AT 100 MHz IN CHLOROFORM-*d*

Compound	$J_{1,2}$	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$	$J_{5,6a}$	$J_{5,6e}$	$J_{6a,6e}$
2[a]	3.7		[b]	9.7	9.7	3.7	9.7
5	3.7	5.1	4.9				
6	≤1.0	≤1.0					
7[c]	4.2	9.7					
8[a]	4.5	≤3.0	2.3	9.8	9.8	5.3	9.8
9[a]	~0	2.3	3.0	9.8	10.5	5.3	10.5
10	3.8	4.9	~4.0	9.0		4.9	9.0
12			~0	10	9.5	4.0	9.5
14			3.8	10	10	5.2	10
15		3.7	9.8		[d]		
17[a]	8.3	3.0	2.3	9.8	9.8	5.3	9.8

[a]Recorded in benzene-d_6. [b]$J_{2,3a}$ 12, $J_{2,3e}$ 5.2, $J_{3a,3a}$ 12, $J_{3a,4}$ 12, and $J_{3e,4}$4.5. [c]Recorded in acetone-d_6. [d]$J_{4,5c}$ 5.4, $J_{4,5a}$ 9.8, and $J_{5a,5e}$ 11.3.

Treatment of **1** with 35% aqueous hydrogen peroxide in 1,4-dioxane in the presence of sodium hydroxide immediately gave a precipitate, recrystallization of which from acetone–methanol afforded the nitro epoxide **11** in 87% yield. The same product was isolated in 81% yield by similar treatment of **1** with hydrogen peroxide in benzene–0.1 M sodium hydroxide in the presence of tributylhexadecylphosphonium bromide as a phase-transfer catalyst. The epoxy structure for **11** was determined from its i.r. spectrum [1563 cm^{-1} (NO_2)] and by elemental analysis; however, its configuration could not be assigned because compound **11** is insufficiently soluble in common solvents used for ^{1}H-n.m.r. spectroscopy and it partially decomposed in warm dimethyl sulfoxide-d_6. On the other hand, similar epoxidation of **1** with 70% aqueous *tert*-butyl peroxide in 1,4-dioxane or in a heterogeneous system (benzene–0.5M sodium hydroxide) provided the mannopyranoside **12** in high yield, together with a small proportion of **11**, as judged from the ^{1}H-n.m.r. spectrum. The mannopyranoside **12** was isolated in 63% yield by recrystallization. Attempts at isolation of these products by column chromatography gave unsatisfactory results, because partial degradation made the isolated yields low. Although compound **12** decomposed partially in acetone-d_6 and in dimethyl sulfoxide-d_6, the ^{1}H-n.m.r. spectrum of pure **12** was recorded in chloroform-*d*. On the basis of $J_{3,4}$ ~0 Hz, the *manno* configuration[8] was assigned to **12**; consequently, the *allo* configuration may be deduced for **11**. Thus equatorial attack occurred predominantly in the reaction of **1** with *tert*-butyl peroxide ion, in contrast to the behavior with hydrogen peroxide ion, suggesting that steric hindrance between the bulky *tert*-butyl peroxide ion and the two oxygen atoms at C-1 and C-4 became the decisive factor.

Although the reaction of **1** with methanol was complex, three isomers (excluding the *manno* isomer) were isolated. Treatment of **1** with sodium

methoxide in methanol–1,4-dioxane gave the *gluco* isomer **7** in 64% yield, identical with the product obtained by oxidation of the glycosid-2-ulose oxime **13** with trifluoroperoxyacetic acid. Treatment of **1** with boiling methanol yielded a mixture of epimeric, 3-*O*-methyl derivatives having the *allo* (**8**) and *altro* (**9**) configurations, from which compounds **8** and **9** were separated by fractional crystallization. The configurations and conformations of these products were determined from the coupling constants; $J_{1,2}$ 4.2 and $J_{2,3}$ 9.7 Hz for **7**, $J_{1,2}$ 4.5, $J_{2,3}$ ≤3.0, and $J_{3,4}$ 2.3 Hz for **8**, and $J_{1,2}$ ~0, $J_{2,3}$ 2.3, and $J_{3,4}$ 3.0 Hz for **9**. Besides these products, the 3-*O*-methyl-2-nitro-1-enitol derivative **14** was often detected by ^{1}H-n.m.r. spectroscopy. This compound was prepared in good yield by treatment of a mixture (**8** and **9** = ~3:1) with sodium acetate in acetic anhydride for 1 h at ~90°. Purification of **14** by conventional column-chromatography on silica gel resulted in partial formation of the 1-deoxy-4-*O*-formyl-1-nitropentitol derivative **15**, which was also prepared by treatment of **14** with pyridine–water. The structure of **15** was determined on the basis of the i.r. [1720 and 1710 (CO) and 1545 cm^{-1} (NO_2)] and ^{1}H-n.m.r. spectra (-OCHO at δ 8.09) and by comparison with data for the 2-epimer[9] of **15**. Formation of **15** should involve the addition of water to **14**, followed by ring opening. Attempts to crystallize **14** from ethanol failed, because ethanol gradually reacted with **14** to give a small amount of a mixture consisting of 3,5-*O*-benzylidene-1-deoxy-2-*O*-ethyl-4-*O*-formyl-1-nitro-D-ribitol and -D-arabinitol (**16**). Finally, compound **14** could be isolated as crystals by flash-column chromatography[10] with benzene as the eluant. The glyc-1-enitol structure for **14** was determined by the i.r. [1630, 1510, and 1500 cm^{-1} (C=C-NO_2)] and ^{1}H-n.m.r. spectra (one methoxyl group at δ 3.69 and alkenic proton at δ 8.16) as well as by comparison with data for the 3-epimer[9] of **14**. The *allo* **8** and *altro* isomers **9** also partially decomposed during conventional column chromatography on silica gel, indicating that the anomeric methoxyl group, but not the 3-methoxyl group, was readily eliminated to yield the glyc-1-enitol **14**. Therefore, nucleophilic addition of methanol to **1** seems to be controlled kinetically. In fact, treatment of a mixture of **8** and **9** (3:1) with sodium methoxide in 1,4-dioxane (the same conditions as employed for the preparation of **7**) gave no *gluco* isomer **7**, but a mixture of **8, 9,** and **14**. It was noteworthy that a small proportion of methyl 4,6-*O*-benzylidene-2-deoxy-3-*O*-methyl-2-nitro-β-D-allopyranoside **17** could be isolated. This compound was undoubtedly formed by addition of methanol to the glyc-1-enitol **14**.

In contrast to the *allo* **8** and *altro* isomers **9**, decomposition of the *gluco* isomer **7** was not observed during column chromatography. Furthermore, similar treatment of **7** with sodium acetate in acetic anhydride for 2 h at ~90° resulted in the recovery of **7**. Such a difference in stability may be attributable to the presence (**8** and **9**) or absence (**7**) of the unfavorable 1,3-diaxial interaction between methoxyl groups at C-1 and C-3.

As shown in Table III, the product ratios for this reaction were remarkably dependent upon the presence or absence of sodium methoxide, and also on the solvents employed. In the absence of sodium methoxide, axial attack occurred almost

TABLE III

REACTIONS OF **1** WITH METHANOL

Solvent	*Product ratios*[a]			
	gluco **7**	allo **8**	altro **9**	*glyc-1-enitol* **14**
Methanol[b]	t	3	1	t
1,4-Dioxane[b]	t	8	5	2
Dimethyl sulfoxide[b]	1	16	6	7
Methanol[c]	2	1	t	1
1,4-Dioxane[c]	16	1	1	2
Dimethyl sulfoxide[c]	7	4	1	t

[a]The product ratios were determined on the basis of integration of benzylidene methine and H-1 signals. [b]A solution of **1** (29 mg) in methanol (0.2 mL) and the solvent (2.8 mL) indicated was heated at ~65° for 1 h. [c]A solution of **1** (29 mg) in the solvent (3 mL) indicated in the presence of 0.1M sodium methoxide (1 mL) was stirred for 30 min at room temperature.

exclusively, whereas, in the presence of sodium methoxide, the ratio of equatorial attack increased, especially in 1,4-dioxane, suggesting that axial attack of methoxide ion should be suppressed by electrostatic repulsion of the oxygen atoms at C-1 and C-4.

These results indicate that the sum of two factors (*i*) and (*ii*) is more important than factor (*iii*) only, if a nucleophile is not sterically bulky and/or does not carry a negative charge*. It is noteworthy that, in factor (*iii*), not only the substituent at the γ-position, but also that at the β'-position, play an important role; the latter is frequently in favor of ignored emphasis on the former[12].

EXPERIMENTAL

General methods. — Melting points were determined with a Yanagimoto micro melting-point apparatus and are uncorrected. Optical rotations were measured with a JASCO DIP-4 polarimeter. I.r. spectra were recorded for potassium bromide pellets with a Hitachi 285 grating infrared spectrophotometer, and ^{1}H-n.m.r. spectra were recorded with a JNM-PS-100 (JEOL) spectrometer with tetramethylsilane as the internal standard. Solutions were evaporated under diminished pressure. Extracts were dried over magnesium sulfate. Column chromatography was conducted on silica gel (Wakogel, C-300). T.l.c. was performed with Merck silica gel GF 254 (Darmstadt). The catalyst used refers to tributylhexadecylphosphonium bromide.

*Methyl 4,6-O-benzylidene-2,3-dideoxy-2-nitro-α-*D-ribo-*hexopyranoside* (**2**).

*We had reported[11] that mainly equatorial attack occurred in the Michael reaction of **1**, except when 1,4-dioxane was used as solvent, suggesting that a carbanion derived from active methylene compounds should be sterically bulky and/or sensitive to electrostatic repulsion.

— A mixture of **1** (refs. 6, 7, 105 mg, 0.36 mmol), sodium borohydride (35 mg), and acetonitrile (10 mL) was stirred for 9 h at room temperature. After the addition of acetic acid (0.3 mL), the mixture was partitioned between water and chloroform. The combined chloroform layers were successively washed with aqueous sodium hydrogencarbonate and water, dried, and then evaporated to afford a solid residue, the ^{1}H-n.m.r. spectrum of which indicated the presence of **2** and small amounts of **3**. Recrystallization from ethanol afforded 71.2 mg (67%) of **2**; m.p. 135–136.5°, $[\alpha]_D^{22}$ +140.8° (*c* 0.8, dichloromethane); ν_{max} 1550 cm^{-1} (NO_2).

Anal. Calc. for $C_{14}H_{17}NO_6$: C, 56.94; H, 5.80; N, 4.74. Found: C, 57.07; H, 5.95; N, 4.87.

Isolation of **3** failed because it epimerized partially to **2**, during either fractional crystallization or chromatographic separation.

Similar treatment of **1** (26 mg) with sodium borodeuteride (14 mg) afforded the saturated nitro compound **4** (18 mg), having the deuterium atom axially oriented.

*Methyl 4,6-O-benzylidene-3-cyano-2,3-dideoxy-2-nitro-α-*D*-allopyranoside* (**5**). — To a solution of **1** (88 mg, 0.3 mmol) in 1,4-dioxane (15 mL) was successively added an acetonitrile solution (1 mL) containing hydrogen cyanide (~1.8M) and potassium cyanide (30 mg) at room temperature. After stirring for 6 h, the mixture was diluted with benzene. The organic layer was washed with saturated aqueous sodium chloride, dried, and evaporated to a syrup. Addition of ethanol to the syrup gave 68 mg (69%) of platelet crystals of **5**; m.p. 155–156.5°, $[\alpha]_D^{22}$ +119° (*c* 1, chloroform); ν_{max} 2250 (CN) and 1560 cm^{-1} (NO_2).

Anal. Calc. for $C_{15}H_{16}N_2O_6$: C, 56.25; H, 5.04; N, 8.75. Found: C, 55.96; H, 4.95; N, 8.52.

*Ethyl 4,6-O-benzylidene-3-cyano-2,3-dideoxy-2-nitro-α-*D*-allopyranoside* (**10**). — Treatment of **1** (88 mg) with hydrogen cyanide as just described afforded a syrup, to which addition of ethanol gave crystals. The mixture was heated until the crystals had dissolved and the solution was kept for 2 d, during which time crystals (32 mg, 32%) of **10** precipitated. An analytical sample was prepared by recrystallization from ethanol; m.p. 162.5–163.5°, $[\alpha]_D^{22}$ +129° (*c* 1, chloroform); ν_{max} 2255 (CN) and 1560 cm^{-1} (NO_2).

Anal. Calc. for $C_{16}H_{18}N_2O_6$: C, 57.48; H, 5.43; N, 8.38. Found: C, 57.26; H, 5.60; N, 8.51.

*Methyl 2,3-anhydro-4,6-O-benzylidene-2-nitro-α-*D*-allopyranoside* (**11**). — (*a*) To a stirred solution of **1** (59 mg, 0.2 mmol) and 35% aqueous hydrogen peroxide (0.35 mL) in 1,4-dioxane (3.5 mL) was added M sodium hydroxide (0.35 mL) at room temperature. After stirring for 15 min, the mixture was diluted with chloroform. The organic layer was washed with water, dried, and evaporated to a solid residue that was recrystallized from acetone–methanol to give 54 mg (87%) of **11**; m.p. 243–245°, $[\alpha]_D^{22}$ +140.5° (*c* 0.22, acetone); ν_{max} 1563 cm^{-1} (NO_2).

Anal. Calc. for $C_{14}H_{15}NO_7$: C, 54.37; H, 4.89; N, 4.53. Found: C, 54.12; H, 4.79; N, 4.34.

(*b*) A mixture of **1** (88 mg, 0.3 mmol), 35% aqueous hydrogen peroxide (0.2 mL), the catalyst (6 mg), benzene (6 mL), and 0.1M sodium hydroxide (0.2 mL) was stirred for 20 min at room temperature. The mixture was diluted with chloroform and the organic layer was washed with water, dried, and evaporated. Recrystallization from benzene afforded 75 mg (81%) of **11**, identical with an authentic specimen.

*Methyl 2,3-anhydro-4,6-O-benzylidene-2-nitro-α-*D*-mannopyranoside* (**12**). — (*a*) To a stirred solution of **1** (59 mg, 0.2 mmol) and 70% aqueous *tert*-butyl peroxide (0.08 mL) in 1,4-dioxane (3.5 mL) was added M sodium hydroxide (0.35 mL) at room temperature. After stirring for 30 min, the mixture was diluted with chloroform. The organic layer was successively washed with aqueous sodium thiosulfate and water, dried, and evaporated to a solid residue, whose ^{1}H-n.m.r. spectrum showed that it was almost pure **12**, together with a trace of **11**. Recrystallization from ethanol–acetone gave 39 mg (63%) of **12**; m.p. 195–197°, $[\alpha]_D^{22}$ +102° (*c* 0.4, dichloromethane); ν_{max} 1555 cm^{-1} (NO_2).

Anal. Calc. for $C_{14}H_{15}NO_7$: C, 54.37; H, 4.89; N, 4.53. Found: C, 54.33; H, 4.71; N, 4.75.

(*b*) A mixture of **1** (88 mg, 0.3 mmol), 70% aqueous *tert*-butyl peroxide (0.12 mL), the catalyst (6 mg), benzene (6 mL), and 0.5M sodium hydroxide (0.6 mL) was stirred for 1.5 h at room temperature. The mixture was diluted with benzene and the organic layer successively washed with aqueous sodium thiosulfate and water, dried, and evaporated to give a solid residue (92 mg), the ^{1}H-n.m.r. spectrum of which showed that compound **12** thus obtained was almost pure, but was contaminated by a trace of **11**. The residue was chromatographed with successive elution by benzene–cyclohexane (1:1 and 2:1, v/v). The first fraction was 32 mg (34%) of **12**, identical with an authentic specimen. The second fraction was 6 mg (6%) of **11**, identical with an authentic specimen.

*Methyl 4,6-O-benzylidene-3-O-methyl-α-*D-arabino*-hexopyranosid-2-ulose oxime* (**13**). — Oxidation[13] of methyl 4,6-*O*-benzylidene-3-*O*-methyl-α-D-glucopyranoside[14] (2.0 g, 6.76 mmol) by Me_2SO afforded the glycosid-2-ulose. Without further purification, the latter was directly treated with hydroxylamine hydrochloride (564 mg, 8.12 mmol) in the presence of sodium acetate (1.22 g, 14.9 mmol) in boiling ethanol for 1 h under reflux. After cooling, the mixture was partitioned between water and chloroform. The organic layer was washed with water, dried, and evaporated. Recrystallization from ethanol gave 1.04 g (50%) of **13**; m.p. 190–191°, $[\alpha]_D^{22}$ −17.4°(*c* 1, dichloromethane); ν_{max} 3350 cm^{-1} (NOH).

Anal. Calc. for $C_{15}H_{19}NO_6$: C, 58.24; H, 6.19; N, 4.53. Found: C, 58.13; H, 6.13; N, 4.48.

*Methyl 4,6-O-benzylidene-2-deoxy-3-O-methyl-2-nitro-α-*D*-glucopyranoside* (**7**). — (*a*) *From the oxime* **13**. To a stirred solution of **13** (309 mg, 1 mmol), sodium hydrogencarbonate (2.76 g), and urea (20 mg) in 1,4-dioxane (4 mL) was added during 10 min a solution of trifluoroperoxyacetic acid in acetonitrile[15], prepared from trifluoroacetic anhydride (0.68 mL), 90% aqueous hydrogen peroxide (0.11

mL), and acetonitrile (1 mL). The mixture was stirred for an additional 2 h, diluted with water, and extracted with chloroform. The combined extracts were successively washed with aqueous sodium thiosulfate and water, dried, and evaporated. The residue was chromatographed, with chloroform as the eluant, to give crystals that were recrystallized from methanol to yield 188.5 mg (58%) of **7**; m.p. 158–159°, $[\alpha]_D^{22}$ +141° (*c* 0.84, chloroform); ν_{max} 1545 cm^{-1} (NO_2).

Anal. Calc. for $C_{15}H_{19}NO_7$: C, 55.38; H, 5.89; N, 4.31. Found: C, 55.36; H, 5.85; N, 4.25.

(*b*) *From the nitro alkene* **1**. To a solution of **1** (29 mg) in 1,4-dioxane (3 mL) was added 0.1M sodium methoxide (1 mL). The mixture was stirred for 30 min at room temperature and then deionized with Amberlite IR-120 (H^+) cation-exchange resin. The resin was filtered off and the filtrate evaporated. The residue (30 mg + 29 mg) was recrystallized from methanol to afford 41.2 mg (64%) of **7**, identical with an authentic specimen.

*Methyl 4,6-O-benzylidene-2-deoxy-3-O-methyl-2-nitro-α-*D*-allo-* (**8**) *and* -D-*altropyranoside* (**9**). — A solution of **1** (145 mg, 0.49 mmol) in methanol (15 mL) was gently boiled under reflux for 1 h in a water bath (bath temperature, 70–75°) and then evaporated to a syrup, the ^{1}H-n.m.r. spectrum of which revealed that it consisted of **8** and **9** in the ratio of ~3:1. Addition of isopropyl ether gave platelet crystals of the allopyranoside **8** (75 mg, 47% yield). From the ^{1}H-n.m.r. spectrum it appeared to be pure **8**, but t.l.c. showed two spots; (R_F 0.44, strong, benzene–ethyl acetate = 10:1 v/v) for **8** and a weak spot (R_F 0.58) corresponding to the glyc-1-enitol **14**. Most of the **8** was degraded during recrystallization from 2-propanol or ethanol, but a small amount of **8** was isolated, which again showed a weak spot corresponding to **14**. During column chromatography on silica gel, most of the allopyranoside was converted into a mixture of the glyc-1-enitol **14** and the 4-*O*-formyl derivative **15**, but a small amount of **8** could be isolated, which was again contaminated with **14** (t.l.c.). Two-dimensional t.l.c. decisively revealed that compound **8**, but not the altropyranoside **9**, was partially changed into the glyc-1-enitol **14** during t.l.c. Compound **8** thus isolated had m.p. 123.5–124.5°, $[\alpha]_D^{22}$ +95.8° (*c* 1, dichloromethane); ν_{max} 1550 cm^{-1} (NO_2).

Anal. Calc. for $C_{15}H_{19}NO_7$: C, 55.38; H, 5.89; N, 4.31. Found: C, 55.34; H, 5.77; N, 4.32.

The residue obtained by evaporation of the mother liquor crystallized from ethanol to give 25 mg of crystals that consisted mainly of the altropyranoside **9**. Recrystallization from ethanol yielded 13 mg (8.2% of **9**, which was pure by t.l.c. and ^{1}H-n.m.r. spectroscopy; m.p. 155–156°, $[\alpha]_D^{22}$ +57.6° (*c* 0.5, chloroform); ν_{max} 1550 cm^{-1} (NO_2).

Anal. Calc. for $C_{15}H_{19}NO_7$: C, 55.38; H, 5.89; N, 4.31. Found: C, 55.28; H, 5.887; N, 4.28.

*Methyl 4,6-O-benzylidene-2-deoxy-3-O-methyl-2-nitro-β-*D*-allopyranoside* (**17**). — A solution of **1** (1 g, 3.41 mmol) in methanol (100 mL) was heated under reflux (bath temperature, 65–70°) for 1 h and then evaporated to a syrup whose ^{1}H-

n.m.r. spectrum showed that it was a mixture of **8** and **9** in the ratio of ~1:1, together with a trace of the glyc-1-enitol **14**. Crystallization from isopropyl ether afforded 166 mg (15% yield) of the allopyranoside **14**. The filtrate was evaporated and crystallized from ethanol to give 135 mg of crystals. Recrystallization from ethanol provided 88 mg (8% yield) of **9**. The combined filtrates were evaporated to a syrup, to which addition of isopropyl alcohol afforded 23 mg (total yield, 10%) of **9**. The filtrate was evaporated to a syrup, which was chromatographed with benzene as the eluant. The first fraction (90 mg) consisted of the glyc-1-enitol **14** and the β-anomer **17**. Repeated recrystallization from 2-propanol yielded 25 mg (2.2%) of **17**; m.p. 127.5–128.5°, $[\alpha]_D^{22}$ −47.4° (*c* 1.1, dichloromethane); ν_{max} 1550 cm^{-1} (NO_2).

Anal. Calc. for $C_{15}H_{19}NO_7$: C, 55.38; H, 5.89; N, 4.31. Found: C, 55.78; H, 5.89; N, 4.31.

A mixture (40 mg) of **8** and **9** was eluted as the second fraction. The third fraction (210 mg) seemed to be a mixture consisting mainly of the 2-*O*-isopropyl derivatives corresponding to **16**, as judged from i.r. and ^{1}H-n.m.r. spectroscopy. The fourth fraction (70 mg) was crystallized from ethanol; its elemental analysis and i.r. spectrum satisfied the structure **16**, but the ^{1}H-n.m.r. spectrum showed that it was a mixture of 2-epimers.

1,5-Anhydro-4,6-O-benzylidene-2-deoxy-3-O-methyl-2-nitro-D-ribo-*hex-1-enitol* (**14**). — A solution of **1** (293 mg, 1 mmol) in methanol (26 mL) was heated under reflux (bath temperature, 80°) for 1 h and then completely evaporated. To the residue was added acetic anhydride (9.3 mL) and anhydrous sodium acetate (620 mg). The mixture was heated for 1 h at ~90° (bath temperature) and then evaporated (~2 mmHg). Flash column-chromatography[10] with benzene as the eluant gave 220 mg (75%) of crystalline **14**, pure enough for the next reaction. An analytical sample was prepared by recrystallization from isopropyl ether; m.p. 123.5–125°, $[\alpha]_D^{22}$ +129° (*c* 1, dichloromethane); ν_{max} 1630, 1510, and 1500 cm^{-1} (C=C-NO_2).

Anal. Calc. for $C_{14}H_{15}NO_6$: C, 57.34; H, 5.16; N, 4.78. Found: C, 57.36; H, 5.09; N, 4.83.

3,5-O-Benzylidene-1-deoxy-4-O-formyl-2-O-methyl-1-nitro-D-*ribitol* (**15**). — (*a*) Conventional column-chromatography of syrupy **14** (98 mg), obtained by the procedure just described, with benzene as the eluant afforded a mixture (30 mg) of **14** and **15** as the first fraction and **15** (48 mg) as the second fraction. An analytical sample of **15** was prepared by recrystallization from 2-propanol; m.p. 111–112° $[\alpha]_D^{22}$ −42° (*c* 1, dichloromethane); ν_{max} 1720, 1710 (CO), and 1545 cm^{-1} (NO_2).

Anal. Calc. for $C_{14}H_{17}NO_7$: C, 54.02; H, 5.51; N, 4.50. Found: C, 54.40; H, 5.62; N, 4.48.

(*b*) Glyc-1-enitol **14** (68 mg, 0.23 mmol) was dissolved in pyridine (0.8 mL)–water (0.8 mL). The mixture was stirred for 12 h at room temperature and then completely evaporated (~2 mmHg). The residue was chromatographed with benzene as the eluant to afford 58.5 mg (81%) of **15**, identical with an authentic specimen.

REFERENCES

1 T. SAKAKIBARA, Y. TACHIMORI, AND R. SUDOH, *Tetrahedron,* in press.
2 For example, H. O. HOUSE, *Modern Synthetic Reactions,* 2nd edn., W. A. Benjamin, California, 1972, p. 627.
3 F. JOHNSON, *Chem. Rev.*, 68 (1968) 375–413.
4 H. H. BAER AND J KOVÁŘ, *Can. J. Chem.*, 54 (1976) 2038–2044, and references cited therein.
5 T. SAKAKIBARA, Y. TACHIMORI, AND R. SUDOH, *Tetrahedron Lett.*, 23 (1982) 5545–5548.
6 Y. TACHIMORI, T. SAKAKIBARA, AND R. SUDOH, *Carbohydr. Res.*, 82 (1980) 51–58.
7 Y. TACHIMORI, T. SAKAKIBARA, AND R. SUDOH, *Carbohydr. Res.*, 95 (1981) 299–303.
8 For example, T. SAKAKIBARA, S. KUMAZAWA, AND T. NAKAGAWA, *Bull. Chem. Soc. Jpn.*, 43 (1970) 2655; H. H. BAER AND W. RANK, *Can. J. Chem.*, 49 (1971) 3192–3196.
9 Y. TACHIMORI, T. SAKAKIBARA, AND R. SUDOH, unpublished data.
10 W. C. STILL, M. KAHN, A. MITRA, *J. Org. Chem.*, 43 (1978) 2923–2925.
11 T. SAKAKIBARA, Y. TACHIMORI, T. MINAMI, AND R. SUDOH, *Carbohydr. Res.*, 91 (1981) 67–76.
12 For example, P. M. COLLINS, D. GARDINER, S. KUMÁŘ, AND W. G. OVEREND, *J. Chem. Soc., Perkin Trans. 1,* (1972) 2596–2610; H. H. BAER, *J. Carbohydr. Nucleos. Nucleot.*, 6 (1979) 51–80; T. SAKAKIBARA AND R. SUDOH, *J. Org. Chem.*, 42 (1977) 1746–1750.
13 J. YOSHIMURA, K. SATO, AND H. HASHIMOTO, *Chem. Lett.*, (1977) 1327–1330.
14 M. MILJKOVIĆ, M. GRIGORIJEVIĆ, AND D. MILJKOVIĆ, *J. Org. Chem.*, 39 (1974) 2118–2120.
15 W. D. EMMONS AND A. S. PAGANO, *J. Am. Chem. Soc.*, 77 (1955) 4557–4559.