Organoboron-Monosaccharides, XIV [1]
Routes to α- and β-D-Mannofuranosyl β-D-Mannofuranosides

Wilhelm Volker Dahlhoff* and Angelika Geisheimer

Max-Planck-Institut für Kohlenforschung, Kaiser-Wilhelm-Platz 1, D-4330 Mülheim an der Ruhr

Dedicated to Professor Dr. Dr. h. c. mult. Günther Wilke on the occasion of his 60th birthday

Z. Naturforsch. **40b**, 141–149 (1985); received October 15, 1984

α/β-D-Mannofuranosyl β-D-Mannofuranosides, Sodium-organooxytriethylborate, Organooxy-tri-*n*-butylstannane Intermediates

Stereoselective glycosylations of 2,3:5,6-di-O-ethylboranediyl-α-D-mannofuranosyl bromide (**1**) by two independent routes involving 1-O-tri-*n*-butyl-stannyl and 1-O-triethylborate α-D-mannofuranosyl derivatives give α-D-mannofuranosyl β-D-mannofuranoside (**8a**) after deprotection. β-D-Mannofuranosyl β-D-mannofuranosides can be prepared by reaction of **1** with the sodium triethylborate derivative of 2,3:5,6-di-O-isopropylidene-β-D-mannofuranose (**11**) and by reacting **1** with hexabutyldistannoxane. The latter approach allows the synthesis of β-D-mannofuranosyl β-D-mannofuranoside (**8b**) after total deprotection.

Introduction

1,1'-linked disaccharides (non-reducing disaccharides) constitute a special group of glycosides that are difficult to prepare stereoselectively as either three or four isomers can be formed [2–4]. The stereoselectivities are usually only satisfactory in favour of the most stable 1,2-*trans*-1,1'-disaccharides.

The first D-mannofuranosyl D-mannofuranoside was prepared by K. Freudenberg *et al.* in ~10% yield by reacting 2,3:5,6-di-O-isopropylidene-α-D-mannofuranosyl chloride with 2,3:5,6-di-O-isopropylidene-D-mannofuranose in the presence of silver carbonate [5]. Later a synthetic approach involving a betaine intermediate gave O-isopropylidene protected α-D-mannofuranosyl α-D-mannofuranoside in 20% yield [6]. The same disaccharide was also been reported as obtainable by a phase transfer method in 80% yield [7]. The data in both of these subsequent papers are in good agreement with the original publication [5] indicating that in all three cases the α,α-linked, *i.e.* most stable disaccharide was obtained.

It will be shown that both of the two remaining and hitherto unreported isomers, namely, α-D-mannofuranosyl β-D-mannofuranoside (**8a**) and β-D-mannofuranosyl β-D-mannofuranoside (**8b**) can be prepared from **1** in reactions which involve clean inversions at the anomeric centre of this O-ethylboranediyl protected glycosyl bromide. The use of **1** as a valuable educt for the syntheses of a series of β-D-mannofuranosides, when reacted with reactive O-nucleophiles such as sodium organooxytriethylborates [1] or O-tri-butyl stannyl derivatives [8] has been reported. Hence, assuming that **1** reacts with inversion, then in order to prepare **8a** and **8b** reactive α- and β-D-mannofuranosyl derivatives are needed as intermediates. These on reaction with **1** should then give the desired products.

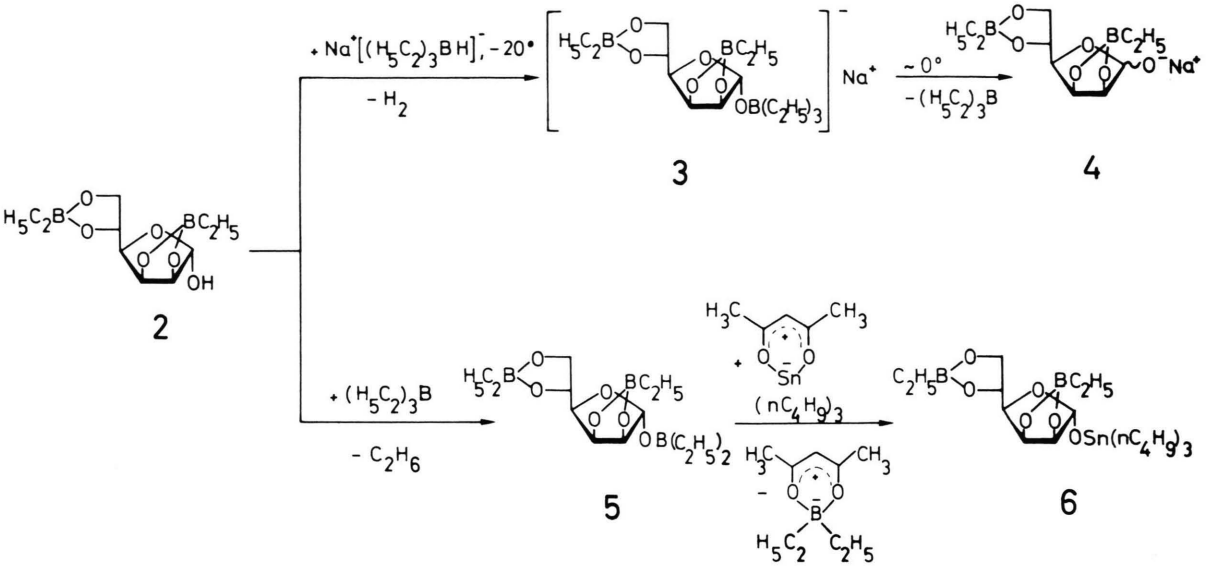
Results and Discussion

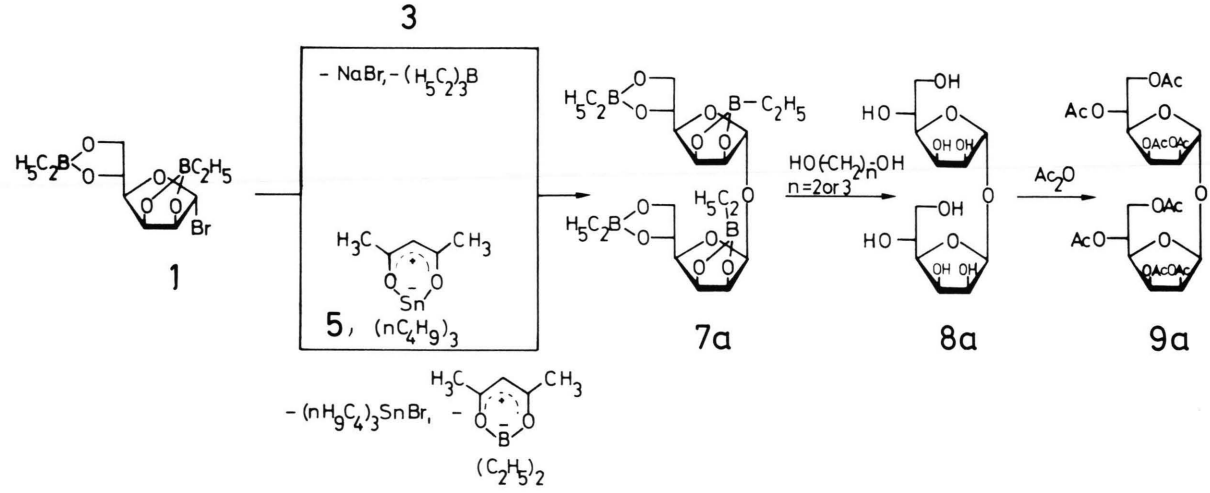
Two independent routes which permit the stereoselective syntheses of **8a** were investigated. In the first method [the borate route], the readily prepared 2,3:5,6-di-O-ethylboranediyl-α-D-mannofuranose (**2**) [9] is reacted with an equimolar amount of sodium triethylhydroborate at −20 °C to give the reactive sodium organooxytriethylborate **3** (Scheme 1).

As **3** eliminates triethylborane >0 °C, to give the insoluble alcoholate **4** which is unsuitable for the glycosylation step, **3** was prepared *in situ* at −20 °C prior to reaction with **1** (Scheme 2). In this way stoichiometric reaction of **1** with **3** gave ~95% pure (GC) O-ethylboranediyl protected α-D-mannofuranosyl β-D-mannofuranoside (**7a**) in essentially quantitative yield.

The second method, [the stannyl route], which was used in order to prepare **7a** involves conversion of **2** to the 1-O-diethylboryl substituted mannofuranosyl derivative **5** by reaction with activated triethylborane at room temperature [10]. **5** then reacts smoothly

* Reprint requests to Dr. W. V. Dahlhoff.
0340–5087/85/0200–0141/$ 01.00/0

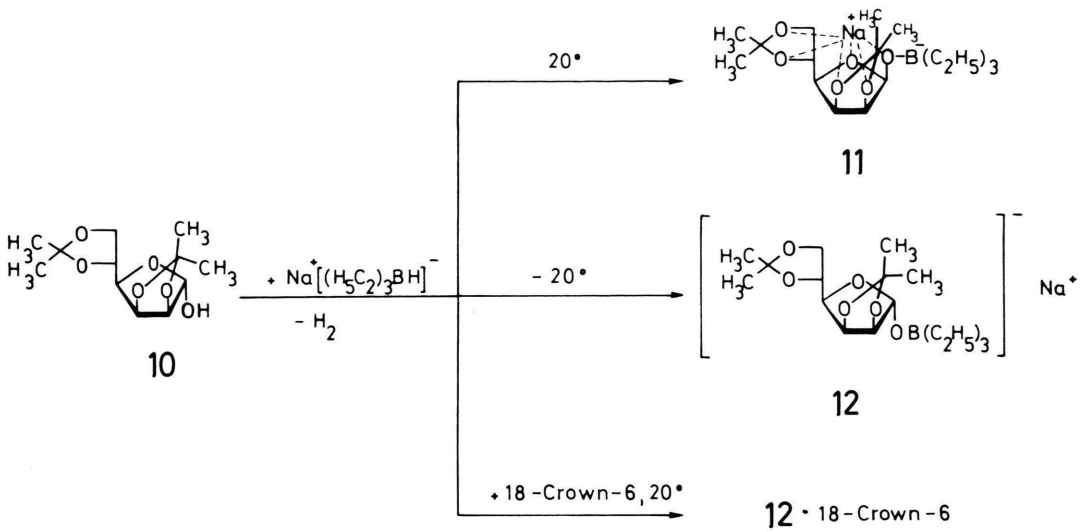




with tri-*n*-butylstannyl acetylacetonate [8b] to give the 1-O-tri-*n*-butylstannylated compound **6.** For glycoside synthesis, it is not necessary to isolate **6,** instead an *in situ* preparation was found to be more convenient. Thus after addition of an equimolar amount of tri-*n*-butylstannyl-acetylacetonate to **5,** tetra-*n*-butyl ammonium bromide catalyst is added prior to reaction with **1.** In this way **7a, b** are obtained in 90% yield with 85% **7b** (GC) after distilling off the volatile side-products. It should be noted that although both routes give **7a** stereoselectively in good yields, the appearance of the products differ considerably. The route *via* **3** gives colourless **7a** whereas the stannyl approach yields a brown residue. Thus the former mode of preparation is advantageous, in particular as colourless **7a** of 99% purity (GC) is easily obtained by addition of pentane to the crude reaction product.

Deprotection of **7a** with propane-1,3-diol/methanol causes no anomerisation or glycoside bond cleavage and pure **8a** is obtained as a colourless solid. The purity of the latter was also confirmed by conversion to the octaacetate **9a.**

For preparation of the least favoured β,β-linked isomer, reactive β-D-O-mannofuranosyl derivatives have to be synthesized. This can be realised by adopting the borate approach with 2,3:5,6-di-O-isopropylidene-D-mannofuranose (**10**) as the educt. After reaction with sodium triethyl-hydro-borate at room temperature, sodium-(2,3:5,6-di-O-isopropylidene-1-O-β-D-mannofuranosyl)-triethylborate (**11**) is obtained as a colourless solid (Scheme 3).

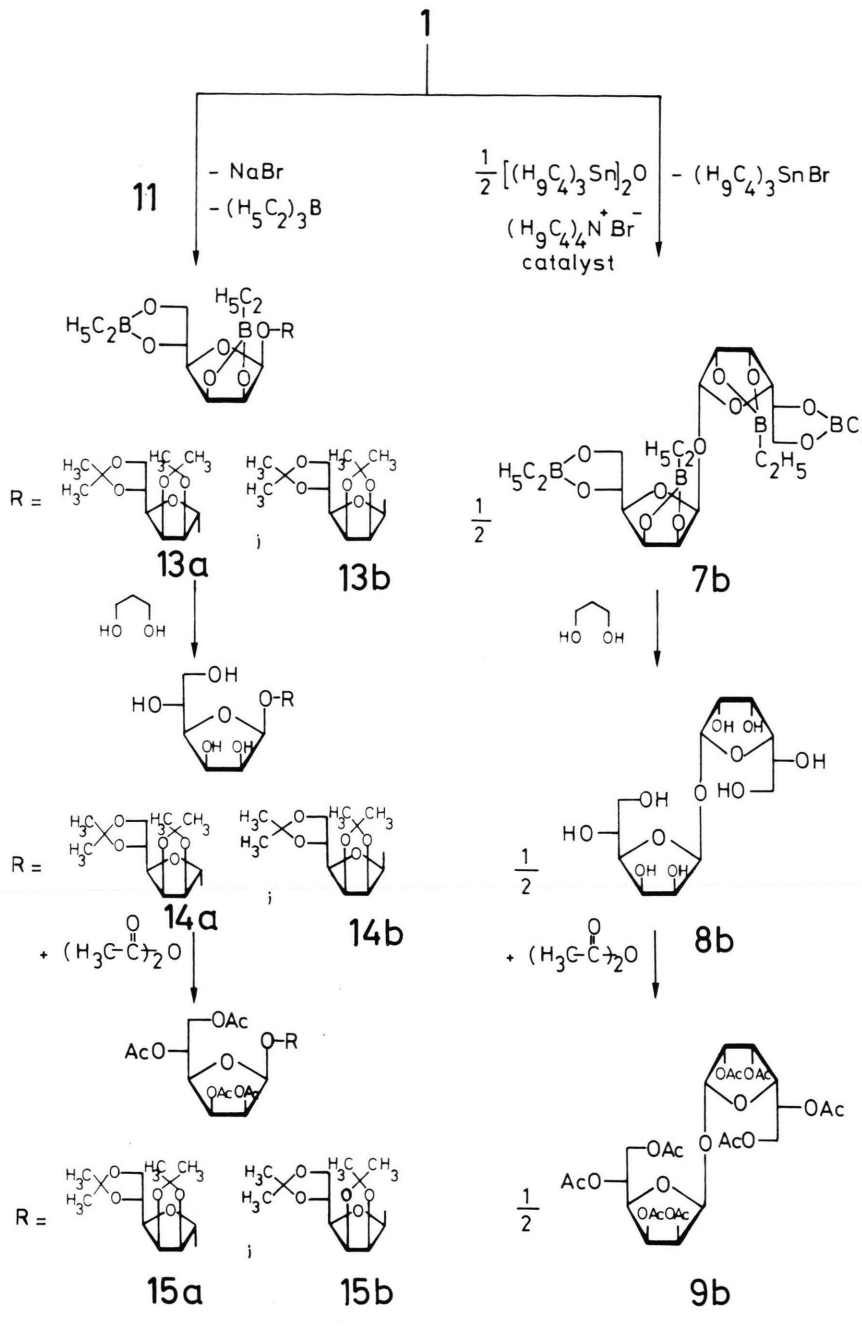


This is not surprising in the light of observations made which show that this moiety has a nearly ideal crown-ether arrangement for complexing the sodium cation [7, 11]. If the above reaction is carried out at −20 °C then the α-borate **12** is the major product initially. In the presence of 18-crown-6, crown ether complexation dominates and **12** with complexed sodium is formed. In contrast to **11** and **12,** we found the latter product to be unsuited for reactions with **1. 11** reacts smoothly with **1** to give disaccharides **13a, 13b.** Best results in favour of **13b** were obtained by preparing **11** *in situ* at room temperature and then cooling to −20 °C prior to addition of **1.** In this way an 85% yield of **13a** and **13b** in the ratio 20:80 was obtained. When the borate **12** was prepared at −20 °C and subsequently reacted with **1, 13a** and **13b** were formed in the opposite ratio of 75:25, reflecting the intermediacy of the kinetic product **12.** The reaction of isolated **11** with **1** was not as selective as the *in situ* preparation and 40% **13a** and 50% **13b** were found.

The mixture of **13a** and **13b** was deboronated to give the disaccharides **14a** and **14b** and subsequently O-acetylated giving the tetra-O-acetates **15a, 15b** prior to the easy separation of the two disaccharides by column chromatography. Both **15a** and **15b** were thus isolated in yields of ~40%. These products were then deacetylated in high yields to give pure **14a** and **14b.** It should be noted that pure **14a** can be separated from the mixture after deboronation by addition of ethanol. Crystalline **14a** (70% of total amount **14a** in the mixture) is obtained in this way.

To prepare the fully deprotected β-D-mannofuranosyl β-D-mannofuranoside **8b,** it is considered it to be a prerequisite that the intermediate should only contain O-ethylboranediyl protective groups, as these fulfil the requirement that they can be removed under mild non-acidic conditions which would not endanger the particularly acid-labile β-D-linkages in this disaccharide.

A reactive β-D-mannofuranosyl aglycone moiety required for reaction with **1** should lead to the de-



sired β,β-linked product. With this intention, two equivalents of **1** were reacted with hexa-*n*-butyldistannoxane[bis-(tributyltin)-oxide] in the presence of a catalytic amount of tetrabutylammonium bromide. It was anticipated that in the first reaction step **1** would react with inversion giving the labile 1-O-tri-*n*-butylstannyl 2,3:5,6-di-O-ethylboranediyl-β-D-mannofuranose, which must then react with **1** prior to anomerizing to the more stable α-D-isomer **6,** in order to give the desired β,β-linked product (**7b**).

Using this approach (Scheme 4), a product mixture was obtained which contained 65% **7b** as ascertained by GC and ^{13}C NMR. This mixture was de-

boronated with propane-1,3-diol to give the totally deprotected disaccharides **8a** and **8b** and subsequently acetylated to yield **9a** and **9b.**

In contrast to **9a, 9b** is only poorly soluble in diethyl ether and hence it could be isolated by extracting **9a** from the mixture with diethyl ether and purifying the insoluble product by column chromatography. In this way pure **9b** with m.p. 234–235 °C was obtained. Alternatively, the crude brown **7a** and **7b** reaction mixture was vacuum distilled to give colourless **7a, 7b.** Then after deprotection and acetylation pure **9b** could be obtained simply by adding diethylether and filtering off the poorly soluble **9b.** 80% of the total amount of **9b** in the mixture was easily isolated in this way. Pure **8b** was prepared from **9b** by deacetylation.

The NMR data for the new β-D-mannofuranosides are consistent with previous assignments [1]. The ^{1}H NMR spectra of the octa- and tetraacetates are listed in Table I.

Characteristic for the β-D-mannofuranosides is the coupling $^3J_{1,2}$ of 4–5 Hz. In contrast the O-isopropylidene and O-ethylboranediyl protected α-D-derivatives have $^3J_{1,2} < 1$ Hz. On deprotection this value increases to ~3 Hz, a value slightly lower than for the deprotected β-D-mannofuranosyl moiety.

The purities and anomeric configurations were easily ascertained by ^{13}C NMR spectroscopy. For the α-D-glycosides the C-1 signals are found in the range δ = 105–107.4 ppm, well-separated from the C-1 signals of the β-D-glycosides which fall in the range δ = 96–101 ppm.

In conclusion, the glycosylations of **1** with reactive 1-O-substituted mannofuranosyl derivatives allows the syntheses of both of the hitherto unreported α/β-D-mannofuranosyl β-D-mannofuranosides. As in a previous paper [1], smooth boron-assisted inversions occur when reacting **1** with reactive aglycones and deprotection does not endanger the labile glycosidic bonds. The fact that only two of the four possible disaccharide isomers are formed when **1** is reacted with **11** again clearly supports this concept as the boron-protected mannofuranosyl moiety portion is exclusively β-D-linked.

Similar glycosylations of other organoboron protected glycosyl bromides [12] are also effective. Hence the approaches described here are valuable for the preparation of other new 1,2-*cis* reducing and non-reducing disaccharides.

Experimental

All experiments were carried out in dry deoxygenated solvents under an argon atmosphere. – The GC analyses were carried out as described previously [1]. Conditions: for **7a, 7b,** 8 °C/min, 80–300 °C, He 1.5 bar, for **9a, 9b, 15a, 15b,** 10 °C/min, 150–320 °C, He 2.5 bar.

Details for spectroscopic and other analyses [14] are as given in **1.**

2,3:5,6-Di-O-isopropylidene-D-mannofuranose was prepared by conventional acetonation of D-mannose [13] and bis-(tributyltin)oxide was purchased from Aldrich-Chemie.

Table I. ^{1}H NMR Data (δ and $J_{H,H}$) for **9a, 9b, 15a** and **15b**[a].

Compound	MHz	Chemical shifts [ppm][b] H-1	H-2	H-3	H-4	H-5	H-6$_a$	H-6$_b$	H-1′	H-2′	H-3′	H-4′	H-5′	H-6′$_a$	H-6′$_b$
9a	400	5.39	4.92	5.63	4.34	5.28	4.68	4.21	5.17	5.26	5.56	4.50	5.28	4.59	4.08
9b	200	5.55	4.98	5.69	4.40	5.17	4.58	4.10							
15a	400	5.41	4.97	5.59	4.28	5.24	4.63	4.21	5.06	4.58	4.98	4.1[c]	4.39	4.1[c]	4.1[c]
15b	400	5.45	5.05	5.63	4.34	5.40	4.55	4.12	4.98	4.66	4.74	3.71	4.31	4.04	4.01
		Coupling constant [Hz] $J_{1,2}$	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$	$J_{5,6_a}$	$J_{5,6_b}$	$J_{6_a,6_b}$	$J_{1',2'}$	$J_{2',3'}$	$J_{3',4'}$	$J_{4',5'}$	$J_{5',6'_a}$	$J_{5',6'_b}$	$J_{6'_a,6'_b}$
9a	400	5.0	5.5	4.9	9.5	2.3	6.0	−12.4	2.9	4.9	4.9	8.4	2.3	4.3	−12.4
9b	200	4.7	5.7	5.3	10.0	2.3	4.6	−12.5							
15a	400	5.0	5.2	4.5	9.6	2.2	4.3	−12.4	0	5.9	3.4	–	–	–	–[d]
15b	400	4.8	5.9	4.9	9.6	2.2	4.5	−12.5	4.2	6.1	4.2	7.9	6.0	4.6	− 8.8

[a] Solvent $CDCl_3$; Instruments: 200 MHz Bruker AM 200, 400 MHz, Bruker WH 400 FT; [b] H-1–H-6, Tetra-O-acetyl β-D-mannofuranosyl moieties; [c] overlapping signals; [d] not determined.

1-O-Diethylboryl-2,3:5,6-di-O-ethylboranediyl-α-D-mannofuranose (**5**)

5 is prepared by the general method described in **10.** From **2** [9] (20 g, 78.2 mmol), colourless **5** (24.9 g, 99%) is obtained. $[\alpha]_D^{20}$ 15.6° (c 3.2, $CHCl_3$).

$C_{14}H_{27}B_3O_6$ (323.8)

Calcd	C 51.93	H 8.40	B 10.02	B_C 4.45,
Found	C 52.0	H 8.31	B 9.95	B_C 4.48.

1-O-Tri-n-butylstannyl-2,3:5,6-di-O-ethylboranediyl-α-D-mannofuranose (**6**)

Tri-*n*-butylstannyl-acetylacetonate [8b] (3.87 g, 9.9 mmol) is added to a stirred solution of **5** (3.9 mmol) in diethylether (30 ml) and after ½ h at room temperature the mixture is concentrated in vacuo (10^{-3} torr, 100 °C) to give **6** (5.1 g, 95%) as a pale yellow viscous residue with $[\alpha]_D^{20}$ 30° (c 2, $CHCl_3$).

MS (70 eV): *m/e* = 488 ($M-C_4H_9$, 67%), 361 (29%), 291 (48%), 235 (41%), 177 (65%), 99 (100%).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 106.17 (C-1), 87.63 (C-2), 80.93 (C-3), 80.70 (C-4), 74.76 (C-5), 67.11 (C-6), [$SnC^1H_2C^2H_2C^3H_2C^4H_3$: C^1 15.19, C^2 28.00, C^3 27.18, C^4 13.63], [7.71, 7.59 ($BCH_2\underline{C}H_3$)], 2.5 (br. $B\underline{C}H_2CH_3$).

$C_{22}H_{44}B_2O_6Sn$ (544.9)

Calcd	C 48.49	H 8.14	B 3.97	Sn 21.78,
Found	C 48.73	H 7.90	B 4.19	Sn 21.50.

2,3:5,6-Di-O-ethylboranediyl-α-D-mannofuranosyl 2,3:5,6-di-O-ethylboranediyl-β-D-mannofuranoside (**7a**)

A. Via **3** *(one-pot synthesis)*

A solution of sodium triethyl-hydro-borate (1.12 g, 9.18 mmol) in 15 ml diethyl ether is added dropwise at −20 °C in 2 h to a solution of **2** (2.35 g, 9.18 mmol) in diethyl ether (20 ml) and triethylborane (5 ml). Hydrogen is liberated (215 ml, 100%) and a gelatinous precipitate of **3** is formed to which a further 10 ml of diethyl ether is added. Then a solution of **1** (2.84 g, 8.9 mmol) in diethyl ether (15 ml) is added dropwise in the course of 1 h. After stirring for 18 h at −10 °C the precipitated sodium bromide is filtered off and the colourless filtrate is concentrated at 30 °C/10^{-3} torr to give colourless, solid **7a** (4.2 g, 93%) with m.p. 101 °C; $[\alpha]_D^{20}$ +13.3 (c 1.1, $CHCl_3$). GC analysis: 95% **7a** and 1% each of **7b** and the α,α-isomer.

B. Via **6** *(one-pot synthesis)*

A solution of tri-*n*-butylstannylacetylacetonate (2.9 g, 7.46 mmol) in diethyl ether (10 ml) is added to a stirred solution of **5** (2.42 g, 7.47 mmol) in diethyl ether (10 ml) at room temperature. The solution immediately turns yellow (formation of diethylborylacetylacetonate). Tetrabutylammonium bromide (0.72 g, 2.24 mmol) is then added and a solution of **1** (2.35 g, 7.37 mmol) in diethyl ether (20 ml) is added dropwise in the course of 40 min. After 1 h, the mixture is filtered and the filtrate concentrated at 100 °C/10^{-3} torr. A brown residue (3.31 g, 91%) containing (GC) 84.4% **7a,** 3.5% **7b** and 5.6% α,α-isomer is obtained. Data for pure **7a:** Isolated in 36% yield by precipitation with pentane. $[\alpha]_D^{20}$ 16.8° (c 0.7, $CHCl_3$) m.p. 114 °C.

MS (70 eV): *m/e* = 465 ($M-C_2H_5$, 1%), 239 (36%), 209 (17%), 141 (100%), 111 (93%), 99 (90%).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 106.3 (C-1, α-D), 100.6 (C-1, β-D), 85.0, 79.8, 82.3, 80.9, 79.8, 79.5, 74.2, 73.8, 67.6, 67.4, 7.65 ($BCH_2\underline{C}H_3$), 2.3 ($B\underline{C}H_2CH_3$).

^1H NMR (80 MHz, $CDCl_3$): δ = 5.21 ($J_{1,2} < 1$ Hz, H-1, α-D), 5.06 (d, $J_{1,2} \sim 4$ Hz, H-1, β-D), 5–3.7 (m); 0.9 (m, BC_2H_5).

$C_{20}H_{34}B_4O_{11}$ (493.7)

Calcd	C 48.65	H 6.94	B 8.76,
Found	C 48.65	H 7.15	B 8.58.

α-D-Mannofuranosyl β-D-mannofuranoside (**8a**)

Methanol (5 ml) and propane-1,3-diol (10 ml) are added to **7a** (1.8 g, 3.6 mmol) and the stirred mixture is concentrated at 60 °C/10^{-3} torr. More diol (2 ml) and methanol (5 ml) are added and the process is repeated to give a semi-solid boron-free residue. Methanol (20 ml) is added to the residue and the colourless solid is filtered off and dried to give **8a** (1.06 g, 85%) with m.p. 172 °C, $[\alpha]_D^{20}$ −11.4° (c 0.8, DMSO).

MS (70 eV): *m/e* = 275 (1%), 163 (16%), 145 (10%), 73 (63%), 31 (100%).

^{13}C NMR (75 MHz, DMSO-d_6): δ = 107.41 (C-1, α-D), 100.57 (C-1, β-D), 80.22, 79.77, 76.45, 72.25, 70.43, 69.86, 69.64, 69.44, 63.35 (C-6), 63.02 (C-6′).

$C_{12}H_{22}O_{11}$ (342.3)

Calcd	C 42.11	H 6.48,
Found	C 42.00	H 6.67.

Octa-O-acetyl α-D-mannofuranosyl β-D-mannofuranoside (**9a**)

8a (0.56 g, 1.64 mmol) is dissolved in pyridine (10 ml), acetic anhydride (10 ml) is added and the

mixture is stirred for 18 h at room temperature and 4 h at 50 °C. Concentration *in vacuo* (10^{-3} torr, 60 °C) gives sirupy **9a** (1.05 g, 94%) of 99.5% purity (GC), $[\alpha]_D^{20}$ −30.2° (c 1.3, $CHCl_3$).

MS (70 eV): *m/e* = 619 (M−CH_3COO, <1%), 331 (58%), 169 (34%), 43 (100%).

^{13}C NMR (75 MHz, $CDCl_3$): δ = [170.59, 170.45, 169.83, 169.68, 169.53, 169.46, 169.26 ($\underline{C}$−CH_3)], 105.45 (C-1, α-D), 100.01, (C-1, β-D), 76.53, 76.13, 75.82, 71.93, 70.55, 68.91, 68.53, 68.29, 62.77 (C-6), 62.60 (C-6'), [20.74, 20.68, 20.66, 20.64, 20.48, 20.35, 20.30, 20.25 ($\underline{C}\underline{C}H_3$)].

$C_{28}H_{38}O_{19}$ (678.6)
Calcd C 49.56 H 5.64,
Found C 49.95 H 5.52.

Sodium-(2,3:5,6-di-O-isopropylidene-1-O-β-D-mannofuranosyl)triethylborate (**11**)

10 (14.4 g, 55.3 mmol) is suspended in diethyl ether (30 ml) and a solution of sodium triethylhydroborate (7.35 g, 60.2 mmol) in diethyl ether (25 ml) is added dropwise in 1 h at room temperature during which times gas evolution occurs [1.58 l with 75% H_2 (MS), 96%]. Colourless **11** (18.5 g, 88%) is isolated by filtration and drying *in vacuo* (10^{-3} torr, 20 °C). Decomp. pt. 125–127 °C; $[\alpha]_D^{20}$ −11.3 (c 2.4, tetrahydrofuran).

^{11}B NMR (25.2 MHz, THF, $(H_5C_2)_2O$−BF_3 ext.): δ = 1.9 ppm (half-width ~340 Hz).

^{13}C NMR (75 MHz, THF-d_8): δ = [112.2, 109.2 $O_2\underline{C}(CH_3)_2$], 101.4 (C-1), 82.5, 80.4, 76.2, 74.2, 67.9 (C-6), [27.1, 26.0, 25.6, 24.1 ($O_2C(\underline{C}H_3)_2$)], 15.6, 15.4 (br. $B\underline{C}H_2CH_3$), 10.7 ($BCH_2\underline{C}H_3$).

$C_{18}H_{34}BNaO_6$ (380.3)
Calcd C 56.85 H 9.01 B 2.84 Na 6.04,
Found C 56.68 H 8.74 B 2.81 Na 5.73.

2,3:5,6-Di-O-isopropylidene-α- and β-D-mannofuranosyl 2.3:5,6-di-O-ethylboranediyl-β-D-mannofuranoside **13a** *and* **13b**

A solution of **11** (3.06 g, 8.04 mmol) in diethyl ether (30 ml) is added dropwise in the course of 5.5 h to a stirred solution of **1** (2.45 g, 7.68 mmol) in diethyl ether (30 ml) at 0 °C (bath temperature). The precipitated NaBr is filtered off 1 h after completion of the dropwise addition and the colourless filtrate is then concentrated *in vacuo* to give highly viscous, partially solid product (4.05 g, 106%) consisting of (GC) 42% **13a,** 51.2% **13b** and 4.3% in the monosaccharide range. $[\alpha]_D^{20}$ −7.4° (c 1.3, $CHCl_3$).

13a *and* **13b** *by preparing* **11** *in situ*

Diethyl ether (40 ml) is added to **10** (2.08 g, 8 mmol) and a solution of sodium triethylhydroborate (0.98 g, 8 mmol) in diethyl ether (20 ml) is added dropwise in 1½ h at room temperature. Hydrogen (185 Nml, 103%) is evolved and a colourless solid precipitates. Stirring is continued for ½ h and the mixture is cooled to −20 °C before adding a solution of **1** (2.5 g, 7.84 mmol) in diethyl ether (20 ml) in a dropwise manner during the course of 3½ h. The mixture was stirred overnight at −15 °C and then filtered to remove the sodium bromide. Concentration of the filtrate *in vacuo* (finally at 10^{-3} torr, 50 °C) gives colourless product (3.8 g, 97%) with $[\alpha]_D^{20}$ −16.3° (c 1.6, $CHCl_3$) containing **13a** and **13b** in the ratio 22:78 (by GC), 11.4% monosaccharide.

MS (70 eV): *m/e* = 483 (B_2, M−CH_3, 17%), 259 (B_0, 8%), 239 (B_2, 13%), 141 (B_1, 53%), 111 (B_1, 60%), 101 (B_1, 100%), 43 (78%).

^{13}C NMR (75 MHz, $CDCl_3$): δ = [114.33, 112.81, 109.33, 109.24 $O_2\underline{C}(CH_3)_2$], 105.87 (C-1, α-D), [100.44, 99.80, 99.49 (C-1, β-D)], 85.04, 81.18, 80.98, 80.61, 80.01, 79.70, 79.65, 79.48, 79.38, 79.09, 77.96, 74.29, 74.09, 73.42, 72.92, 67.65, 67.45, 66.87, 66.74 (C-6), [26.99, 26.93, 25.91, 25.57, 25.47, 25.22 (double int.), 24.56 $O_2C(\underline{C}H_3)_2$], [7.65, 7.61, 7.48, 7.41 ($BCH_2\underline{C}H_3$)], 2.7 (br. $B\underline{C}H_2CH_3$).

2,3:5,6-Di-O-isopropylidene α- and β-D-mannofuranosyl tetra-O-acetyl-β-D-mannofuranoside **15a** *and* **15b**

Propane-1,3-diol (20 ml) and pyridine (4 ml) are added to **13a, 13b** (6.38 g, 12.8 mmol) and all volatile components are then removed *in vacuo* (bath temperature 60 °C/10^{-3} torr). The boron-free semisolid residue of **14a, 14b** is dissolved in pyridine (30 ml) and acetic anhydride (20 ml) is added. After 40 h of stirring at room temperature the reaction is complete (TLC) and the mixture is concentrated *in vacuo* (10^{-3} torr/60 °C) to leave a viscous residue which is treated with diethyl ether (3×20 ml) and concentrated *in vacuo* (12 torr) each time. A straw-coloured foamy solid (7 g, 93%) consisting of (GC) 40% **15a** and 43.2% **15b** (14.6% monosaccharides) is obtained.

6.63 g of the above mixture was separated by column chromatography: 700 g silica gel; eluent ethyl acetate/pentane 1:1 (800 ml), 5 ml fractions. Fraction 10–25: 0.87 g (13.1%) monosaccharide, fractions 50–95: 2.43 g (37%) **15a,** GC: 94% **15a,** 0.7% **15b,** fractions 105–120: 2.65 g (40% **15b**), GC: 95% **15b,** 1.5% **15a.**

Data for **15a:** m.p. 40 °C, $[\alpha]_D^{20}$ −54.9° (c 0.5, $CHCl_3$).

MS (70 eV): *m/e* = 575 (M−CH_3, 7%), 533 (3%), 331 (15%), 185 (16%), 127 (13%), 101 (18%), 43 (100%).

^{13}C NMR (75 MHz, $CDCl_3$): δ = [170.39, 169.78, 169.70, 169.47 ($\overset{\circ}{C}CH_3$)], [112.87, 109.36 $O_2\underline{C}(CH_3)_2$], 106.58 (C-1, α-D), 98.88 (C-1, β-D), 85.31, 80.99, 79.76, 75.87, 73.08, 71.97, 69.01, 68.66, 66.88 (t), 62.72 (t), [27.00, 26.04, 25.32, 24.83 $O_2C(\underline{C}H_3)_2$], [20.68 (double int.), 20.53, 20.35 ($O\overset{\circ}{C}\underline{C}H_3$)].

$C_{26}H_{38}O_{15}$ (590.6)
Calcd C 52.89 H 6.49,
Found C 52.73 H 6.76.

Data for **15b:** $[\alpha]_D^{20}$ −60.7° (c 1.3, $CHCl_3$).

MS (70 eV): *m/e* = 575 (M−CH_3, 3%), 331 (28%), 185 (10%), 169 (17%), 127 (11%), 101 (21%), 43 (100%).

^{13}C NMR (75 MHz, $CDCl_3$): δ = [170.51, 169.96, 169.58, 169.45 ($O\overset{\circ}{C}\underline{C}H_3$)], [114.37, 109.3 $O_2\underline{C}(CH_3)_2$], 99.52, 97.51 (C-1, β-D), 80.45, 79.37, 78.22, 76.34, 73.58, 71.26, 69.12, 68.30, 66.88 (t), 63.00 (t), [26.97, 25.81, 25.74, 25.39 $O_2C(\underline{C}H_3)_2$], [20.71 (double int.), 20.54, 20.41 ($\overset{\circ}{C}\underline{C}H_3$)].

$C_{26}H_{38}O_{15}$ (590.6)
Calcd C 52.89 H 6.49,
Found C 52.80 H 6.55.

2,3:5,6-Di-O-ethylboranediyl-β-D-mannofuranosyl 2,3:5,6-di-O-ethylboranediyl-β-D-mannofuranoside (**7b**)

Tetrabutylammonium bromide (1.35 g, 4.2 mmol) is added to a solution of **1** (4.44 g, 13.9 mmol) in diethylether (12 ml) at 0°. A solution of hexabutyldistannoxane (4.2 g, 7.1 mmol) in diethylether (12 ml) is than added dropwise in 1 h to the stirred mixture. After 20 min catalyst is filtered off and the colourless filtrate is concentrated *in vacuo* (10^{-3} torr, 20°–110°) for 4 h. A dark brown product (3.45 g, 100%) is obtained with (GC) 63.6% **7b,** 22.3% **7a** and 7.4% of the α,α-isomer. $[\alpha]_D^{20}$ −22.3° (c 0.6, $CHCl_3$).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 99.6 (C-1), 80.01, 79.3, 81.14, 74.42, 67.37 (C-6), 7.66, 7.42 ($BCH_2\underline{C}H_3$), 2.5 (br. $B\underline{C}H_2CH_3$).

Octa-O-acetyl-β-D-mannofuranosyl β-D-mannofuranoside (**9b**)

The crude reaction product (1.37 g, 2.8 mmol) containing 64% **7b** is treated with pyridine (2 ml) and propane-1,3-diol (10 ml) and the stirred solution is concentrated *in vacuo* (10^{-3} torr, 60°). Highly viscous, brown **8a, 8b** mixture is obtained when is acetylated with acetic anhydride (10 ml) in pyridine (10 ml) for 18 h at room temperature and 4 h at 40°. After removal of the volatile components *in vacuo* (10^{-3} torr, 60°) dark brown residue (1.86 g, 99%) containing (GC) 61% **9b,** 23% **9a** is obtained. Diethylether (20 ml is added to the residue and the after stirring under reflux the ether is decanted off. This is repeated to give a brown solid (1.1 g, 61%) containing 80% **9b** which is purified by column chromatography (Stationary phase: aluminium oxide (10% water), eluent chloroform/acetonitrile (4/1)). The chromatographic separation of **9b** should be carried out with small portions (max. 400 mg) of the mixture. From 350 mg mixture with 80% **9b** (GC), pure **9b** (100 mg, 38% of total **9b** amount in the mixture) was isolated.

Data for pure **9b:** m.p. 234–235°, $[\alpha]_D^{20}$ −116.5 (c 0.6, $CHCl_3$). **9b** is insoluble in benzene or methanol and poorly soluble in tetrahydrofuran, acetonitrile and diethylether.

MS (70 eV): *m/e* = 619 (M−$CH_3\overset{\circ}{C}O$, <1%), 331 (50%), 169 (46%), 43 (100%).

^{13}C NMR (75 MHz, $CDCl_3$): δ = [170.47, 169.89, 169.55, 169.38 ($\overset{\circ}{C}CH_3$)], 96.07 (C-1), 76.07 (C-4), 71.39 (C-2), 68.99 (C-5), 68.33 (C-3), 62.78 (C-6), [20.70, 20.66, 20.45, 20.33 ($\overset{\circ}{C}\underline{C}H_3$)].

$C_{28}H_{38}O_{19}$ (678.6)
Calcd C 49.56 H 5.64,
Found C 48.50 H 5.40.

Alternative procedure for obtaining **9b** by obviating column chromatography.

A colourless mixture of **7a, 7b** (0.55 g, with (GC) 24% **7a** and 52.5% **7b**) which had been obtained in 45% yield by vacuum distillation (bp. 160°/10^{-3} torr) was deboronated with propane-1,3-diol (5 ml) concentrated *in vacuo* (10^{-3} torr) and acetylated (5 ml acetic anhydride, 5 ml pyridine). **9a, 9b** (0.74 g, 98%) is obtained with (GC) 44.5% **9b,** 33.5% **9a** and 5% α,α-isomer. Diethylether (10 ml) is added to this mixture and **9b** precipitates out. **9b** (260 mg, 79% of the total **9b** content in the mixture) is isolated by filtration and drying.

β-D-Mannofuranosyl β-D-mannofuranoside (**8b**)

9b (0.32 g, 0.47 mmol) is dissolved in chloroform (3 ml), methanol (5 mol) and sodium methoxide (3 mg) are added and the mixture is stirred at room temperature for 3 h. A colourless clear solution is obtained which is concentrated *in vacuo* (10^{-3} torr) to give solid **8b** (0.16 g, 99%) with m.p. 121°, $[\alpha]_D^{20}$ −126.1° (c 0.5, DMSO).

MS (70 eV): *m/e* = 275 (3%), 235 (9%), 163 (100%), 145 (81%), 127 (37%), 85 (97%), 43 (96%).

^{13}C NMR (75 MHz, DMSO-d_6): δ = 94.44 (C-1), 80.78 (C-4), 72.00 (C-2), 69.90 (C-5), 69.63 (C-3), 63.07 (C-6).

$C_{12}H_{22}O_{11}$ (342.3)
Calcd C 42.11 H 6.48,
Found C 42.03 H 6.51.

[1] W. V. Dahlhoff, A. Geisheimer, G. Schroth, and R. Mynott, Z. Naturforsch. **39b,** 1004 (1984).
[2] C. K. Lee, Developments in Food Carbohydrates, Vol. 2, Applied Science Publishers Ltd., London 1980, p. 5.
[3] J. Stanek, M. Cerny, and J. Pacak, The Oligosaccharides, Academic Press, New York 1965, p. 219.
[4] J. Yoshimura, K. Hara, T. Sato, and H. Hashimoto, Chem. Lett. **1983,** 319.
[5] K. Freudenberg, A. Wolf, E. Knopf, and S. H. Zaheer, Ber. **61,** 1743 (1928).
[6] W. A. Szarek, H. C. Jarrell, and J. K. N. Jones, Carbohydr. Res. **57,** C-13 (1977).
[7] P. Di Cesare and B. Gross, Carbohydr. Res. **58,** C-1 (1977).
[8] a) W. V. Dahlhoff and K. M. Taba, XIIth International Carbohydrate Symposium, Utrecht 1984, Abstract A 1.33;
b) K. M. Taba, R. Köster, and W. V. Dahlhoff, Synthesis **1984,** 399.
[9] W. V. Dahlhoff, A. Geisheimer, and R. Köster, Synthesis **1980,** 935.
[10] R. Köster, K.-L. Amen, and W. V. Dahlhoff, Liebigs Ann. Chem. **1975,** 752.
[11] R. R. Schmidt, U. Moering, and M. Reichrath, Chem. Ber. **115,** 39 (1982).
[12] W. V. Dahlhoff and R. Köster, Heterocycles **18,** 421 (1982).
[13] Methods in Carbohydr. Chemistry, R. L. Whistler and M. L. Wolfrom (eds): Vol. II, Academic Press, New York and London 1963, p. 318.
[14] Dr. R. Benn, G. Schroth (^1H NMR), Dr. R. Mynott, B. Gabor, B. Bongard (^{13}C NMR), Dr. D. Henneberg, H. Damen, D. Schmöller, W. Joppek (MS), Dr. G. Schomburg, F. Sagheb, J. Rosentreter (GC), Dr. G. Schomburg, A. Deege, H. Hinrichs (HPLC), Max-Planck-Institut für Kohlenforschung, Mülheim a.d. Ruhr.