Chiral Aldehydes by Ring Contraction of Pento- and Hexopyranoside Epoxides

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The chiral aldehydes (−)-(2*S*,5*S*)- and (−)-(2*S*,5*R*)-2-[[[dimethyl(1,1,2-trimethylpropyl)silyl]oxy]methyl]-5-methoxy-2,5-dihydrofuran-3-carbaldehyde (**2** and **4**) were synthesized in 60 and 15% yield, respectively, by lithium bromide induced rearrangement of 6-*O*-silylated methyl 2,3- and 3,4-anhydro-α- and -β-D-hexopyranosides, obtained in two steps from methyl α- and β-D-glucopyranoside. Rearrangement of various other pento- and hexoside epoxides permitted the suggestion of probable reaction routes. Hydrogenation of the unsaturated aldehydes gave the corresponding saturated aldehydes in good yield.

Rearrangement of epoxycyclohexanols into α,β-unsaturated cyclopentenals are currently being investigated in our laboratory.[1] Over the last few years we have concentrated our efforts on the synthesis of chiral aldehydes by lithium bromide induced rearrangement of sugar epoxides.[2] The enantiomeric isoprenoid aldehydes **1r** and **1s** synthesized from D- and L-arabinose, respectively, were later used as starting materials for the synthesis of enantiomerically pure norbornane derivatives,[3] the mycotoxin botryodiplodin,[4] and several naturally occurring lignans.[5] We now report our further synthetic efforts to prepare **1r** and **1s** and on the synthesis of the new aldehydes **2–8** (Scheme I, Table I) from the sugar epoxides **9–22**. In addition, the 1,6-anhydro epoxides **23–26** were investigated and shown (as expected) to be unsuitable for rearrangement into aldehydes. The new aldehydes **2–8** should find use as chiral synthons for the preparation of many different types of natural products.

In previous papers[1,2] we have suggested, based on deuterium-labeling experiments, a general synthetic route consisting of bromide ion mediated opening and closing of epoxide rings in equilibrium with the corresponding bromohydrins followed by ring contraction and loss of water to form five-membered-ring α,β-unsaturated aldehydes. In the present investigation, we present additional information that supports our earlier mechanistic interpretations.

The rearrangement of **9r** (Chart I) was investigated under many different reaction conditions where reagents, solvents, and temperature were varied. In no case was the yield of **1r** improved over that obtained with our original reaction conditions (LiBr/*N*,*N*,*N*′,*N*′-tetramethylurea (TMU), refluxing toluene). A series of pentopyranosides (**9–17**) were investigated and the results are shown in Table I. The cis epoxy alcohols **9** and **14** gave a higher yield of **1** than the trans epoxy alcohols **15** and **16**. The methoxy epoxides **10** and **13** reacted very slowly and 52% and 48%, respectively, were recovered after prolonged reaction times. None of the desired aldehyde was isolated. With **13**, the 4- and 3-bromodeoxy compounds **27** and **28** (Scheme II) were formed in 28% yield in a 4:1 ratio, whereas **10** gave only **29** in 23% yield. The iodohydrin **11** was as efficient as **9s** in producing **1s**. Finally, an attempt was made to rearrange the thioglycoside epoxide **17**. However, only a low yield (ca. 5%) of a mixture of aldehydes was obtained. No attempt was made to determine the structure or to improve the yield.

Table I. Yields of Aldehydes by Rearrangement of Pentoside and Hexoside Epoxides (cf. Chart I)

entry no.	starting mtrl (confgn)	reactn condtns[a]	product	yield[b] (%)
1	**9r** (β-D-ribo)	A	**1r**	27
	9s (β-L-ribo)	A	**1s**	(ref 2)
	9s$_d$ (β-L-ribo)	A	**1s**$_d$	(ref 2)
	9s$_{d'}$ (β-L-ribo)	A	**1s**	(ref 2)
2	**9r** (β-D-ribo)	B	**1r**	17
3	**9r** (β-D-ribo)	C	**1r**	28
4	**9r** (β-D-ribo)	D	**1r**	29
5	**9s** (β-L-ribo)	E	**1s**	22
6	**10** (β-D-ribo)	A	**10**, **29**	48, 23
7	**11** (β-L-xylo)	F	**1s**	22
	12s (β-L-ribo)	A	**1s**	(ref 2)
	12s$_d$ (β-L-ribo)	A	**1s**$_d$	(ref 2)
8	**13** (β-D-ribo)	A	**13**, **27**, **28**	52, 22, 4
9	**14** (α-D-ribo)	A	**1s**	21
10	**15r** (α-L-lyxo)	A	**1r**	14
11	**15s**$_d$ (α-D-lyxo)	A	**1s**, **1s**$_d$	9, 3
12	**16** (β-L-lyxo)	A	**1s**	16
13	**17** (α-D-ribo)	A	*c*	5
14	**18** (α-D-allo)	A	**2**, **30**[d]	58
15	**19** (α-D-galacto)	A	**2**	59
16	**20** (α-D-manno)	A	**2**	24
17	**21** (β-D-allo)	A	**4**	15
18	**22** (β-D-allo)	A	**4**, **21**	10, 5
19	**23** (β-D-allo)	A	*e*	
20	**24** (β-D-manno)	A	*e*	
21	**25** (β-D-allo)	A	*f*	
22	**26** (β-D-manno)	A	*f*	

[a] A: LiBr/TMU, toluene, 110 °C. B: LiBr/TMU, 2,6-di-*tert*-butyl-4-methylphenol, toluene, 80 °C. C: LiBr, *o*-dimethoxybenzene, 120 °C. D: LiBr/TMU, xylene, 140 °C. E: LiI/TMU, toluene, 110 °C. F: Lithium triphenylmethoxide, toluene, 110 °C. [b] Isolated yield. [c] Inseparable mixture of three aldehydes. [d] A small amount of **30** (→ **31**) was obtained by chromatography. [e] Starting material was destroyed and no aldehyde was formed. [f] Starting material was recovered.

The methyl α-D-hexoside epoxides **18**, **19**, and **20** (Chart I) gave the 2,5-trans aldehyde **2** in 58, 59, and 24% yield, respectively. No other aldehyde was formed. A small amount of the methyl 4-bromodeoxy-α-D-guloside **30** (isolated as the corresponding bis-dinitrobenzoate **31**; Scheme II) was formed in the rearrangement of **18**. The structure of **31** was determined by ^{1}H NMR. The absence of large coupling constants for the pyranosidic ring hydrogens rules out altro and gluco configurations and is indicative of a guloside. A coupling constant of 1.5 Hz was found for the signals at 4.66 and 4.34 ppm (H-4 and H-5, respectively), which showed that the bromine is situated in the 4-position.

(1) Bergman, R.; Magnusson, G. *J. Org. Chem.* **1986**, *51*, 212.
(2) Sundin, A.; Frejd, T.; Magnusson, G. *J. Org. Chem.* **1986**, *51*, 3927.
(3) Sundin, A.; Frejd, T.; Magnusson, G. *Tetrahedron Lett.* **1985**, *26*, 5605.
(4) Rehnberg, N.; Frejd, T.; Magnusson, G. *Tetrahedron Lett.* **1987**, *28*, 3589. Rehnberg, N.; Magnusson, G. *Acta Chem. Scand.* **1990**, *44*, 377.
(5) Rehnberg, N.; Magnusson, G. *Tetrahedron Lett.* **1988**, *29*, 3599. Rehnberg, N.; Magnusson, G. *J. Org. Chem.* **1990**, *55*, 4340.

0022-3263/90/1955-5467$02.50/0

Scheme I

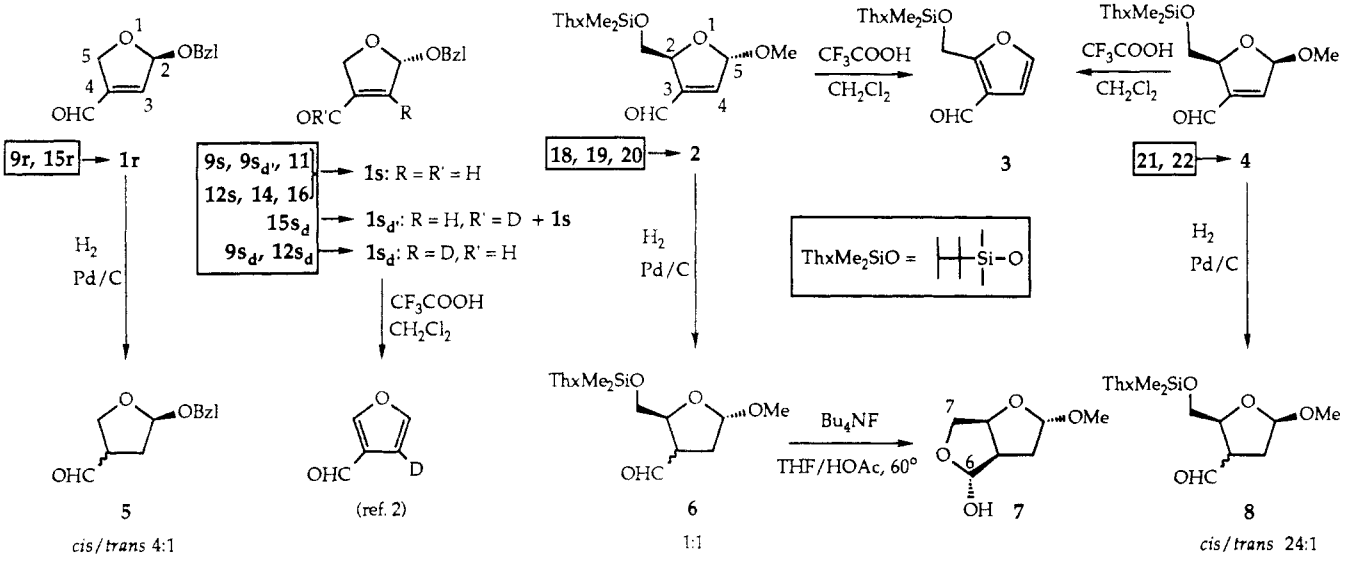
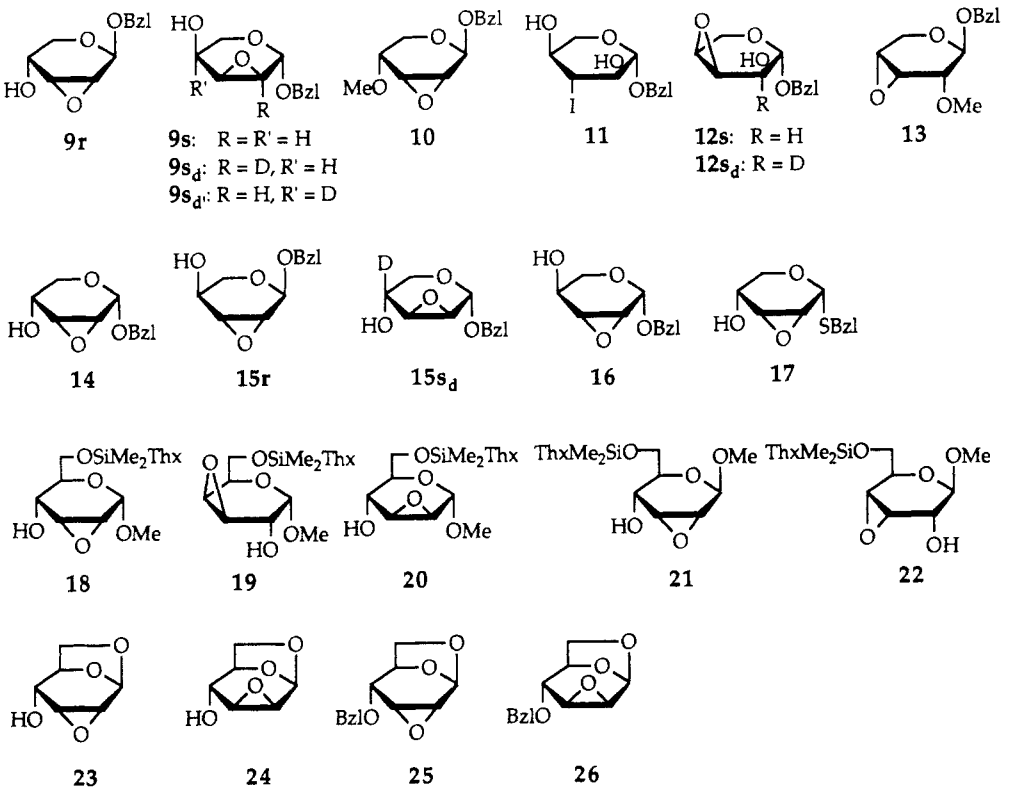


Chart I



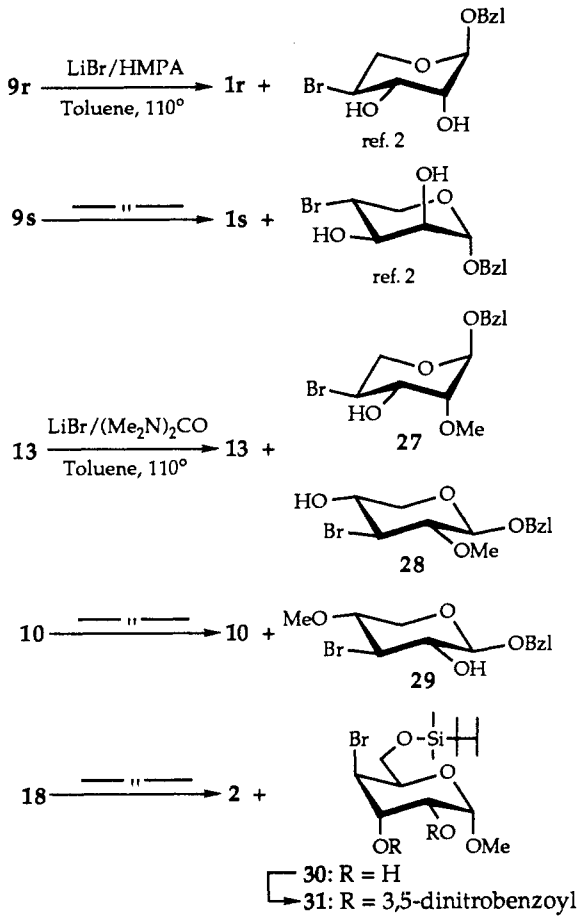
The methyl β-D-hexoside epoxides **21** and **22** gave the 2,5-cis aldehyde **4**, albeit in low yield (ca. 15 and 10%, respectively). A small amount of **21** was isolated as a byproduct in the rearrangement of **22**, indicating an equilibrium (cf. Scheme V). The yield of **2** was quite acceptable but that of **4** was low. However, the preparative procedures have merit because of the unique structures and enantiomeric purity of **2** and **4**, their convenient isolation by simple filtration on a short column of silica gel, and the preparation in only three steps from commercially available methyl α- and β-D-glucopyranoside. It was not rigorously proven that **2** and **4** were enantiomerically pure. However, racemization is highly improbable since it must include epimerization at both C-2 and C-5.

The structures of **2** and **4** were determined as follows. The chemical shifts of the key hydrogens and carbons were very similar in all the aldehydes **1**, **2**, and **4** (Table II). The structure of **1** has been unequivocally determined[2-5] and, therefore, the 3-position of the formyl group in **2** and **4** is strongly indicated. Structural proof came from various chemical transformations of **2** and **4**, which gave the al-

Table II. Chemical Shifts of Key Hydrogens and Carbons in Aldehydes 1, 2, and 4

atom type	chemical shift (δ, ppm)		
	1	2	4
OC*H*O	6.08	5.91	5.82
=C*H*	6.69	6.68	6.70
C*H*O	9.91	9.88	9.87
*O*CHO	107.3	108.0	107.8
*=*CH	140.4	142.5	142.4
*C*HO	187.1	187.1	187.1

Scheme II

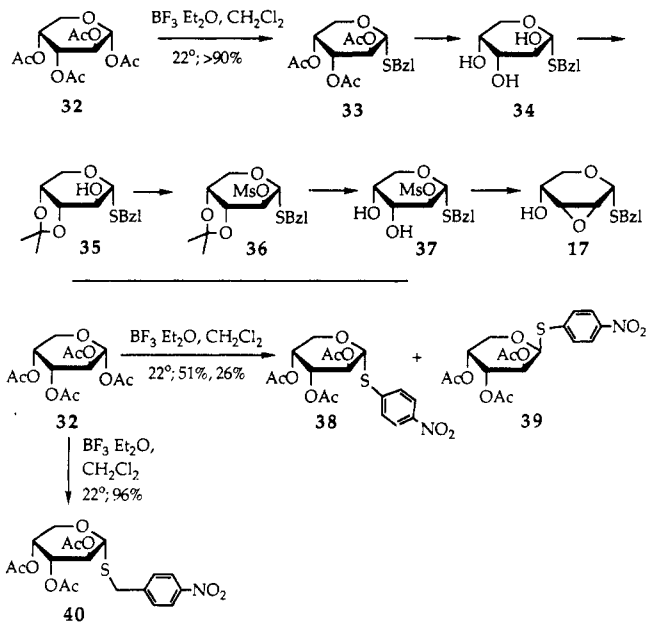


dehydes **3** and **6**–**8** (see below).

Finally, all attempts to produce aldehydes by rearrangement of the known[6] epoxides **23**–**26** failed as expected since the necessary conformational "flip" (cf. Scheme V) is not possible due to their conformational rigidity. The epoxy alcohols **23** and **24** were destroyed during the lithium bromide reaction, whereas the benzyl ether epoxides **25** and **26** were rather unreactive (or the epoxide rings were reversibly opened) and permitted only the isolation of starting material even after prolonged reaction time (2.5 h).

Hydrogenation of the aldehydes **1**, **2**, and **4** gave the corresponding saturated aldehydes **5**, **6**, and **8** (Scheme I) as cis/trans mixtures (4:1, 1:1, and 24:1, respectively) in 75, 72, and 63% isolated yields. The bulkiness of the various substituents present on the dihydrofuran rings of **1**, **2**, and **4** determines the ratio of the two diastereomers formed in each case. The structure of the major isomer of **5** was determined by ^{1}H NMR. One of the H-3 proton signals exhibited a large geminal (ca. 13 Hz) and two small vicinal coupling constants (0.6 and 2.9 Hz) indicative of a 2,3- and 3,4-trans relationship.[7] Therefore, the formyl group and the benzyloxy group must be cis oriented as expected due to stereoselective hydrogenation of **1** from the least hindered side. The major isomer of **8** showed no diagnostic coupling constants (i.e., $J < 4.3$ Hz[7]) for H-3 and the configuration of the formyl group cannot be determined. However, hydrogenation of **4** should occur, as

Scheme III



with **1**, from the least hindered side predominantly to give **8** having all three ring substituents in a cis arrangement.

Desilylation of **6** caused the 2,3-cis isomer to cyclize and the hemiacetal **7** was obtained pure in 28% yield. The configuration of the hydroxyl group of **7** was evident from the ^{1}H NMR coupling constant $J_{7,4} = 2.3$ Hz. In the alternative (endo) configuration, the coupling constant should be in the range 4.3–6.8 Hz.[7] The 2,3-trans isomer of **6** did not cyclize (no isomeric hemiacetal was found in the reaction mixture), presumably because the product would be highly strained.

Treatment of **2** and **4** with trifluoroacetic acid in dichloromethane caused 2,5-elimination of methanol, and the furan aldehyde **3** (Scheme I) was formed in 57 and 76% isolated yields, respectively. In a similar fashion, **1** gave furan-3-carboxaldehyde by elimination of benzyl alcohol.[2] The two aromatic protons in **3** are vicinally situated as indicated by the ^{1}H and ^{13}C NMR chemical shifts and H-4,5 coupling constant (1.8 Hz), which established the structure.[8]

The epoxides **9r**, **9s**, **9s$_d$**, **9s$_{d'}$**, **12s**, **12s$_d$**, **15r**, **15s$_d$**, and **16** have been reported.[2,9] The thioglycoside epoxide **17** was prepared in 60% overall yield from 1,2,3,4-tetra-*O*-acetyl-α-D-arabinopyranose **32** (Scheme III). Boron trifluoride etherate induced glycosylation[10] of α-toluenethiol, using **32** as glycosyl donor, gave crude glycoside **33** and deacetylation (→ crude **34**), followed by acetonide formation gave crystalline **35** (90%). Mesylation (→ crude **36**), removal of the acetonide group (→ crude **37**), and treatment with methanolic sodium methoxide gave crystalline **17**. All intermediates, except **35**, were used without purification. We were pleased with the high yielding BF_3-mediated glycosylation of α-toluenethiol and investigated a few additional thiols under similar reaction

(6) (a) **23**, **25**: Cerny, M.; Trnka, T.; Beran, P.; Pacak, J. *Collect. Czech. Chem. Commun.* **1969**, *34*, 3377. (b) **24**, **26**: Trnka, T.; Cerny, M. *Collect. Czech. Chem. Commun.* **1971**, *36*, 2216. (c) **24**: Thiem, J.; Prahst, A.; Lundt, I. *Liebigs Ann. Chem.* **1986**, 1044.

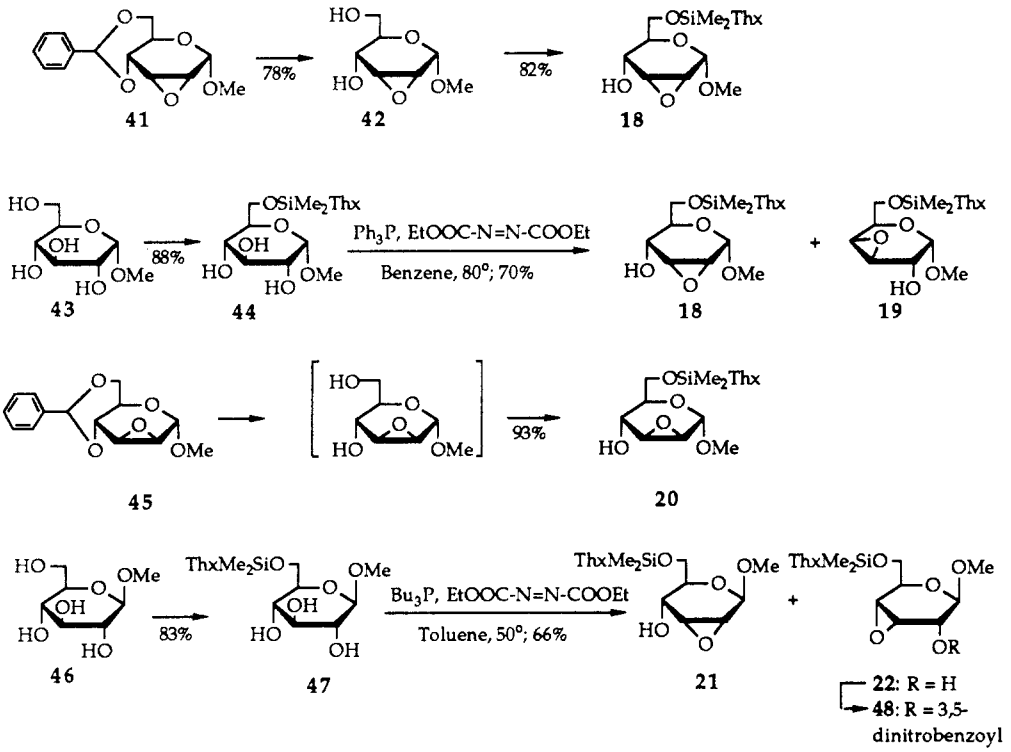
(7) Stevens, J. D.; Fletcher, H. G., Jr. *J. Org. Chem.* **1968**, *33*, 1799.

(8) (a) Gronowitz, S.; Johnson, I.; Hörnfeldt, A.-B. *Chem. Scr.* **1975**, *7*, 211. (b) *Tables of Spectral Data for Structure Determination of Organic Compounds*; Springer Verlag: Berlin, Heidelberg, 1989.

(9) (a) **9r**, **10**: Garegg, P. J. *Acta Chem. Scand.* **1960**, *14*, 957. (b) **9s**: Holy, A.; Sorm, F. *Collect. Czech. Chem. Commun.* **1969**, *34*, 3383. (c) **14**: Buchanan, J. G.; Clode, D. M.; Vethaviyasar, N. *J. Chem. Soc., Perkin Trans. 1* **1976**, 1449. (d) **9r**, **9s**: Pettersson, L.; Frejd, T.; Magnusson, G. *J. Org. Chem.* **1984**, *49*, 4540. (e) **15s$_d$**: ref 2. (f) **14**, **16**: Inghardt, T.; Frejd, T.; Magnusson, G. *J. Org. Chem.* **1988**, *53*, 4542.

(10) (a) Ferrier, R. J.; Furneaux, R. H. *Methods Carbohydr. Chem.* **1980**, *8*, 251. (b) Dahmén, J.; Frejd, T.; Magnusson, G.; Noori, G. *Carbohydr. Res.* **1983**, *114*, 328.

Scheme IV



conditions. *p*-Nitrothiophenol gave a separable 2:1 mixture of the α- (**38**) and β-arabinosides (**39**) in 77% yield whereas *p*-nitro-α-toluenethiol gave the pure α-glycoside **40** in 96% isolated yield. The structures of **38** and **39** were determined by ^{1}H NMR analysis: $J_{2,3}$ is large for both compounds (8.0 and 10.5 Hz, respectively), which indicates a $^1C_4$ conformation. The chemical shifts and coupling constants for the anomeric protons of **38** and **39** (5.03 ppm/7.1 Hz and 6.14 ppm/5.2 Hz) are indicative of α- and β-thioglycosides, respectively.

Selective silylation in the 6-position of methyl 2,3-anhydro-α-D-gluco- and -mannopyranoside using dimethyl(1,1,2-trimethylpropyl)chlorosilane furnished the epoxy alcohols **18** and **20** in 82 and 93% yield, respectively (Scheme IV). The silylated glycosides **44** and **47** were treated with the Mitsunobu reagent triphenylphosphine or tributylphosphine and diethyl azodicarboxylate (essentially as described for the corresponding *tert*-butyldimethylsilyl ethers[11]) to give mixtures of **18** and **19** (70%; 4:1) and **21** and **22** (66%; 8:5), respectively. The mixtures were separated by column chromatography to give pure **18**, **19**, and **21**. Compound **22** was impure and the corresponding dinitrobenzoate **48** was prepared for structural analysis. The epoxide mixtures **18**/**19** and **21**/**22** are preferably used without separation since **18** and **19** rearrange into aldehyde **2** with similar efficiency, which is also the case for rearrangement of **21** and **22** into **4** (Table I).

The epoxides **23**–**26** (Chart I) were prepared according to literature procedures starting from laevoglucosan.[6]

Mechanistic Considerations. The ring-opening, formation, and rearrangement reactions of epoxides under basic or neutral conditions are governed by a few empirical rules: (i) the ring opening is S_N2 (or borderline S_N2) in character; (ii) metal ions (e.g. Li^+, Mg^{2+}) catalyze the ring opening; (iii) in cyclohexane and pyranose epoxides, the ring opening is trans-1,2-diaxial in character (Fürst–Plattner rule); (iv) epoxide ring formation from halohydrin salts requires a 1,2-trans-diaxial arrangement of the participating groups (microscopic reversibility of the Fürst–Plattner rule); (v) in the rearrangement of cyclohexane and pyranose derivatives, the migrating group and the leaving group must have an antiperiplanar relationship, which means that the leaving group must be equatorial. By following these rules we rationalized the product pattern from LiBr-induced rearrangement of various deuterated epoxycyclohexanols into cyclopentenecarbaldehydes and cyclohexenones.[1] A similar investigation with epoxypentopyranosides showed the same principles at work.[2] The present investigation with the pentosides **9**–**17** corroborates earlier findings and helps to rationalize the rearrangements of the hexosides **18**–**22**.

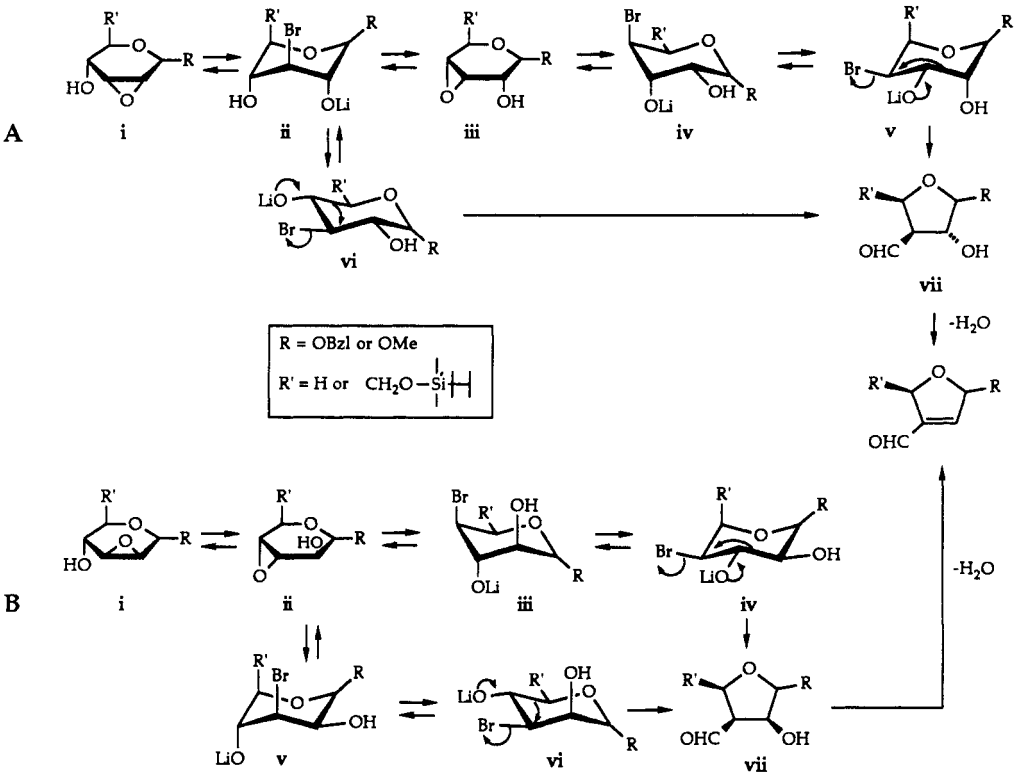
The benzyl 2,3-anhydroribosides **9** gave aldehydes **1** and the benzyl 4-bromodeoxylyxosides shown in Scheme II. The deuterated compound **9s**$_{d'}$ gave **1s**, which had lost the deuterium label, whereas **9s**$_d$ and **12s**$_d$ gave **1s**$_d$ carrying a vinylic deuterium label. This is only compatible with the route Ai → Av (Scheme V; only the D series of the sugars is shown), which was corroborated by the observation that the 3-iodoxyloside **11** gave **1s** in approximately the same yield as did **9s**.

The benzyl 4-methoxy-2,3-anhydro-β-D-riboside **10** reacted much slower with bromide ion than the corresponding epoxy alcohols **9** and **12**. No aldehyde was formed and approximately half of the starting material was recovered together with the expected benzyl 3-bromodeoxyxyloside **29** (cf. Table I and Scheme II). Compound **29** should, in principle, be able to rearrange (via the methoxy analogue of Aii but in the $^4C_1$ conformation) to an aldehyde carrying the formyl group vicinal to the anomeric carbon. However, none of the epoxides have produced such aldehydes. Baer and co-workers[12] on the other hand reported migration of the anomeric carbon on treatment of a hexoside tosylate with lithium triethylborohydride, which gave the corresponding primary alco-

(11) Brandstetter, H. H.; Zbiral, E. *Helv. Chim. Acta* **1980**, *63*, 327.

(12) Baer, H. H.; Astles, D. J.; Chin, H.-C.; Siemsen, L. *Can. J. Chem.* **1985**, *63*, 432.

Scheme V



hol, presumably via reduction of an intermediary aldehyde.

The benzyl 2-methoxy-3,4-anhydro-β-D-riboside **13** gave as the main product the benzyl 4-bromodeoxy-α-L-lyxoside **27**, which is a close relative to the intermediate (see above) Av and was therefore expected to rearrange to give **1r** via elimination of methanol. However, as with the 4-methoxy epoxide **10**, the 2-methoxy epoxide **13** did not rearrange, and it seems as if the methoxy group (in contrast to the hydroxy group) retards the rearrangement reaction. This example adds to the abundant literature on how subtle structural changes may alter the outcome of molecular rearrangements.

The benzyl 2,3-anhydro-α-D-riboside **14** gave **1s**. It is possible that the intermediate Aii rapidly undergoes a conformational flip to Avi (stabilized due to the anomeric effect) avoiding the formation of Aiii and thereby rearranging directly to Avii.

The benzyl 2,3-anhydro-α-L-lyxoside **15r** gave **1r** in rather low yield. The deuterated α-D-lyxoside **15s**$_d$ was shown to produce a 3:1 mixture of **1s** and **1s**$_{d'}$, which indicates that both the route via Biv and Bvi (Scheme V) are functioning in the rearrangement. This is the first indication of epoxide migration in pyranosides under the present reaction conditions (although we have reported epoxide migrations in *trans*-epoxycyclohexanols[1]). The **1s**/**1s**$_{d'}$ ratio (3:1) obtained is probably a result of the known preponderance for nucleophilic attack in the 4-position of 3,4-anhydro-α-arabinosides[13] (cf. Bii). The corresponding 3,4-anhydro-β-arabinoside (from **16**) is on the other hand known[13] to undergo attack preferentially in the 3-position, and it would be interesting to see if the **1s**/**1s**$_{d'}$ ratio is reversed when a deuterium-labeled **16** is used as starting material. Compound **16** gave **1s** in low yield.

Bromohydrins in the hexopyranoside series are conformationally more stable than their pentopyranoside counterparts because C-6 almost always prefers an equatorial position. Therefore we postulate that bromohydrins of the D series of the hexopyranosides rearrange via $^4C_1$ conformations. This is in line with the results obtained by Baer et al. in their rearrangements of tosylated hexopyranosides under reductive conditions.[12]

The methyl 2,3-anhydro-α-D-alloside **18** should undergo preferential nucleophilic attack in the 2-position.[13] However, the 2-bromodeoxyaltroside formed is a 2,3-diaxial bromohydrin, which should therefore only be present in equilibrium with **18**. Attack in the 3-position gives on the other hand a 3-bromodeoxyglucoside (Aii), which should immediately undergo a conformational flip to Avi followed by ring contraction and dehydration to give the aldehyde **2**. The methyl 4-bromodeoxy-α-D-guloside (**30**) (cf. Aiv) was formed as a byproduct, indicating transient existence of a 3,4-anhydroalloside (Aiii). The formation of **30** (Aiv) represents a "blind alley" in the rearrangement of **18** since the conformational flip into rearrangeable Av is prohibited by the equatorial preference of C-6.

The methyl 3,4-anhydro-α-D-galactoside **19** should be preferentially (but reversibly) attacked in the 3-position,[13] giving a nonreactive 3-bromodeoxyguloside. Attack in the 4-position gives on the other hand a 4-bromodeoxyglucoside (Avi with 4-Br and 3-LiO), which was shown above to rearrange smoothly to aldehyde. By coincidence, **18** and **19** give the aldehyde **2** in the same relatively high yield (approximately 60%); **18** and **19** are formed as a mixture by a Mitsunobu-type reaction of the readily available 6-O-silylated methyl α-D-glucopyranoside **44** and separation is therefore unnecessary.

The methyl 2,3-anhydro-α-D-mannoside **20** gave a low yield of **2**. Bromide ion attack should occur preferentially in the 3-position[13] but this leaves an unreactive 3-bromodeoxyaltroside. Epoxide migration gives a 3,4-anhydroaltroside (cf. Bii), which is preferentially attacked in the 4-position, giving the unreactive 4-bromodeoxyidoside (cf. Biii). Attack in the 3-position finally gives the 3-bromodeoxymannoside Bv which, in the preferred conformation

(13) Williams, N. R. *Adv. Carbohydr. Chem. Biochem.* **1970**, *25*, 109.

Bvi, rearranges to aldehyde. The rather complicated reaction path of **20** may account for the relatively low yield compared to **18** and **19**.

The methyl 2,3- and 3,4-anhydro-β-D-allosides **21** and **22** both gave a low yield of the aldehyde **4**. The isolation of a small amount of **21** from the rearrangement of **22** clearly shows that Aii must be an intermediate in the reaction. Further mechanistic rationales are, however, not possible at the moment.

Finally, the 1,6-anhydro epoxides **23–26** did not produce aldehydes. They are known to undergo nucleophilic attack in the mode that gives 2,3-diaxially substituted products; these all represent "blind alleys" in the rearrangement reactions discussed here. The benzylated epoxides **25** and **26** were rather unreactive (as were the methoxy epoxides **10** and **13**), whereas the epoxy alcohols **23** and **24** were rapidly destroyed by the lithium bromide treatment. The reason remains to be found.

Conclusions. Lithium bromide mediated rearrangements of pyranosidic monosaccharide epoxides lead to chiral α,β-unsaturated aldehydes with an additional aldehyde group masked as a glycosidic acetal. So far only 1,4-dicarbonyl systems have been observed.

The best yields are obtained with epoxides that, on opening by bromide ion, form 3- or 4-bromodeoxy-α-D-*glucosides* by a straightforward and short route, thereby creating a stable $^4C_1$ conformation suitable for ring contraction. However, the *preferred* position for nucleophilic attack in hexoside epoxides[13] always leads to diaxial bromohydrins unsuitable for ring contraction. Therefore, such preferred attacks are considered only to form transient intermediates in equilibrium with the epoxide from which it was formed.

Experimental Section

Liquid chromatography purifications were performed in the gravity mode. Optical rotations were measured with a Perkin-Elmer 141 polarimeter. Melting points are uncorrected. Mass spectra were recorded on a Finnigan 4021 spectrometer. NMR spectra were recorded on a Varian XL-300 spectrometer. Chemical shifts are given in ppm downfield from Me_4Si with reference to internal $CHCl_3$ (7.26 ppm), C_6HD_5 (7.16 ppm), HDO (4.63 ppm), or CHD_2OD (3.31 ppm). The heptane used is a mixture of isomers with a boiling range of 94–100 °C. The following abbreviation was used: TMU, *N,N,N',N'*-tetramethylurea.

The following compounds have been reported: (2*R*)- and (2*S*)-2-(benzyloxy)-2,5-dihydrofuran-4-carbaldehyde (**1r** and **1s**),[2] benzyl 2,3-anhydro-β-D-ribopyranoside (**9r**),[9a,d] benzyl 2,3-anhydro-β-L-ribopyranoside (**9s**),[9b,d] benzyl 2,3-anhydro-4-*O*-methyl-β-D-ribopyranoside (**10**),[9a] benzyl 2,3-anhydro-α-D-ribopyranoside (**14**),[9c] benzyl 2,3-anhydro-4-deuterio-α-D-lyxopyranoside (**15s$_d$**),[2] benzyl 2,3-anhydro-β-L-lyxopyranoside (**16**),[9f] 1,6:2,3-dianhydro-β-D-allopyranose (**23**),[6a] 1,6:2,3-dianhydro-β-D-mannopyranose (**24**),[6b,c] 4-*O*-benzyl-1,6:2,3-dianhydro-β-D-allopyranose (**25**),[6a] 4-*O*-benzyl-1,6:2,3-dianhydro-β-D-mannopyranose (**26**),[6b] 1,2,3,4-tetra-*O*-acetyl-α-D-arabinopyranose (**32**),[14] methyl 4,6-*O*-benzylidene-2,3-anhydro-α-D-allopyranoside (**41**),[15] methyl 2,3-anhydro-α-D-allopyranoside (**42**),[16] and methyl 4,6-*O*-benzylidene-2,3-anhydro-α-D-mannopyranoside (**45**).[17]

Methyl α-D-glucopyranoside (**43**) and methyl β-D-glucopyranoside (**46**) are commercially available.

Rearrangement of Benzyl 2,3-Anhydro-β-D- and -L-ribopyranoside (9r and 9s). Entry 1. Compound **9r**[9a,d] (500 mg, 2.25 mmol) was dissolved in toluene (9 mL) and added to a solution of lithium bromide (313 mg, 3.61 mmol) and TMU (419 mg, 3.61 mmol) in refluxing toluene (9 mL). After 8 min the reaction mixture was cooled in an ice bath, diethyl ether (9 mL) and silica gel were added, and the mixture was filtered. Chromatography (SiO_2, heptane/EtOAc 7:1) gave **1r** (122 mg, 27%).

Rearrangement of **9r**, **9s**, **9s$_d$**, and **9s$_{d'}$** were described in a previous paper.[2]

Entry 2. Compound **9r** (500 mg, 2.25 mmol) was dissolved in toluene (9 mL) and added to a solution of lithium bromide (624 mg, 7.2 mmol), TMU (2.45 g, 21.1 mmol), and the radical scavenger 2,6-di-*tert*-butyl-4-methylphenol (24 mg, 0.11 mmol) in toluene (9 mL, 80 °C). After 30 min the reaction mixture was cooled and worked up as in entry 1 to yield **1r** (79 mg, 17%).

Entry 3. Compound **9r** (500 mg, 2.25 mmol) was dissolved in toluene (9 mL) and added to a solution of lithium bromide (313 mg, 3.6 mmol) in *o*-dimethoxybenzene (9 mL, 120 °C). After 6.5 min the reaction mixture was cooled and worked up as in entry 1 to yield **1r** (130 mg, 28%).

Entry 4. Compound **9r** (500 mg, 2.25 mmol) was dissolved in dry *o*-xylene (9 mL) and added to lithium bromide (337 mg, 3.88 mmol) and TMU (613 mg, 5.28 mmol) in refluxing *o*-xylene (9 mL). After 1 min the reaction mixture was cooled and worked up as in entry 1 to yield **1r** (131 mg, 29%).

Entry 5. Benzyl 2,3-anhydro-β-L-ribopyranoside[9b,d] (**9s**, 500 mg, 2.25 mmol) was dissolved in toluene (9 mL) and added to a solution of lithium iodide (482 mg, 3.60 mmol) and TMU (837 mg, 7.21 mmol) in refluxing toluene (9 mL). After 8 min the reaction mixture was cooled and worked up as in entry 1 to yield **1s** (102 mg, 22%).

Rearrangement of Benzyl 2,3-Anhydro-4-*O*-methyl-β-D-ribopyranoside (10). Entry 6. Compound **10** (550 mg, 2.33 mmol) was dissolved in toluene (9 mL) and added to a solution of lithium bromide (313 mg, 3.60 mmol) and TMU (419 mg, 3.60 mmol) in refluxing toluene (9 mL). After 16 min of reflux, the reaction mixture was cooled and treated as in entry 1 to give starting material (262 mg, 48%) and benzyl 3-bromo-3-deoxy-4-*O*-methyl-β-D-xylopyranoside (**29**, 170 mg, 23%): mp 103–104 °C (heptane/EtOAc); $[\alpha]^{25}_D$ −39.0° (*c* 1.7, $CDCl_3$); ^1H NMR ($CDCl_3$) δ 7.38–7.33 (m, 5 H, PhH), 4.91, 4.63 (AB q, 1 H each, J = 11.7 Hz, PhCH_2), 4.39 (d, 1 H, J = 6.5 Hz, H-1), 4.21 (dd, 1 H, J = 11.8, 4.6 Hz, H-5), 3.85 (t, 1 H, J = 8.9 Hz, H-3), 3.68 (ddd, 1 H, J = 9.0, 6.4, 4.0 Hz, H-2), 3.53 (s, 3 H, MeO), 3.50 (dt, 1 H, J = 8.8, 4.6 Hz, H-4), 3.27 (dd, 1 H, J = 11.8, 8.9 Hz, H-5), 2.74 (d, 1 H, J = 4.0 Hz, OH). Anal. Calcd for $C_{13}H_{17}BrO_4$: C, 49.2; H, 5.4. Found: C, 49.5; H, 5.4.

Rearrangement of Benzyl 3-Deoxy-3-iodo-β-L-xylopyranoside (11). Entry 7. Butyllithium in hexane (0.67 mL, 0.95 mmol) was added to a solution of triphenylmethanol (260 mg, 1.0 mmol) in toluene (4.5 mL), which gave a white precipitate that persisted even after heating to reflux. TMU (194 mg, 1.67 mmol) was added followed by a solution of benzyl 3-deoxy-3-iodo-β-L-xylopyranoside (**11**, 348 mg, 0.99 mmol) in toluene (4.5 mL). The solution was refluxed for 6 min and worked up as in entry 1 to yield **1s** (45 mg, 22%).

Rearrangement of Benzyl 3,4-Anhydro-2-*O*-methyl-β-D-ribopyranoside (13). Entry 8. Compound **13** (385 mg, 1.63 mmol) was treated as in entry 1 to yield, after 50 min of reflux, starting material (201 mg, 52%) and an inseparable mixture of two compounds, assigned as benzyl 4-bromo-4-deoxy-2-*O*-methyl-α-L-lyxopyranoside (**27**) and benzyl 3-bromo-3-deoxy-2-*O*-methyl-β-D-xylopyranoside (**28**) (132 mg, 26%, **27**/**28** 11:2).

Compound **27**: ^1H NMR ($CDCl_3$) δ 5.02 (d, 1 H, J = 1.92 Hz, H-1 equat.), 4.78, 4.52 (AB q, 1 H each, J = 11.9 Hz, PhCH_2), 3.48 (s, 3 H, MeO).

Compound **28**: 4.91, 4.64 (AB q, 1 H each, J = 11.9 Hz, PhCH_2), 4.42 (d, 1 H, J = 6.6 Hz, H-1, axial), 3.62 (s, 3 H, MeO).

Rearrangement of Benzyl 2,3-Anhydro-α-D-ribopyranoside[9c] (14). Entry 9. Compound **14** (500 mg, 2.25 mmol) was dissolved in toluene (9 mL) and added to a solution of lithium bromide (313 mg, 3.60 mmol) and TMU (419 mg, 3.60 mmol) in refluxing toluene (9 mL). After 8 min the reaction mixture was cooled and worked up as in entry 1 to yield **1s** (97 mg, 21%).

Rearrangement of Benzyl 2,3-Anhydro-α-L- and -D-lyxopyranoside (15r and 15s). Entry 10. Compound **15r** (500 mg, 2.25 mmol) was treated as in entry 9 to yield **1r** (64 mg, 14%).

Entry 11. Compound **15s$_d$**[2] (351 mg, 1.57 mmol) was treated as in entry 9 to yield a mixture of **1s** and **1s$_{d'}$** (38 mg, 12%, 73:27) according to mass spectrometric analysis. Pure **1s** gave on

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(15) (a) Szeja, W. *Carbohydr. Res.* **1988**, *183*, 135. (b) Wiggins, L. F. *Methods Carbohydr. Chem.* **1963**, *2*, 188.
(16) Robertson, G. J.; Dunlop, H. G. *J. Chem. Soc.* **1938**, 472.
(17) Hicks, D. R.; Fraser-Reid, B. *Synthesis* **1974**, 202.

chemical ionization with NH_3 peaks at 222 ($M + NH_4^+$) and 223. The **1s**/**1s**$_{d'}$ mixture showed an increased peak height at 223. The integral of the formyl proton signal in ^1H NMR was approximately 75% of that for **1s**.

Rearrangement of Benzyl 2,3-Anhydro-β-L-lyxopyranoside[9f] (16). Entry 12. Compound **16** (500 mg, 2.25 mmol) was treated as in entry 9 to yield **1s** (71 mg, 16%).

Rearrangement of Benzyl 2,3-Anhydro-1-thio-α-D-ribopyranoside (17). Entry 13. Compound **17** (500 mg, 2.10 mmol) was treated as in entry 9 but with more TMU (570 mg, 4.91 mmol). An inseparable product mixture (21 mg, 5%) was formed. The ^1H NMR spectrum showed three singlets in the aldehyde region (δ 9.75, 9.62, 9.50, relative intensity 1:1:8) and the major isomer had signals at 6.43 (m, 1 H, H-3) and 6.09 (dt, 1 H, J = 5.0, 2.5 Hz, H-2), similar to the spectrum of **1**.[2]

Entry 14. (−)-(2*S*,5*S*)-2-[[[Dimethyl(1,1,2-trimethylpropyl)silyl]oxy]methyl]-5-methoxy-2,5-dihydrofuran-3-carbaldehyde (2). Methyl 2,3-anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-allopyranoside (**18**, 2.33 g, 7.31 mmol) was dissolved in toluene (31.3 mL) and added to a solution of lithium bromide (1.05 g, 12.1 mmol) and TMU (1.99 g, 17.1 mmol) in refluxing toluene (31.3 mL). After 8 min the reaction mixture was cooled in an ice bath and diethyl ether (60 mL) was added. Silica gel (3 g) was added and the mixture was filtered. Chromatography (SiO_2, heptane/EtOAc 10:1) gave **2** (1.28 g, 58%): $[\alpha]^{25}_D$ −61.3° (*c* 0.8, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 9.88 (d, 1 H, J = 0.4 Hz, CHO), 6.68 (t, 1 H, J = 1.8 Hz, H-4), 5.91 (dd, 1 H, J = 4.3, 1.3 Hz, H-5), 5.14 (dq, 1 H, J = 4.5, 2.2 Hz, H-2), 3.92 (dd, 1 H, J_{AB} = 11.5 Hz, J = 2.6 Hz, OCH_2), 3.88 (ddd, 1 H, J_{AB} = 11.5, J = 2.3, 0.4 Hz, OCH_2), 3.43 (s, 3 H, MeO), 1.55 (heptet, 1 H, J = 6.8 Hz, Me_2CH), 0.83, 0.82 (d, 3 H each, J = 7.0 and 6.8 Hz, Me_2CH), 0.78, 0.77 (s, 3 H each, Me_2C), 0.06, 0.02 (s, 3 H each, Me_2Si); ^{13}C NMR ($CDCl_3$) δ 187.1 (CHO), 145.5 (C-3), 142.5 (C-4), 108.0 (C-5), 84.7 (C-2), 62.6 (MeO), 54.7 (OCH_2), 34.2 (Me_2CH), 25.0 (Me_2C), 20.3, 20.2, 18.51, 18.46 (Me_2CHMe_2C), −3.6, −3.8 (Me_2Si). Anal. Calcd for $C_{15}H_{28}O_4Si$: C, 60.0; H, 9.4. Found: C, 59.6; H, 9.2.

Increasing the polarity of the eluent (EtOAc/heptane 1:1) gave impure **30** (404 mg) that was dissolved in dry pyridine (10 mL). 3,5-Dinitrobenzoyl chloride (700 mg, 3.03 mmol) was added. After 20 min the pyridine was removed and the residue was dissolved in diethyl ether and washed with water (10 mL), aqueous NaOH (5 mL, 2 M), and hydrochloric acid (2 × 5 mL, 10%). Drying (Na_2SO_4) and chromatography (SiO_2, heptane/EtOAc 10:1) gave methyl 4-bromo-4-deoxy-2,3-di-*O*-(3,5-dinitrobenzoyl)-α-D-gulopyranoside (**31**; 176 mg, 14%): mp 110–114 °C (EtOH/toluene); $[\alpha]^{25}_D$ +75.4° (*c* 0.8, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 9.36 (d, 2 H, J = 2.1 Hz, ArH), 9.33 (t, 1 H, J = 2.1 Hz, ArH), 9.14 (t, 1 H, J = 2.1 Hz, ArH), 8.85 (d, 2 H, J = 2.2 Hz, ArH), 6.00 (t, 1 H, J = 3.0 Hz, H-3), 5.88 (t, 1 H, J = 3.9 Hz, H-2), 5.19 (d, 1 H, J = 3.8 Hz, H-1), 4.46 (dd, 1 H, J = 3.2, 1.7 Hz, H-4), 4.34 (ddd, 1 H, J = 7.4, 5.9, 1.4 Hz, H-5), 3.85, 3.74 (d AB q, 1 H each, J_{AB} = 10.0, J = 7.4, J = 5.8 Hz, H-6), 3.63 (s, 3 H, MeO), 1.62 (heptet, 1 H, J = 6.9 Hz, Me_2CH), 0.86 (d, 6 H, J = 7.0 Hz, Me_2CH), 0.85 (s, 6 H, Me_2C), 0.17, 0.16 (s, 6 H, Me_2Si); ^{13}C NMR δ 161.9, 161.1 (CO), 149.0, 148.6, 132.9, 132.5, 130.0, 129.4, 123.2, 122.8 (arom.), 96.6 (C-1), 71.9, 67.9, 65.2, 63.4, 56.3, 48.1 (C-2–6, MeO), 34.1 (Me_2CH), 25.1 (C-Si), 20.2, 18.5 (Me_2CHMe_2C), −3.45, −3.52 (Me_2Si). Anal. Calcd for $C_{29}H_{35}BrN_4O_{15}Si$: C, 44.2; H, 4.5. Found: C, 44.6; H, 4.4.

Rearrangement of Methyl 3,4-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-galactopyranoside (19). Entry 15. Compound **19** (500 mg, 1.57 mmol) was treated as in entry 14 to yield **2** (279 mg, 59%).

Rearrangement of Methyl 2,3-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-mannopyranoside (20). Entry 16. Compound **20** (300 mg, 0.94 mmol) was treated as in entry 14 to yield **2** (67 mg, 24%).

Entry 17. (−)-(2*S*,5*R*)-2-[[[Dimethyl(1,1,2-trimethylpropyl)silyl]oxy]methyl]-5-methoxy-2,5-dihydrofuran-3-carbaldehyde (4). Methyl 2,3-anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-β-D-allopyranoside (**21**, 473 mg, 1.48 mmol) was dissolved in toluene (5.9 mL) and added to a solution of lithium bromide (214 mg, 2.46 mmol) and TMU (404 mg, 3.48 mmol) in refluxing toluene (5.9 mL). After 47 min the reaction mixture was cooled in an ice bath and diethyl ether (20 mL) was added. Washing with water (4 × 5 mL), drying (Na_2SO_4), and chromatography (SiO_2, heptane/EtOAc 10:1) gave **4** (66 mg, 15%): $[\alpha]^{25}_D$ −16.9° (*c* 0.9, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 9.87 (d, 1 H, J = 0.4 Hz, CHO), 6.70 (t, 1 H, J = 1.6 Hz, H-4), 5.82 (t, 1 H, J = 1.3 Hz, H-5), 4.99–4.96 (m, 1 H, H-2), 3.91, 3.78 (d AB q, 1 H each, J_{AB} = 11.0, J = 5.4, J = 2.5 Hz, OCH_2), 3.47 (s, 3 H, MeO), 1.60 (heptet, 1 H, J = 6.9 Hz, Me_2CH), 0.86 (d, 6 H, J = 6.8 Hz, Me_2CH), 0.82 (s, 6 H, Me_2C), 0.08 (s, 6 H, Me_2Si); ^{13}C NMR ($CDCl_3$) δ 187.1 (CHO), 145.5 (C-3), 142.4 (C-4), 107.8 (C-5), 84.9 (C-2), 64.8 (CH_3O), 55.2 (OCH_2), 34.1 (Me_2CH), 25.2 (Me_2C), 20.2, 18.5 (Me_2CHMe_2C), −3.55, −3.63 (Me_2Si). Anal. Calcd for $C_{15}H_{28}O_4Si$: C, 60.0; H, 9.4. Found: C, 59.5; H, 9.4.

Rearrangement of Methyl 3,4-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-β-D-allopyranoside (22). Entry 18. Compound **22** (1.00 g, 3.14 mmol, of ca. 60% purity; see prep.) was treated as in entry 17 to yield, after refluxing for 8 min, **4** (92 mg, 10%) and **21** (53 mg, 5%).

2-[[[Dimethyl(1,1,2-trimethylpropyl)silyl]oxy]methyl]-furan-3-carbaldehyde (3). Compound **4** (64 mg, 0.21 mmol) was dissolved in dry dichloromethane (1.9 mL) containing trifluoroacetic acid (6 μL). After 15 min dichloromethane (5 mL) and saturated aqueous sodium hydrogen carbonate (5 mL) was added. The aqueous phase was extracted with dichloromethane (5 mL). The organic solutions were combined and dried (Na_2SO_4). Evaporation of solvent and chromatography (SiO_2, heptane/EtOAc 10:1) gave **3** (43 mg, 77%): MS (rel intensity) 183 (84), 155 (27), 109 (37); ^1H NMR ($CDCl_3$) δ 10.13 (d, 1 H, J = 0.6 Hz, CHO), 7.37 (dd, 1 H, J = 2.0, 0.6 Hz, H-5), 6.74 (d, 1 H, J = 2.0 Hz, H-4), 4.93 (s, 2 H, CH_2), 1.63 (heptet, 1 H, J = 6.9 Hz, Me_2CH), 0.88 (d, 6 H, J = 7.2 Hz, Me_2CH), 0.87 (s, 6 H, Me_2C), 0.16 (s, 6 H, Me_2Si); ^{13}C NMR ($CDCl_3$) δ 185.5 (CHO), 162.3 (C-2), 142.6 (C-5), 123.7 (C-3), 108.2 (C-4), 57.4 (CH_2), 34.1 (Me_2CH), 25.3 (Me_2C), 20.2, 18.4 (Me_2CHMe_2C), −3.4 (Me_2Si). Compound **2** treated essentially as above gave **3** in 57% yield.

(2*R*,4*R*/*S*)-2-(Benzyloxy)tetrahydrofuran-4-carbaldehyde (5). (+)-(2*R*)-2-(Benzyloxy)-2,5-dihydrofuran-4-carbaldehyde[2] (**1r**, 606 mg, 2.97 mmol) was dissolved in toluene (10 mL) and hydrogenated (H_2, Pd/C, 100 mg, 10%). After 40 min the toluene was evaporated and the residue was chromatographed (SiO_2, heptane/EtOAc 5:1) to give **5** (464 mg, 76%) as a mixture of epimers (2,4-cis/2,4-trans 4:1): $[\alpha]^{25}_D$ −111° (*c* 1.2, $CHCl_3$); MS (rel intensity) 206 (M^+, 2), 163 (4), 107 (11), 100 (14), 99 (15), 92 (24), 91 (100); ^1H NMR of the mixture ($CDCl_3$) δ 2,4-cis epimer of **5** 9.70 (d, 1 H, J = 2.2 Hz, CHO), 7.34–7.30 (m, 5 H, PhH), 5.26 (dd, 1 H, J = 4.5, 0.6 Hz, H-2), 4.69, 4.44 (AB q, 1 H each, J = 11.9 Hz, $PhCH_2$), 4.27 (dd, 1 H, J = 9.0, 5.0 Hz, H-5), 4.11 (t, 1 H, J = 8.6 Hz, H-5), 2.98 (ddddd, 1 H, J = 10.3, 8.0, 5.1, 3.0, 2.2 Hz, H-4), 2.36 (dd with further coupling, 1 H, J = 12.9, 2.9 Hz, H-3), 2.23 (ddd, 1 H, J = 13.4, 10.3, 4.4 Hz, H-3); 2,4-trans epimer of **5** 9.65 (d, 1 H, J = 2.2 Hz, CHO), 7.34–7.30 (m, 5 H, PhH), 5.30 (d, 1 H, J = 5.8 Hz, H-2), 4.71, 4.48 (AB q, 1 H each, J = 11.7 Hz, $PhCH_2$), 4.21 (dd, 1 H, J = 9.1, 4.2 Hz, H-5), 4.11 (t, 1 H, J = 8.6 Hz, H-5), 3.29–3.18 (m, 1 H, H-4), 2.39–2.13 (2 H, H-3, obscured by signals from the 2,4-cis epimer).

(2*S*,3*R*/*S*,5*S*)-2-[[[Dimethyl(1,1,2-trimethylpropyl)silyl]oxy]methyl]-5-methoxytetrahydrofuran-3-carbaldehyde (6) and (+)-(1*S*,3*S*,5*R*,6*R*/*S*)-2,7-Dioxa-6-hydroxy-3-methoxybicyclo[3.3.0]octane (7). Compound **2** (773 mg, 2.57 mmol) was dissolved in toluene (15.5 mL) and hydrogenated (H_2, Pd/C, 150 mg, 10%). After 35 min the solvent was evaporated and the residue was chromatographed (SiO_2, heptane/EtOAc 20:1) to give **6** as a 1:1 mixture of 2,3-cis/2,3-trans epimers (556 mg, 72%). **6**: ^1H NMR ($CDCl_3$) δ 5.09 (d, 1 H, J = 4.9 Hz, H-5), 5.04 (m, 1 H, H-5), 3.34 (s, 3 H, CH_3O), 3.39 (s, 3 H, CH_3O).

Tetrabutylammonium fluoride trihydrate (1.16 g, 3.68 mmol) was added to a solution of **6** (556 mg) in tetrahydrofuran/acetic acid (11 mL, 19:1). The solution was placed in an oil bath (60 °C). After 2 h the solvent was removed and the residue was chromatographed (SiO_2, heptane/EtOAc 1:1) to give **7** (107 mg, 28%): $[\alpha]^{25}_D$ +79.8° (*c* 1.0, D_2O); MS (rel intensity) 143 (M^+ − OH, 2), 142 ($M^+ - H_2O$, 2), 129 ($M^+ - CH_3O$, 9), 111 (8), 103 (9), 58 (100); ^1H NMR ($CDCl_3$) δ 5.29 (d, 1 H, J = 2.3 Hz, H-6), 5.06 (d, 1 H, J = 4.8 Hz, H-3), 4.79 (dd, 1 H, J = 7.0, 4.0 Hz, H-1), 4.11 (dd, 1 H, J = 10.2, 4.0 Hz, H-8), 3.98 (d, 1 H, J = 10.2 Hz, H-8), 3.31 (s, 3 H, MeO), 2.99 (q with further coupling, 1 H, J = 8.2 Hz, H-5), 2.48 (d, 1 H, J = 2.3 Hz, OH), 2.22 (dd, 1 H, J

= 13.1, 9.7 Hz, H-4), 1.77 (ddd, 1 H, J = 13.0, 7.9, 4.9 Hz, H-4). Addition of 1 drop of CD_3OD changed the signal at 5.29 to a singlet and made the signal at 2.48 disappear. A low intensity signal [7%, δ 5.36 (d, J = 5.6 Hz, H-6)] was tentatively assigned to the 6S stereoisomer.

(−)-(2*S*,3*R*/*S*,5*R*)-2-[[[Dimethyl(1,1,2-trimethylpropyl)-silyl]oxy]methyl]-5-methoxytetrahydrofuran-3-carbaldehyde (8). Compound 4 (56 mg, 0.19 mmol) was dissolved in toluene (1 mL) and hydrogenated (H_2, Pd/C, 20 mg, 10%). After 1 h toluene was evaporated and the residue was chromatographed (SiO_2, heptane/EtOAc 15:1) to give 8 (35 mg, 63%) as a mixture of epimers (2,3-cis/2,3-trans 24:1): $[\alpha]^{25}_D$ −80.6° (*c* 0.5, $CHCl_3$); MS 217 (2), 185 (16), 155 (22), 117 (100), 111 (29); ^{1}H NMR of the mixture ($CDCl_3$) δ 2.3-cis epimer of 8 9.80 (d, 1 H, J = 3.4 Hz, CHO), 5.07 (dd, 1 H, J = 5.1, 2.7 Hz, H-5), 4.40 (dt, 1 H, J = 7.7, 5.0 Hz, H-2), 3.81, 3.73 (d AB q, 1 H each, J_{AB} = 10.6, J = 7.8, J = 4.9 Hz, OCH_2), 3.35 (s, 3 H, CH_3O), 3.04 (dddd, 1 H, J = 9.0, 7.6, 5.6, 3.4 Hz, H-3), 2.32, 2.23 (dd, AB q, 1 H each, J_{AB} = 13.8, J = 5.7, 2.7, J = 9.0, 5.1 Hz, H-4), 1.60 (heptet, 1 H, J = 6.9 Hz, Me_2CH), 0.86 (d, 6 H, J = 6.8 Hz, Me_2CH), 0.83 (s, 6 H, Me_2C), 0.10, 0.09 (s, 6 H, Me_2Si); 2,3-trans epimer of 8 9.70 (d, 1 H, J = 2.3 Hz, CHO).

Benzyl 2,3-Anhydro-4-*O*-methyl-β-D-ribopyranoside (10). Methyl *p*-toluenesulfonate (5.11 mL, 33.8 mmol) was added to a solution of benzyl 2,3-anhydro-β-D-ribopyranoside[9a] (**9r**, 5.00 g, 22.5 mmol) and potassium *tert*-butoxide (5.05 g, 45.0 mmol) in *tert*-butyl alcohol (100 mL). After 40 min, the reaction mixture was made slightly acidic by dropwise addition of acetic acid. Removal of solvents gave a residue that was dissolved in ether (100 mL) and water (50 mL). The water phase was extracted with ether (25 mL) and the ether phases were combined and washed with water (2 × 20 mL). Drying (Na_2SO_4), removal of solvents, and crystallization (heptane/EtOAc) gave **10** (3.20 g, 60%): mp 97–100 °C; $[\alpha]^{25}_D$ −20.8° (*c* 0.9, $CHCl_3$) [lit.[9a] mp 98–100 °C; $[\alpha]^{25}_D$ −19° (*c* 1.0, $CHCl_3$)]; ^{1}H NMR (C_6D_6) δ 7.28–7.06 (m, 5 H, PhH), 4.85 (s, 1 H, H-1), 4.67, 4.30 (AB q, 1 H each, J = 11.8 Hz, $PhCH_2$), 3.58, 3.42 (d AB q, 1 H each, J_{AB} = 12.0, J = 4.9, J = 4.7 Hz, H-5), 3.15 (dt, 1 H, J = 4.8, 3.0 Hz, H-4), 3.10 (s, 3 H, CH_3O), 3.01–2.97 (m, 2 H, H-2, H-3).

Benzyl 3-Deoxy-3-iodo-β-L-xylopyranoside (11). Compound **9s**[9b,d] (5.00 g, 22.5 mmol) and sodium iodide (5.63 g, 37.5 mmol) were dissolved in acetic acid (115 mL). After 2 days the solvent was removed and the residue was dissolved in ethyl acetate (100 mL) and washed with water (25 mL), saturated aqueous sodium hydrogen carbonate (25 mL), sodium thiosulfate solution (25 mL, 10%), and saturated aqueous sodium hydrogen carbonate (25 mL). Drying (Na_2SO_4), removal of solvents, and crystallization (heptane/EtOAc) gave 11 (6.14 g, 78%): mp 65–70 °C (heptane/$CHCl_3$); $[\alpha]^{25}_D$ −7.6° (*c* 1.1, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.38–7.31 (m, 5 H, PhH), 4.94, 4.62 (AB q, each 1 H, J = 11.6 Hz, $PhCH_2$), 4.32 (d, 1 H, J = 7.0 Hz, H-1), 4.09 (dd, 1 H, J = 11.5, 4.9 Hz, H-5), 4.02–3.93 (m, 1 H, H-4), 3.88 (t, 1 H, J = 9.8 Hz, H-3), 3.68 (ddd, 1 H, J = 10.0, 7.1, 2.9 Hz, H-2), 3.28 (dd, 1 H, J = 11.5, 9.3 Hz, H-5), 2.78 (d, 1 H, J = 2.9 Hz, OH), 2.41 (d, 1 H, J = 3.4 Hz, OH). Anal. Calcd for $C_{12}H_{15}IO_4$: C, 41.2; H, 4.3. Found C, 41.5; H, 4.4.

Benzyl 3,4-Anhydro-2-*O*-methyl-β-D-ribopyranoside (13). A solution of potassium *tert*-butoxide (800 mg, 7.14 mmol) in *tert*-butyl alcohol (20 mL) was added to benzyl 4-bromo-4-deoxy-α-L-lyxopyranoside[2] (983 mg, 3.24 mmol). After 30 min, the benzyl 3,4-anhydro-β-D-ribopyranoside formed was methylated for 1 h with methyl *p*-toluenesulfonate (0.83 mL, 6.49 mmol). Ether (50 mL) and water (30 mL) were added, the aqueous phase was extracted with ether (10 mL), and the organic solutions were combined and washed with water (2 × 10 mL). Drying (Na_2SO_4) and chromatography (SiO_2, heptane/EtOAc) gave 13 (472 mg, 62%): mp 45–46 °C (heptane): $[\alpha]^{25}_D$ −162° (*c* 0.8, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.37–7.30 (m, 5 H, PhH), 4.76, 4.54 (AB q, each 1 H, J = 11.8 Hz, $PhCH_2$), 4.63 (d, 1 H, J = 3.4 Hz, H-1), 4.08 (ddd, 1 H, J = 13.3, 2.1, 0.5 Hz, H-5), 3.96 (dd, 1 H, J = 13.4, 0.7 Hz, H-5), 3.55 (s, 3 H, MeO), 3.55–3.50 (m, 2 H, H-2, H-3), 3.36 (ddd, 1 H, J = 4.0, 2.1, 0.8 Hz, H-4). Anal. Calcd for $C_{13}H_{16}O_4$: C, 66.1; H, 6.8. Found: C, 65.8; H, 6.8.

Benzyl 2,3-anhydro-α-L-lyxopyranoside (15r) was prepared from benzyl 2,3-anhydro-β-D-ribopyranoside (**9r**)[9a,d] as described in the preparation of benzyl 2,3-anhydro-α-D-lyxopyranoside (**15s**).[9f] Compound **15r**: mp 62–63.5 °C; $[\alpha]^{25}_D$ −105° (*c* 0.8, $CHCl_3$) [lit.[9f] for **15s** mp 63.5–64.5 °C; $[\alpha]^{25}_D$ +105° (*c* 1.02, $CHCl_3$)]; ^{1}H NMR spectrum is in agreement with literature data[9f] except that H-3 is better described as a doublet (J = 3.5 Hz) than as a multiplet.

Benzyl 2,3-Anhydro-1-thio-α-D-ribopyranoside (17). Crude 37 was dissolved in methanolic sodium methoxide (40 mL, 0.72 M). After 15 min the reaction mixture was neutralized with acetic acid. Removal of methanol gave a residue that was dissolved in ethyl acetate (100 mL) and washed with saturated aqueous sodium hydrogen carbonate (2 × 25 mL). Drying (Na_2SO_4) and removal of solvents gave a residue that was chromatographed (SiO_2, heptane/EtOAc 1:1) to give crystalline 17 (2.28 g, 67% over all yield from **35**): mp 115–116 °C (heptane/EtOAc); $[\alpha]^{25}_D$ +416° (*c* 0.52, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.35–7.24 (m, 5 H, PhH), 5.03 (d, 1 H, J = 2.3 Hz, H-1), 4.11–4.08 (m, 1 H, H-4), 3.85, 3.76 (AB q, 1 H each, J = 13.5 Hz, $PhCH_2$), 3.72 (dd, 1 H, J = 11.3, 9.2 Hz, H-5), 3.52 (dd, 1 H, J = 10.5, 5.0 Hz, H-5), 3.49 (s, 2 H, H-2, H-3), 2.03 (d, 1 H, J = 10.4 Hz, HO); ^{13}C NMR ($CDCl_3$) δ 138.0 (Ph-*C*), 129.0, 128.6, 127.2 (Ph-*CH*), 76.8 (C-1), 65.1, 60.8, 57.3, 54.3 (C-2–5), 34.2 ($PhCH_2$). Anal. Calcd for $C_{12}H_{14}O_3S$: C, 60.5; H, 5.9. Found: C, 60.6; H, 5.9.

Methyl 2,3-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-allopyranoside (18). To a solution of **42** (130 mg, 0.73 mmol) and imidazole (99 mg, 1.45 mmol) was added dimethyl(1,1,2-trimethylpropyl)chlorosilane (0.16 mL, 0.80 mmol). After 90 min, the reaction mixture was diluted with diethyl ether (40 mL) and water (10 mL). The organic phase was washed with water (2 × 5 mL) and dried (Na_2SO_4). Removal of solvent and chromatography (SiO_2, heptane/EtOAc 2:1) gave 18 (189 mg, 82%): mp 75 °C (heptane); $[\alpha]^{25}_D$ +78.3° (*c* 0.9, $CHCl_3$); ^{1}H NMR spectrum was identical with that of 18 prepared in the Mitsunobu reaction (see below). Anal. Calcd for $C_{15}H_{30}O_5Si$: C, 56.6; H, 9.5. Found: C, 56.5; H, 9.7.

Methyl 2,3-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-allopyranoside (18) and Methyl 3,4-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-galactopyranoside (19). Compound **44** (500 mg, 1.49 mmol), triphenylphosphine (429 mg, 1.64 mmol), diethyl azodicarboxylate (285 mg, 1.64 mmol), and molecular sieves (0.50 g, 4 Å) were refluxed in dry benzene for 90 min.[11] After cooling, the reaction mixture was diluted with ether (20 mL) and washed with hydrochloric acid (2 × 5 mL, 5%) and saturated aqueous sodium hydrogen carbonate (5 mL). Drying (Na_2SO_4) and chromatography (SiO_2, heptane/EtOAc 4:1) gave 18 (263 mg, 56%) and 19 (66 mg, 14%).

Compound 18: ^{1}H NMR ($CDCl_3$) δ 4.87 (d, 1 H, J = 3.1 Hz, H-1), 3.92 (ddd, 1 H, J = 8.9, 6.7, 2.0 Hz, H-4), 3.81, 3.75 (d AB q, 1 H each, J_{AB} = 10.5, J = 5.3, J = 4.9 Hz, H-6), 3.65 (dt, 1 H, J = 9.5, 4.8 Hz, H-5), 3.54 (dd, 1 H, J = 4.2, 3.1 Hz, H-2), 3.46 (dd, 1 H, J = 4.3, 1.9 Hz, H-3), 3.44 (s, 3 H, MeO), 2.58 (d, 1 H, J = 6.5 Hz, OH), 1.62 (heptet, 1 H, J = 6.9 Hz, Me_2CH), 0.87 (d, 6 H, J = 6.8 Hz, Me_2CH), 0.85 (s, 6 H, Me_2C), 0.12 (s, 6 H, Me_2Si); ^{13}C NMR ($CDCl_3$) δ 94.5 (C-1), 68.3, 67.8, 63.9, 55.6, 55.1, 53.8 (C-2–6, MeO), 34.0 (Me_2CH), 25.2 (C-Si), 20.24, 20.18, 18.5, 18.4 (Me_2CHMe_2C), −3.6 (Me_2Si).

Compound 19: $[\alpha]^{25}_D$ +31.2° (*c* 0.8, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 4.64 (dd, 1 H, J = 4.8, 1.0 Hz, H-1), 3.96 (t, 1 H, J = 6.8 Hz, H-5), 3.81 (dd, 1 H, J = 10.3, 4.6 Hz, H-2), 3.74 (dd, 2 H, J = 6.8, 1.3 Hz, H-6), 3.47 (s, 3 H, MeO), 3.29 (d, 1 H, J = 4.5 Hz, H-3 or H-4), 3.24 (dd, 1 H, J = 4.1, 1.1 Hz, H-3 or H-4), 2.49 (d, 1 H, J = 10.5 Hz, OH), 1.63 (heptet, 1 H, J = 6.9 Hz, Me_2CH), 0.89 (d, 6 H, J = 6.9 Hz, Me_2CH), 0.86 (s, 6 H, Me_2C), 0.12 (s, 6 H, Me_2Si); ^{13}C NMR ($CDCl_3$) δ 95.9 (C-1), 66.4, 63.9, 62.5, 55.7, 53.5, 50.5 (C-2–6, CH_3O), 34.2 (Me_2CH), 25.1 (C-Si), 20.2, 18.5 (Me_2CHMe_2C), −3.5, −3.6 (Me_2Si). Anal. Calcd for $C_{15}H_{30}O_5Si$: C, 56.6; H, 9.5. Found: C, 56.4; H, 9.6.

Methyl 2,3-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-mannopyranoside (20). Methyl 4,6-*O*-benzylidene-2,3-anhydro-α-D-mannopyranoside[17] (**45**, 500 mg, 1.89 mmol) and Pd/C (100 mg, 10%) were suspended in a mixture of ethanol (1.00 mL) and tetrahydrofuran (10 mL) and stirred under hydrogen. After 10 h, more catalyst (100 mg) was added and the hydrogenolysis was continued for 14 h. The catalyst was filtered off and the solvent was removed. The crude methyl 2,3-anhydro-α-D-mannopyranoside and imidazole (258 mg, 3.79

mmol) were dissolved in *N,N*-dimethylformamide (5 mL) and dimethyl(1,1,2-trimethylpropyl)chlorosilane (0.41 mL, 2.08 mmol) was added. After 1.5 h, water (25 mL) and ether (100 mL) were added. The ether phase was washed with water (2 × 15 mL) and dried (Na_2SO_4). Removal of solvents and chromatography (SiO_2, heptane/EtOAc 4:1) gave **20** (559 mg, 93%): $[\alpha]^{25}_D$ +41.9° (*c* 0.9, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 4.84 (d, 1 H, *J* = 0.6 Hz, H-1), 3.83 (dd, 1 H, *J* = 9.3, 4.9 Hz, H-6), 3.79 (dd, 1 H, *J* = 8.8, 2.0 Hz, H-4), 3.64 (dd, 1 H, *J* = 9.4, 8.4 Hz, H-6), 3.55 (dt, 1 H, *J* = 8.6, 5.1 Hz, H-5), 3.45 (s, 3 H, MeO), 3.27 (d, 1 H, *J* = 3.7 Hz, H-2 or H-3), 3.15 (d, 1 H, *J* = 2.1 Hz, OH), 3.11 (d with further coupling, *J* = 3.4 Hz, H-2 or H-3), 1.62 (heptet, 1 H, *J* = 6.9 Hz, Me_2CH), 0.88 (d, 6 H, *J* = 7.0 Hz, Me_2CH), 0.86 (s, 6 H, Me_2C), 0.15, 0.14 (s, 6 H, Me_2Si). Anal. Calcd for $C_{15}H_{30}O_5Si$: C, 56.6; H, 9.5. Found: C, 57.0; H, 9.6.

Methyl 2,3-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-β-D-allopyranoside (21) and Methyl 3,4-Anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-β-D-allopyranoside (22). Compound **47** (1.00 g, 2.97 mmol), tributylphosphine (660 mg, 3.26 mmol), diethyl azodicarboxylate (570 mg, 3.27 mmol), and molecular sieves (1.00 g, 4 Å) were stirred in dry toluene for 2 h at room temperature and then placed in an oil bath (50 °C) for 2 h.[11] After cooling, the reaction mixture was diluted with ether (40 mL) and washed with hydrochloric acid (2 × 10 mL, 5%) and saturated aqueous sodium hydrogen carbonate (10 mL). Drying (Na_2SO_4) and chromatography (SiO_2, heptane/EtOAc) gave **21** (390 mg, 41%) together with impure **22** (260 mg, purity 60%).

Compound **21**: $[\alpha]^{25}_D$ −26.4° (*c* 1.7, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 4.74 (d, 1 H, *J* = 0.5 Hz, H-1), 4.04 (ddd, 1 H, *J* = 8.6, 4.6, 2.1 Hz, H-4), 3.84 (dd, 1 H, *J* = 10.1, 5.1 Hz, H-6), 3.71 (dd, 1 H, *J* = 10.2, 7.0 Hz, H-6), 3.50 (s, 3 H, MeO), 3.47 (dd, 1 H, *J* = 3.9, 1.9 Hz, H-3), 3.39 (ddd, 1 H, *J* = 8.6, 7.0, 5.2 Hz, H-5), 3.36 (d, 1 H, *J* = 4.2 Hz, H-2), 3.00 (d, 1 H, *J* = 4.6 Hz, OH), 1.62 (heptet, 1 H, *J* = 6.9 Hz, Me_2CH), 0.88 (d, 6 H, *J* = 6.7 Hz, Me_2CH), 0.85 (s, 6 H, Me_2C), 0.125, 0.121 (s, 6 H, Me_2Si); ^{13}C NMR ($CDCl_3$) δ 97.9 (C-1), 69.8, 68.3, 64.6, 56.8, 56.7, 53.8 (C-2–6, MeO), 34.1 (Me_2CH), 25.1 (C-Si), 20.2, 20.1, 18.5, 18.4 (Me_2CHMe_2C), −3.59, −3.64 (Me_2Si).

Compound **22**: ^1H NMR ($CDCl_3$) δ 4.32 (d, 1 H, *J* = 7.1 Hz, H-1). Compound **22** was further characterized as methyl 3,4-anhydro-6-*O*-[dimethyl(1,1,2-trimethylpropyl)silyl]-2-*O*-(3,5-dinitrobenzoyl)-β-D-allopyranoside (**48**): $[\alpha]^{25}_D$ −104° (*c* 1.2, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 9.26 (t, 1 H, *J* = 2.1 Hz, ArH), 9.20 (d, 2 H, *J* = 2.1 Hz, ArH), 5.28 (dd, 1 H, *J* = 7.4, 1.9 Hz, H-2), 4.72 (d, 1 H, *J* = 7.4 Hz, H-1), 4.08 (dd, 1 H, *J* = 6.9, 4.6 Hz, H-5), 3.91 (dd, 1 H, *J* = 10.5, 4.6 Hz, H-6), 3.79 (dd, 1 H, *J* = 10.5, 6.9 Hz, H-6), 3.66 (ddd, 1 H, *J* = 4.3, 1.9, 0.6 Hz, H-3), 3.61 (d, 1 H, *J* = 4.3 Hz, H-4), 3.47 (s, 3 H, MeO), 1.65 (heptet, 1 H, *J* = 6.9 Hz, Me_2CH), 0.91 (d, 6 H, *J* = 6.8 Hz, Me_2CH), 0.88 (s, 6 H, Me_2C), 0.154, 0.151 (s, 6 H, Me_2Si).

1,6:2,3-Dianhydro-β-D-allopyranose (23) was prepared in 100% yield from 4-*O*-benzyl-1,6:2,3-dianhydro-β-D-allopyranose (**25**) by hydrogenolysis of the benzyl group.[6a] Compound **23** was crystallized from diisopropyl ether/chloroform: mp 96–97.5 °C; $[\alpha]^{25}_D$ +56.5° (*c* 1.3, water) [lit.[6a] mp 93–95 °C; $[\alpha]^{25}_D$ +55° (*c* 0.6, water)]; ^1H NMR ($CDCl_3$) δ 5.60 (d, 1 H, *J* = 0.8 Hz, H-1), 4.40 (d with further coupling, 1 H, *J* = 6.8 Hz, H-5), 3.91 (dd, 1 H, *J* = 8.1, 6.8 Hz, H-6), 3.67 (ddd, 1 H, *J* = 8.3, 2.1, 0.4 Hz, H-6), 3.65–3.60 (m, 1 H, H-4), 3.40 (t with further coupling, 1 H, *J* = 4.5 Hz, H-3), 3.15 (dd, 1 H, 3.9, 1.3 Hz, H-2), 2.89 (d, 1 H, *J* = 11.7 Hz, OH).

1,6:2,3-Dianhydro-β-D-mannopyranose (24) was prepared in 100% yield from 4-*O*-benzyl-1,6:2,3-dianhydro-β-D-mannopyranose[6b] (**26**) by hydrogenolysis of the benzyl group.[6b] Crude **24**: $[\alpha]^{25}_D$ −31.7° (*c* 1.1, methanol) [lit.[6c] $[\alpha]^{25}_D$ −33.8° (*c* 1.02, methanol)]; ^1H NMR ($CDCl_3$) δ 5.69 (dd, 1 H, *J* = 3.2, 0.6 Hz, H-1), 4.42 (ddt, 1 H, *J* = 6.4, 2.3, 1.5 Hz, H-5), 3.91 (d, 1 H, *J* = 9.6 Hz, H-4), 3.78 (ddd, 1 H, *J* = 7.3, 2.4, 0.5 Hz, H-6), 3.74 (t, 1 H, *J* = 6.8, Hz, H-6), 3.44 (ddd, 1 H, *J* = 3.8, 3.0, 0.8 Hz, H-2), 3.14 (ddd, 1 H, *J* = 3.7, 1.5, 0.9 Hz, H-3), 2.42 (d, 1 H, *J* = 9.9 Hz, OH).

Benzyl 2,3,4-Tri-*O*-acetyl-1-thio-α-D-arabinopyranoside (33). 1,2,3,4-Tetra-*O*-acetyl-α-D-arabinopyranose[14] (**32**, 20.0 g, 62.9 mmol) and α-toluenethiol (14.7 mL, 126 mmol) were dissolved in dichloromethane (200 mL). The solution was cooled (ice bath) and boron trifluoride etherate (26.7 mL, 213 mmol) was added during 2 min. After 20 min, the reaction mixture was diluted with dichloromethane (100 mL) and washed with saturated aqueous sodium hydrogen carbonate (200 mL), aqueous sodium hydroxide (4 × 70 mL, 2 M), and water (70 mL). Drying (Na_2SO_4) and removal of solvents gave crude **33**. An analytical sample was prepared by chromatography (SiO_2, heptane/EtOAc 2:1): ^1H NMR ($CDCl_3$) δ 7.33–7.26 (m, 5 H, PhH), 5.28–5.25 (m, 1 H, H-4), 5.25 (t, 1 H, *J* = 8.8 Hz, H-2), 5.02 (dd, 1 H, *J* = 8.8, 3.4 Hz, H-3), 4.37 (d, 1 H, *J* = 8.4 Hz, H-1), 4.12 (dd, 1 H, *J* = 12.8, 3.7 Hz, H-5), 3.93, 3.86 (AB q, 1 H each, *J* = 12.8 Hz, $PhCH_2$), 3.61 (dd, 1 H, *J* = 12.8, 1.8 Hz, H-5), 2.14, 2.04, 2.02 (s, 3 H each, AcO).

Benzyl 1-Thio-α-D-arabinopyranoside (34). Crude **33** was dissolved in methanolic sodium methoxide (300 mL, 0.29 mM). After 40 min, the reaction mixture was neutralized by the addition of Duolite (H^+) resin and filtered. The solvent was removed to give crude **34**. An analytical sample was prepared by chromatography (SiO_2, heptane/EtOAc 2:1): mp 117–118 °C (acetone/heptane); $[\alpha]^{25}_D$ +93.9 (*c* 0.73, H_2O) [lit.[18] for benzyl 1-thio-α-L-arabinopyranoside, mp 109 °C (acetone); $[\alpha]^{25}_D$ −94.6° (*c* 3.07, H_2O)]; ^1H NMR (CD_3OD) δ 7.35–7.21 (m, 5 H, PhH), 4.22 (d, 1 H, *J* = 8.4 Hz, H-1), 3.97 (dd, *J* = 12.2, 3.3 Hz, H-5), 3.92, 3.83 (AB q, 1 H each, *J* = 12.8 Hz, $PhCH_2$), 3.86–3.84 (m, 1 H, H-4), 3.63 (t, 1 H, *J* = 8.4 Hz, H-2), 3.51 (dd, 1 H, *J* = 12.2, 1.7 Hz, H-5), 3.46 (dd, 1 H, *J* = 8.4, 3.4 Hz, H-3).

Benzyl 3,4-*O*-Isopropylidene-1-thio-α-D-arabinopyranoside (35). *p*-Toluenesulfonic acid (205 mg) and triethyl orthoformate (17.9 mL, 108 mmol) was dissolved in acetone (108 mL) and added to the crude **34**. After 20 min, triethylamine (4.6 mL) was added and the solvent was removed. The residue was chromatographed (SiO_2, heptane/EtOAc 2:1) to give crystalline **35** (16.7 g, 90% over all yield from **32**): mp 59.5–60.0 °C (diisopropyl ether); $[\alpha]^{25}_D$ +76.2° (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.35–7.25 (m, 5 H, PhH), 4.27 (dd, 1 H, *J* = 12.8, 2.4 Hz, H-5), 4.24–4.21 (m, 1 H, H-4), 4.15 (d, 1 H, *J* = 9.4 Hz, H-1), 3.99 (dd, 1 H, *J* = 6.9, 5.3 Hz, H-3), 3.93, 3.87 (AB q, 1 H each, *J* = 13.3 Hz, $PhCH_2$), 3.71 (dd, 1 H, *J* = 12.8, 3.0 Hz, H-5), 3.63 (ddd, 1 H, *J* = 9.3, 6.8, 2.8 Hz, H-2), 2.25 (d, 1 H, *J* = 2.8 Hz, HO), 1.53, 1.36 (s, 3 H each, Me). Anal. Calcd for $C_{15}H_{20}O_4S$: C, 60.8; H, 6.8. Found: C, 60.7; H, 6.8.

Benzyl 3,4-Isopropylidene-2-*O*-(methylsulfonyl)-1-thio-α-D-arabinopyranoside (36). To an ice-cooled solution of **35** (4.26 g, 14.4 mmol) in dry pyridine (43 mL) was added methanesulfonyl chloride (2.24 mL, 28.8 mmol). After 1 h, water (1 mL) was added and the solvent was evaporated. The residue was dissolved in diethyl ether (50 mL) and water (10 mL). The ether solution was washed with hydrochloric acid (2 × 5 mL, 5%) and saturated aqueous sodium hydrogen carbonate (5 mL). Drying (Na_2SO_4) and removal of solvents gave a residue that was coevaporated with toluene (2 × 40 mL). Crude **36**: ^1H NMR ($CDCl_3$) δ 7.36–7.25 (m, 5 H, PhH), 4.65 (dd, 1 H, *J* = 9.0, 7.0 Hz, H-2), 4.30–4.24 (m, 2 H, H-4, H-5), 4.26 (d, 1 H, *J* = 8.9 Hz, H-1), 4.17 (dd, 1 H, *J* = 6.9, 5.2 Hz, H-3), 3.95, 3.87 (AB q, 1 H each, *J* = 12.9 Hz, $PhCH_2$), 3.69 (dd, 1 H, *J* = 13.8, 3.8 Hz, H-5), 3.13 (s, 3 H, $MeSO_3$), 1.59, 1.37 (s, 3 H each, Me_2C).

Benzyl 2-*O*-(Methylsulfonyl)-1-thio-α-D-arabinopyranoside (37). To the crude **36** dissolved in ethanol (43 mL, 96%) was added trifluoroacetic acid (43 mL). During the addition the temperature increased to 52 °C. After 10 min, toluene (40 mL) was added and the solvent was removed. The residue was dissolved in toluene (100 mL) and washed with saturated aqueous sodium hydrogen carbonate (2 × 25 mL). The water phase was extracted with ethyl acetate (2 × 25 mL). The ethyl acetate solution was washed with saturated aqueous sodium hydrogen carbonate (25 mL). The organic solutions were combined and dried (Na_2SO_4). Removal of solvents gave crude **37** that was coevaporated with toluene (40 mL). An analytical sample was prepared by chromatography (SiO_2, heptane/EtOAc 1:2): mp 94–95.5 °C (heptane/EtOAc); $[\alpha]^{25}_D$ +79.2° (*c* 0.46, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.33–7.26 (m, 5 H, PhH), 4.70 (t, 1 H, *J* = 8.7 Hz, H-2), 4.29 (d, 1 H, *J* = 9.0 Hz, H-1), 4.13 (dd, 1 H, *J* = 12.6, 2.8 Hz, H-5), 4.05–4.02 (m, 1 H, H-4), 3.98, 3.90 (AB q, 1 H each, *J* = 12.8 Hz, $PhCH_2$), 3.76 (dd, 1 H, *J* = 8.3, 3.5 Hz, H-3), 3.52 (dd, 1 H, *J* = 12.7, 1.6 Hz, H-5), 3.14 (s, 3 H, $MeSO_3$). Anal. Calcd

(18) Zinner, H.; Koine, A.; Nimz, H. *Chem. Ber.* **1960**, *93*, 2705.

for $C_{13}H_{18}O_6S_2$: C, 46.7; H, 5.4. Found: C, 46.8; H, 5.4.

4-Nitrophenyl 2,3,4-Tri-*O*-acetyl-1-thio-α-D-arabinopyranoside (38) and 4-Nitrophenyl 2,3,4-Tri-*O*-acetyl-1-thio-β-D-arabinopyranoside (39). Compound **32** (1.00 g, 3.14 mmol) and 4-nitrothiophenol (1.46 g, 9.42 mmol) were dissolved in dichloromethane (10 mL). The solution was cooled (ice bath) and boron trifluoride etherate (2.00 mL, 16.0 mmol) was added during 2 min. After 2 h, the reaction mixture was diluted with ethyl acetate (30 mL) and washed with saturated aqueous sodium hydrogen carbonate (15 mL), aqueous sodium hydroxide (4 × 10 mL, 2 M), and water (3 × 10 mL). Drying (Na_2SO_4), removal of solvents, and chromatography (SiO_2, heptane/EtOAc 3:1) gave **38** (665 mg, 51%) and **39** (332 mg, 26%).

Compound **38**: mp 143.5–144.5 °C (heptane/EtOAc); $[\alpha]^{25}_D$ +27.4° (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 8.16 (d with further coupling, 2 H, *J* = 9.0 Hz, ArH), 7.59 (d with further coupling, 2 H, *J* = 9.1 Hz, ArH), 5.34 (pentet with further coupling, 1 H, *J* = 2.7 Hz, H-4), 5.28 (dd, 1 H, *J* = 8.0, 7.2 Hz, H-2), 5.17 (dd, 1 H, *J* = 7.9, 3.3 Hz, H-3), 5.03 (d, 1 H, *J* = 7.0 Hz, H-1), 4.20 (dd, 1 H, *J* ≈ 12.5, 5.0 Hz, H-5), 3.77 (dd, 1 H, *J* = 12.6, 2.4 Hz, H-5), 2.13, 2.11, 2.09 (s, 3 H each, AcO). Anal. Calcd for $C_{17}H_{19}NO_9S$: C, 49.4; H, 4.6; N, 3.4. Found: C, 49.6; H, 4.7; N, 3.4.

Compound **39**: mp 142–143 °C (heptane/EtOAc); $[\alpha]^{25}_D$ −258° (*c* 1.1, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 8.14 (d with further coupling, 2 H, *J* = 9.0 Hz, ArH), 7.53 (d with further coupling, 2 H, *J* = 9.1 Hz, ArH), 6.14 (d, 1 H, *J* = 5.2 Hz, H-1), 5.44 (dd, 1 H, *J* = 10.5, 5.2 Hz, H-2) 5.38–5.37 (m, 1 H, H-4), 5.28 (dd, 1 H, *J* = 10.5, 3.4 Hz, H-3), 4.30 (dd, 1 H, *J* = 13.3, 1.5 Hz, H-5), 3.80 (dd, 1 H, *J* = 13.2, 2.7 Hz, H-5), 2.16, 2.12, 2.06 (s, 3 H each, AcO). Anal. Calcd for $C_{17}H_{19}NO_9S$: C, 49.4; H, 4.6. Found: C, 49.2; H, 4.5.

4-Nitrobenzyl 2,3,4-Tri-*O*-acetyl-1-thio-α-D-arabinopyranoside (40). Compound **32** (1.00 g, 3.14 mmol) and 4-nitro-α-toluenethiol[19] (1.59 g, 9.42 mmol) were dissolved in dichloromethane (10 mL). The solution was cooled with ice and boron trifluoride etherate (2.00 mL, 16.0 mmol) was added during 2 min. After 35 min, the reaction mixture was diluted with diethyl ether (20 mL) and washed with saturated aqueous sodium hydrogen carbonate (15 mL), water (10 mL), aqueous sodium hydroxide (2 × 10 mL, 2 M), and water (10 mL). Drying (Na_2SO_4), removal of solvents, and chromatography (SiO_2, heptane/EtOAc 2:1) gave **40** (1.28 g, 96%): $[\alpha]^{25}_D$ +78.6° (*c* 1.2, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 8.18 (d with further coupling, 2 H, *J* = 8.8 Hz, ArH), 7.49 (d with further coupling, 2 H, *J* = 8.8 Hz, ArH), 5.29 (dt, 1 H, *J* = 3.6, 2.0 Hz, H-4), 5.25 (t, 1 H, *J* = 8.5 Hz, H-2), 5.05 (dd, 1 H, *J* = 8.7, 3.4 Hz, H-3), 4.41 (d, 1 H, *J* = 8.1 Hz, H-1) 4.10 (dd, 1 H, *J* = 12.8, 3.8 Hz, H-5), 4.22, 3.91 (AB q, 1 H each, *J* = 13.1 Hz, PhCH_2), 3.63 (dd, 1 H, *J* = 12.8, 2.0 Hz, H-5), 2.14, 2.07, 2.04 (s, 3 H each, AcO). Anal. Calcd for $C_{18}H_{21}NO_9S$: C, 50.6; H, 5.0. Found: C, 50.3; H, 4.8.

Methyl 2,3-Anhydro-α-D-allopyranoside (42). Methyl 4,6-*O*-benzylidene-2,3-anhydro-α-D-allopyranoside[15] (**41**, 250 mg, 0.95 mmol) was hydrogenolyzed (H_2, Pd/C, 50 mg, 10%) in a mixture of ethanol (2 mL) and tetrahydrofuran (6 mL). After 16 h, the catalyst was filtered off, the solvent was removed, and the residue was chromatographed (SiO_2, EtOAc) to give **42** (130 mg, 78%): $[\alpha]^{25}_D$ +167° (*c* 0.7, methanol) [lit.[16] $[\alpha]^{25}_D$ +153° (*c* 2.058, methanol)]; ^1H NMR (CD_3OD) δ 4.90 (d, 1 H, *J* = 3.2 Hz, H-1), 3.83–3.75, 3.65–3.59 (m, 2 H each, H-4, H-5, H-6), 3.51 (dd, 1 H, *J* = 4.2, 3.1 Hz, H-2), 3.38 (dd, 1 H, *J* = 4.2, 1.7 Hz, H-3).

(19) Price, T. S.; Twiss, D. F. *J. Chem. Soc.* **1909**, *95*, 1725.

Methyl 6-*O*-[Dimethyl(1,1,2-trimethylpropyl)silyl]-α-D-glucopyranoside (44). Dimethyl(1,1,2-trimethylpropyl)chlorosilane (11.2 mL, 56.8 mmol) was added to an ice-cooled solution of methyl α-D-glucopyranoside (**43**, 10.0 g, 51.5 mmol) in pyridine (51.5 mL, 4 Å). When the addition was completed, the ice bath was removed and the reaction mixture was left for 16 h. Methanol (10 mL) was added and the solvent was removed. The residue was dissolved in ethyl acetate (200 mL) and washed with a mixture of 10% hydrochloric acid and 10% aqueous ammonium sulfate (2 × 50 mL, 1:2) and saturated aqueous sodium hydrogen carbonate (40 mL). Drying (Na_2SO_4), removal of solvents, and chromatography (SiO_2, EtOAc) gave **44** (15.2 g, 88%): $[\alpha]^{25}_D$ +88.1° (*c* 1.3, $CHCl_3$); ^1H NMR (CD_3OD) δ 4.64 (d, 1 H, *J* = 3.8 Hz, H-1), 3.90 (dd, 1 H, *J* = 11.2, 2.1 Hz, H-6), 3.76 (dd, 1 H, *J* = 11.1, 5.4 Hz, H-6), 3.61 (t, 1 H, *J* = 9.2 Hz, H-3), 3.51 (dddd, 1 H, *J* = 10.0, 5.4, 2.1, 0.6 Hz, H-5), 3.39 (s, 3 H, MeO), 3.36 (dd, 1 H, *J* = 9.6, 3.8 Hz, H-2), 3.29 (dd, 1 H, *J* = 10.0, 8.8 Hz, H-4), 1.65 (heptet, 1 H, *J* = 6.9 Hz, Me_2CH), 0.92 (d, 6 H, *J* = 6.9 Hz, Me_2CH), 0.88 (s, 6 H, Me_2C), 0.13 (s, 6 H, Me_2Si). Anal. Calcd for $C_{15}H_{32}O_6Si$: C, 53.5; H, 9.6. Found: C, 53.4; H, 9.6.

Methyl 6-*O*-[Dimethyl(1,1,2-trimethylpropyl)silyl]-β-D-glucopyranoside (47). Dimethyl(1,1,2-trimethylpropyl)chlorosilane (16.0 mL, 81.2 mmol) was added to an ice-cooled solution of methyl β-D-glucopyranoside hemihydrate (**46**, 10.0 g, 49.2 mmol) in dry pyridine (52 mL). The reaction mixture was placed in an oil bath (100 °C) for 1 h. After cooling to room temperature, methanol (5 mL) was added and the solvent was removed. The residue was treated as in the preparation of **44** to give **47** (13.69 g, 83%): mp 100–100.5 °C (heptane/EtOAc); $[\alpha]^{25}_D$ −37.5° (*c* 1.2, $CHCl_3$); ^1H NMR (CD_3OD) δ 4.13 (d, 1 H, *J* = 7.7 Hz, H-1), 3.96 (dd, 1 H, *J* = 11.3, 1.9 Hz, H-6), 3.77 (dd, 1 H, *J* = 11.3, 5.2 Hz, H-6), 3.51 (s, 3 H, CH_3O), 3.34–3.11 (m, 4 H, H-2–5), 1.65 (heptet, 1 H, *J* = 6.9 Hz, Me_2CH), 0.92 (d, 6 H, *J* = 6.8 Hz, Me_2CH), 0.88 (s, 6 H, Me_2C), 0.13 (s, 6 H, Me_2Si). Anal. Calcd for $C_{15}H_{32}O_6Si$: C, 53.5; H, 9.6. Found: C, 53.9; H, 9.7.

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Supplementary Material Available: ^1H NMR spectra of **3**, **5**, **7**, **8**, and **22** and ^{13}C NMR spectra of **3** and **8** (7 pages). Ordering information is given on any current masthead page.