Highly Selective Formation of a β-C-Glucosidic Bond in the Reactions of ArSCl–Glucal Adducts with Silicon-Containing Nucleophiles

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2-(Arylthio)-2-deoxyglucosyl chlorides, which are easily prepared as a mixture of stereoisomers upon the Ad_E reaction of ArSCl with *tri-O*-benzyl-D-glucal, upon treatment with a Lewis acid catalyst can be transformed into cationoid intermediates, presumably episulfonium ions. The latter were shown to be efficient electrophiles capable of alkylating various Si-containing nucleophiles such as TMSCN, allyltrimethylsilane, TMS enol ethers, and ketene acetals with formation of the corresponding 2-deoxy-2-(arylthio)-*C*-glucosides in preparatively acceptable yields. The final outcome of the reaction corresponds to a net *trans*-addition of ArS and carbon nucleophile moieties across the double bond of the starting glucal. The stereofacial selectivity of this addition is sensitive to variations in the reaction conditions but generally a below-plane attack is preferable. A highly selective formation of the β-*C*-glucosidic bond (ratio of β-gluco:α-manno isomers up to 19:1) can be achieved if the coupling is carried out in CH_2Cl_2 solution. Thus, the reaction might serve as a convenient method for the synthesis of diverse 2-deoxy-2-(arylthio)-β-*C*-glucosides containing aliphatic, cycloaliphatic, or aromatic residues and functional groups like carbonyl, carboxyl, or the double bond.

The interest in the synthesis of *C*-glycosides emerged initially due to the isolation of a number of biologically active compounds containing this moiety[1] and later was additionally spurred on owing to the recognition of the potential usefulness of various carbon glycosides in biochemical studies as nonhydrolyzable analogs of naturally occurring *O*-glycosides.[2] The increased reactivity of the anomeric acetal center offers numerous options for using carbohydrate derivatives (lactols, pyranosides, pyranosyl halides) as electrophiles in Lewis acid mediated C–C bond-forming reactions.[3a] Various silylated derivatives turned out to be especially useful as carbon nucleophiles in such reactions. These silyl compounds lead to the preferential or even exclusive formation of α-*C*-glycosides, and it is generally assumed that this result is due to the intermediate formation of an oxocarbenium cation, with a preference toward nucleophilic approach from the α-side being determined by the anomeric effect of the ring oxygen.[3] A stereoselective preparation of β-*C*-glycosides represents a substantially more troublesome task and involves utilization of multistep procedures. Thus, reaction of glycolactones with Grignard reagents followed by hydride reduction of the resulting tertiary alcohols was elaborated by Kishi and co-workers as a preparative method of β-*C*-glycoside synthesis.[4a] Bednarski *et al.* found that β-*C*-glycosyl aldehydes can be prepared by the base-catalyzed isomerization of the corresponding α-isomers which are made by ozonolysis of α-*C*-glycosyl allenes.[4b] Stork's group suggested a protocol for a stereospecific introduction of a styryl group at the anomeric center at either the α- or β-position *via* a radical-induced intramolecular cyclization of the appropriate precursor having a temporary silicon connection.[4c]

At the same time it was also established that a highly preferential formation of β-*O*-glycosides can be easily achieved with the help of bridged electrophiles generated from precursors bearing the appropriate substituents at C-2.[5a] Thus, the well-known propensity of the arylthio group to stabilize an incipient β-carbocationic center owing to the formation of an episulfonium ion (ESI)-like species was successfully elaborated by Nicolaou *et al.* into an efficient method for the formation of either α- or β-*O*-glycosidic bonds depending on the reaction conditions.[5b] In this study the required precursors, 2-(arylthio)glycosyl fluorides, were prepared *via* fluorination of the respective 1-(arylthio)glycosides with Et_2NSF_3 which proceeded with a 1,2-ArS shift. A more direct pathway leading to ESI intermediates involves the Ad_E reaction of the protected glucals with arylsulfenium electrophiles. Thus, Ogawa described the Ad_E reaction of the protected glucal with PhSOR in the presence of TMSOTf as a general method for the preparation of 2-deoxy-2-(phenylthio)glycosides.[5c] The stereoselectivity of glycosylation in this reaction was

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(5) (a) See for a review: Toshima, K.; Tatsuda, K. *Chem. Rev.* **1993**, *93*, 1503. (b) Nicolaou, K. C.; Ladduwahetty, T.; Randall, J. L.; Chucholovsky, A. *J. Am. Chem. Soc.* **1982**, *104*, 2466. (c) Ito, Y.; Ogawa, T. *Tetrahedron Lett.* **1987**, *28*, 2723. (d) Ramesh, S.; Kaila, N.; Grewal, G.; Franck, R. W. *J. Org. Chem.* **1990**, *55*, 5 see also references cited therein. (e) Grewal, G.; Kaila, N.; Franck, R. W. *J. Org. Chem.* **1992**, *57*, 2084.

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rather low (β:α = 4:1, at best), but later studies by Franck's group revealed that the utilization of the phenylbis(phenylthio)sulfonium salt as a starting electrophile might substantially improve the selectivity of β-glycosidic bond formation (up to β:α = 12:1).[5d,e] Quite a number of other procedures also based on the use of bridged electrophiles were successfully employed for stereodirected *O*-glycoside syntheses.[5a] Strange as it may seem, neither of these methods has ever been tested as an option for the preparation of *C*-glycosides. This is probably due to the alleged lower carbophilicity of bridged cationoid species like ESI in comparison with their nonbridged counterpart.

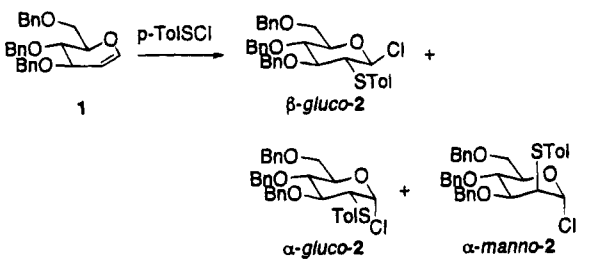
However, ample experimental evidence accumulated in the previous studies of our group on the generation and reactivity pattern of ESI's has unequivocally revealed that in fact these bridged species are able to alkylate a number of typical carbon nucleophiles (Nu_C), like aromatic π-donors,[6a] trimethylsilyl enol ethers,[6b-e] ketene acetals,[6f] allylsilanes,[6f,g] and vinyl ethers.[6h,i] It was established that the sequence (i) Ad_E reaction of ArSCl with alkenes to give the corresponding adducts, 2-(arylthio)alkyl chlorides, (ii) treatment of these adducts with Lewis acid (LA) leading to *in situ* generation of ESI's, and (iii) reaction of the latter with Nu_C results in an overall *trans* and Markovnikov addition of ArS and Nu_C across the double bond of the starting alkene. This sequence was shown to be general in its scope in regard to all the components involved[6d,g,h] and thus represents a promising method of β-arylthioalkylation of a wide set of Nu_C.

It was anticipated that application of this reaction to unsaturated carbohydrate derivatives, namely protected glucals, might offer novel opportunities for the preparation of various *C*-glucosides. Here we report some results attesting to the usefulness of this route.[7]

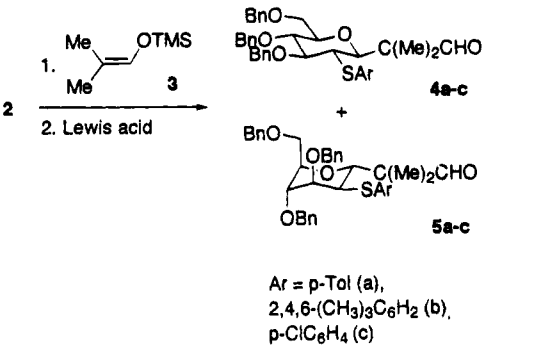
Results and Discussion

Generation of the ArSCl Adduct with Tri-*O*-benzyl-D-glucal. The readily available compound, tri-*O*-benzyl-D-glucal (**1**), was selected as a model substrate in the present study. Reaction of **1** with ArSCl has been utilized in several previous studies dealing with *O*-glycoside synthesis although experimental details were not given.[8] The interaction of *p*-TolSCl with **1** in CH_2Cl_2 at ambient temperature was found to be complete after a few minutes and can be followed by the disappearance of the orange color of the ArSCl to produce the colorless adduct **2**. The ^1H NMR spectrum in CD_2Cl_2 recorded after 3 min shows that initially a mixture of two isomers, β-gluco-**2** and α-gluco-**2**, in a ratio of ca. 4:5 is formed.

Scheme 1



Scheme 2



Ar = p-Tol (a), 2,4,6-$(CH_3)_3C_6H_2$ (b), p-ClC_6H_4 (c)

This ratio changes to 2:3 in about 30 min, and after 3 h signals of β-gluco-**2** in both ^1H and ^{13}C NMR disappear completely. Along with these adducts the presence of a small amount (ca. 10–15%) of the third isomer, having presumably the α-manno structure (α-manno-**2**) was also observed. Its content did not change noticeably with time. If the reaction of **1** with *p*-TolSCl was carried out in CH_3NO_2 the equilibrium mixture of adducts contained α-gluco-**2** and α-manno-**2** isomers in a ratio of 2:1. No attempts were made to isolate individual isomers, and the mixture of adducts, **2**, was used in further reactions without any purification (Scheme 1).

General Procedure. Previous data indicated that trimethylsilyl enol ethers (TMSEE) are among the most reactive carbon nucleophiles to be alkylated by ESI electrophiles.[6b-e] TMSEE **3** was selected for elaboration of the optimal conditions required for the interaction with electrophile generated from adducts **2** as well as for elucidation of the influence of factors like temperature and solvent polarity, nature of ArS electrophile, Lewis acid, and protecting group in the glucal on the steric course and efficiency of the coupling.

It was found that reaction of **3** with adducts **2** in CH_2Cl_2 solution occurs readily at −78 °C in the presence of 1.2 equiv of $SnCl_4$. After a standard workup of the reaction mixture two main products, **4a** and **5a**, were isolated in a ratio of 87:13 in a combined yield of 73%. The structure of both products corresponds to a net *trans*-addition of the electrophilic and nucleophilic components across the double bond of **1**. The major product **4a** belongs to a β-*C*-glucopyranoside and the minor compound **5a** to a α-*C*-mannopyranoside series (*vide infra*) (Scheme 2).

Effect of Lewis Acid. It is well known that the stereochemical outcome of the electrophilic alkylation might reveal a striking sensitivity to variations in the nature of the Lewis acid used for the generation of the reacting electrophile.[9] In our case these variations

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(9) See, for example: Annunziata, R.; Cinquini, M.; Cozzi, F.; Cozzi, P. G.; Consolandi, E. *J. Org. Chem.* **1992**, *57*, 456. Reetz, M. T. *Acc. Chem. Res.* **1993**, *26*, 462. Reetz, M. T. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 556.

Table 1. Effect of Lewis Acid on the Stereochemistry of the Reaction of Adduct 2 (Ar = *p*-Tol) with Nucleophile 3 (See Scheme 2)

entry	Lewis acid	ratio **4a:5a**	yield, %
1	SnCl	87:13	73
2	$TiCl_4$	88:12	78
3	$ZnCl_2$	95:5	84
4	$LiClO_4$	95:5	51

Table 2. Effect of ArS Substituent on the Stereochemistry of the Reaction of Adduct 2 with Nucleophile 3 (see Scheme 2)

entry	ArSCl	yield, %	ratio, β-gluco:α-manno
1	*p*-TolSCl	73	87:13
2	2,4,6-$(CH_3)_3C_6H_2SCl$	80	97:3
3	*p*-ClC_6H_4SCl	84	84:16

Table 3. Effect of Temperature and Solvent on the Stereochemistry of the Reaction of Adduct 2 (Ar = p-Tol) with Nucleopile 3 (see Scheme 4)

entry	solvent	temp, °C	yield, %	ratio, **4a:5a**
1	CH_2Cl_2	−78	73	87:13
2	CH_2Cl_2	−25	75	87:13
3	CH_2Cl_2	0	76	86:14
4	CH_3NO_2	−25	89	1:1

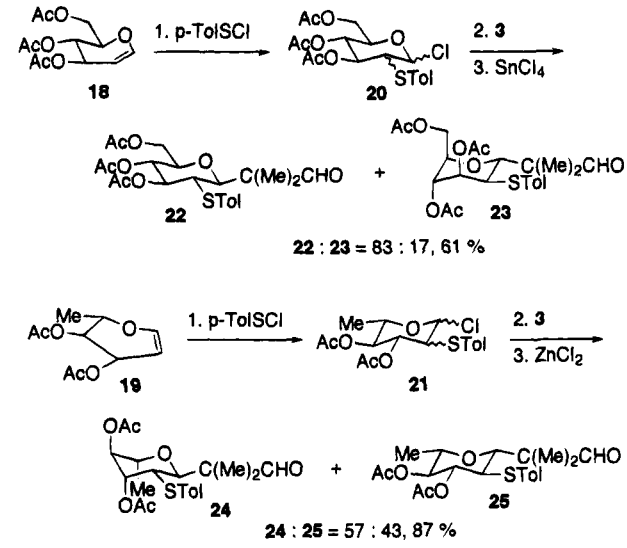
produced a noticeable but not very dramatic effect (see Table 1). Thus, the ratio **4a:5a** for all practical purposes does not change if $TiCl_4$ is used as the Lewis acid instead of $SnCl_4$. At the same time utilization of $ZnCl_2$ led to a substantially higher stereoselectivity of **4a** formation. Comparable results also could be achieved with $LiClO_4$ but in this case the yield turned out to be noticeably lower.[10]

Effect of Arylthio Substituent. In as much as the reaction proceeds *via* formation of ESI (or a structure that mimics ESI), one could have anticipated that variations in the nature of the aryl group at the sulfur atom should affect reaction selectivity.[5d,e] The introduction of additional donating substituents onto the aryl ring should increase the bridging capacity of sulfur, and thus the stereoselectivity of the overall transformation should also be increased. The reverse should be true for the introduction of electron-withdrawing groups. Experimental results (see Table 2) revealed that an exclusive *trans*-addition is observed in all cases regardless of changes in the nature of the initial electrophile. At the same time, variations in the latter parameter were found to affect somehow the β-gluco:α-manno composition, and maximum selectivity of formation of the former isomer was observed for the bulkiest electrophile, MzSCl.

Effect of Temperature and Solvent. The standard reaction of adducts **2** with the nucleophile **3** in CH_2Cl_2 in the presence of $SnCl_4$ was performed at −78, −25, and 0 °C. It turns out that the isomeric ratio does not depend upon temperature (Table 3). In contrast to the lack of a temperature effect, a change of CH_2Cl_2 for the more polar solvent CH_3NO_2 significantly affects the stereochemistry of the coupling. In the latter case the isomer ratio became 1:1.

Scope of the Reaction. We have observed that under standard conditions in the presence of $SnCl_4$ adducts **2** are able to react with a variety of Si-containing nucleophiles such as TMSCN (**6**), allyltrimethylsilane (**7**), TMSEE of methyl cyclopropyl ketone (**8**), acetophenone

Scheme 3



(**9**), crotonaldehyde (**10**), and methyl 2-methylpropionate (**11**), (Table 4). It was rewarding to find that in all cases reactions proceeded in an uncomplicated manner with a high stereoselectivity of formation of the corresponding β-gluco isomers **12**–**17** in preparatively acceptable yields. Thus, the elaborated procedure seems to be widely applicable for a stereoselective preparation of a variety of 2-(arylthio)-2-deoxy-*C*-β-glucosides containing aliphatic, cycloaliphatic, or aromatic moieties and functional groups like carbonyl or double bond.

Along with **1** we also have studied the opportunity to carry the described sequence of reactions with tri-*O*-acetyl-D-glucal (**18**), as well as 3,4-di-*O*-acetyl-6-deoxy-L-glucal (**19**). It was found that the interaction of **18** or **19** with ArSCl in CH_2Cl_2 proceeded very slowly, and even at room temperature the reaction was still incomplete after several hours. A more suitable solvent for this reaction turned out to be CH_3CN. The ^1H NMR spectra of both reaction mixtures indicated that several isomers of the corresponding 2-(arylthio)-2-deoxypyranosyl chlorides **20** or **21** were present, but unfortunately, no structural assignments could be made.

In order to avoid possible complications due to the nucleophilicity of CH_3CN,[11] the latter was carefully removed on a rotary evaporator and further reactions of adducts **20** or **21** were carried out in CH_2Cl_2. In the case of adduct **20** the reaction with nucleophile **3** takes place in the presence of $SnCl_4$ at 0 °C (compared to −78 °C for **1**). The result of the reaction was formation of two products, **22** and **23**, in a ratio of 83:17. The former has the β-gluco configuration, and the latter is the α-manno isomer (Scheme 3). The interaction of adduct **21** with the same nucleophile gave a somewhat better yield if the weaker Lewis acid $ZnCl_2$ was used. In this case the reaction was not selective, and a mixture of two isomers, α-manno (**24**) and β-gluco (**25**), was obtained (**24**:**25** = 57:43).

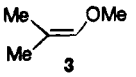
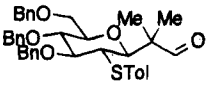
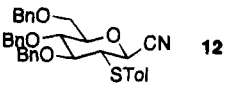
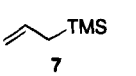
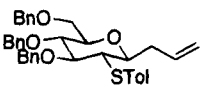
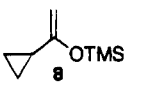
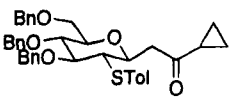
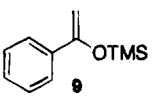
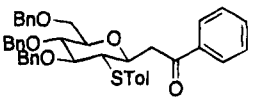
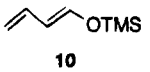
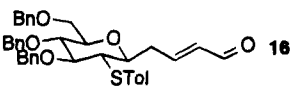
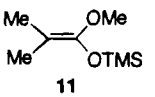
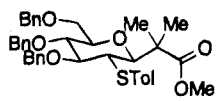
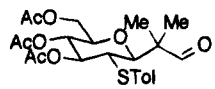
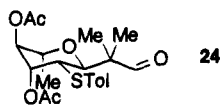
Structure Assignments. The composition of all the synthesized products was ascertained by HRMS data.[12] The structure of adducts was determined with the help of ^1H NMR, ^{13}C NMR (DEPT), ^1H–^1H homonuclear

(10) Utilization of $LiClO_4$ as a Lewis acid in electrophilic reactions is well-documented, e.g.: Grieco, P. A.; Cooke, R. J.; Henry, K. J.; VanderRoest, J. M. *Tetrahedron Lett.* **1991**, *32*, 4665. Chini, M.; Crotti, P.; Favero, L.; Pineschi, M. *Tetrahedron Lett.* **1991**, *32*, 7586. Pearson, W. H.; Schkeryantz, J. M. *J. Org. Chem.* **1992**, *57*, 2986.

(11) Gordon, D. N.; Danishefsky, S. J. *J. Org. Chem.* **1991**, *56*, 3713.

(12) A detailed analysis of the mass spectral fragmentation pattern of β-*gluco* isomers prepared in this study is presented in separate publication: Rosynov, B. V.; Liukkonen, R. J.; Carlson, R. M.; Kuehl, D. W.; Smoliakova, I. P.; Caple, R.; Kuehl, C. J.; Smit, W. A. *Org. Mass Spectrom.* **1994**, *29*, 309.

Table 4. Synthesis of C-Glucosides from Glucals 1, 18, and 19[a]

Entry	Glucal	Nu	Major product	Yield, %	Ratio of isomers[b]
1	1	 3	 **4a**	73	87 : 13
2	1	TMSCN 6	 **12**	88	95 : 5
3	1	 7	 **13**	79	95 : 5
4	1	 8	 **14**	48	90 : 10
5	1	 9	 **15**	76	95 : 5
6	1	 10	 **16**	31	90 : 10
7	1	 11	 **17**	87	95 : 5
8	**18**	**3**	 **22**	61	83 : 17
9	**19**	**3**	 **24**	87	43 : 57

[a] All reactions were performed in the presence of 1.2 equiv of $SnCl_4$ at −78 °C (entry 1−7) or 0 °C (entries 8 and 9). $ZnCl_2$ was used as the Lewis acid in two cases (entry 7, 8). [b] β-gluco:α-manno.

Table 5. Characteristic Parameters of the ^1H NMR Spectra (δ, ppm, multiplicity, J, Hz) in $CDCl_3$ for β-Gluco Isomers 4a and 4c and α-Manno Isomers 5a and 5c

compd	^1CH	^2CH	^3CH	^4CH	^5CH
4a	3.60 d, $J_{1,2}$ = 10.75	3.07, t, $J_{1,2}$ = $J_{2,3}$ = 10.75	3.67, m		3.48, dd, $J_{5,6a}$ = 2.5, $J_{5,6b}$ = 4.0, $J_{4,5}$ = 9.75
4c	3.58, d, $J_{1,2}$ = 10.7	3.02, br t, $J_{1,2}$ = $J_{2,3}$ = 10.7	3.66, m		3.54, ddd, $J_{5,6a}$ = 2.3, $J_{5,6b}$ = 4.0, $J_{4,5}$ = 10.0
5a	4.08 d, $J_{1,2}$ = 10.5	3.52, dd, $J_{1,2}$ = 10.5, $J_{2,3}$ = 3.0	3.90, br t, $J_{2,3}$ = 3.0, $J_{3,4}$ = 3.8	3.63, dd, $J_{3,4}$ = 3.8, $J_{4,5}$ = 2	4.175, br t, J = 6.75
5c	4.07, d, $J_{1,2}$ = 10.0	3.50, dd, $J_{1,2}$ = 10.0, $J_{2,3}$ = 3.0	3.85, br t, $J_{2,3}$ = 3.0, $J_{3,4}$ = 3.7	3.65, dd, $J_{3,4}$ = 3.7, $J_{4,5}$ = 1.9	4.18, br t, J = 6.4

decoupling, and in several cases, 2D $^1H-^1H$ homonuclear COSY and 2D $^1H-^{13}C$ heteronuclear correlations.

In all cases the major products belong to the series of β-gluco isomers. Thus, ^1H NMR spectra of all the compounds with a β-gluco configuration (**4a-4c**, **12−17**, **22**, and **25**) reveal the presence of a triplet (or dd) with J = 10.45−11.2 Hz in the region of 3 ppm assigned to the proton at C-2 (C*H*SAr). The observed pattern of splitting and value of J_{vic} unambiguously proved the *trans*-diaxial orientation of this proton and protons at the adjacent C-1 and C-3 centers as it should be in the β-gluco series (see Table 5 and Experimental Section). This conclusion was additionally checked by the $^1H-^1H$ homonuclear decoupling analyses which allowed us to identify the signal of the proton at C-1 in the spectra of **4a**, **4c**, **12**, **17**, **22**, and **25** as a doublet (ddd for compounds **13−16**) with $J_{1,2}$ = 10.45−11.2 Hz at 3.32−4.07 ppm.

The α-manno configuration and conformation of the minor isomers **5a**, **5c**, **23**, and **24**, as shown in Schemes 2 and 3, were unambiguously established upon analysis

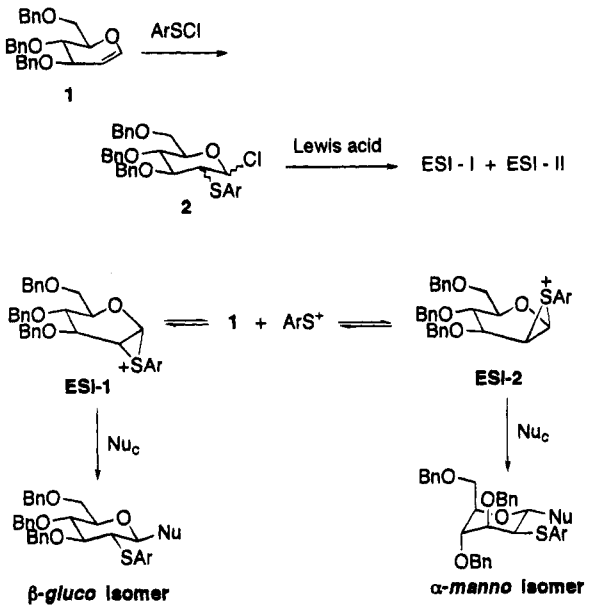
of the coupling constant of all protons (see Table 5 and Experimental Section). Thus, the splitting pattern of ^1H signals for the protons at C-1 and C-2 is in full accord with the *trans*-diequatorial configuration of the substituents at these centers. This conclusion is also consistent with the NOE and $^1H-^1H$ homonuclear decoupling analyses. Obviously, the conformation with axial substituents at C-3, C-4, and C-5 as is shown in the structures of these compounds (Schemes 2 and 3) became preferable due to the presence of the bulky equatorial substituent at C-1. In the case of **12-17** the minor isomers have not been isolated as individual compounds, and their structure as α-manno derivatives was accepted by analogy.

Discussion

The exclusive formation of the adducts like **4a** and **5a** corresponding to the *trans*-addition of the ArS electrophile and Nu_C across the double bond of **1** leave little doubt about the involvement of ESI's as intermediates at the product-determining step of the described sequence, since a universally high stereoselectivity of ESI ring opening reaction has been amply demonstrated earlier.[6] The observed high diastereofacial selectivity of the formation of β-gluco isomers like **4a** for the whole series of ArSCl-mediated reactions of glucal derivatives with Nu_C described in this paper (see Table 4) strongly suggests that among two viable intermediates, namely ESI-1 and ESI-2, the former is formed preferentially, at least in solvents of moderate polarity as CH_2Cl_2. The utilization of the sterically demanding 2,4,6-$Me_3C_6H_2SCl$ as the electrophile obviously served as an additional factor favoring formation of ESI-1. These data are consistent with previous observations of Franck's group on the steric course of the related *O*-glycosylation sequence which were interpreted as evidence in favor of a highly predominant formation of ESI-1 intermediate as a result of the preferable below-plane attack of ArS^+ at the glucal double bond.[5d,e] Reasonably consistent explanations for this preference can be found in the recent paper describing the application of PPFMO theory to the analysis of the selectivity pattern of electrophilic additions to the double bond of dihydropyrans derived from sugars (Scheme 4).[13]

It was more difficult to account for the observed almost nondiscriminant formation of trans-adducts **4a** and **5a** if the reaction sequence was carried out in CH_3NO_2 (see Table 3). NMR ^1H monitoring of the initial step of the reaction, namely interaction of **1** with ArSCl in CD_3NO_2, revealed that the mixture **2** formed under these conditions consists mainly of α-gluco-**2** and α-manno-**2** in the ratio ca. 2:1 (cf. with the above data with a less than 10–15% of α-manno-**2** content for the reaction in CH_2Cl_2). Hence, it was tempting to speculate about the possible correlation of the final **4a**:**5a** ratio with the composition of mixture **2**. However, a control experiment revealed that the latter factor has no relevance to the isomeric composition of the final product. In fact, the utilization of the mixture **2** prepared in CH_2Cl_2 (which contained ca. 10% of α-manno-**2**, the rest being α-gluco-**2**) for the further reaction with **3** in CH_3NO_2 resulted in about the same nonselectivity for the formation of the mixture of **4a** and **5a** (**4a**:**5a** = 62:38). These results forced us to conclude that upon the action of Lewis acid the initially formed mixture of isomeric adducts **2** is transformed into an *equilibrium* mixture of isomeric intermediates ESI-1 and ESI-2 (cf. data in ref 5e). Since these species might differ in solvation and ion-pairing capacity, the composition of this mixture and hence the overall steric outcome of the reaction might be sensitive not only to the nature of the glucal substrate but also to the variations in the nature of the solvent and Lewis acid.

Scheme 4



Conclusion

The results of the present study clearly demonstrate the potential of the utilization of ESI-like intermediates, easily obtainable from the protected glucal–ArSCl adducts, as electrophiles in the reactions with a set of representative Si-containing carbon nucleophiles. The elaborated protocol seems to represent a fairly general method which secures a highly stereoselective preparation of a series of 2-(arylthio)-2-deoxy-β-*C*-glucosides bearing various substituents at the side chain. This sequence nicely complements previously described procedures of electrophilic *C*-glycosylation which resulted in the preferential formation of α-*C*-glycosides. The presence of various functional groups in the adducts like **4** and **12–17** offers numerous and rather obvious opportunities for their further utilization as chiral synthetic intermediates.

Experimental Section

Instrumentation and Materials. ^1H and ^{13}C NMR spectra of all compounds were recorded in $CDCl_3$. Preparative TLC was carried out by using glass plates, 200 × 250 mm, with an unfixed layer of Merck silica gel 60, 230–400 mesh. Analytical TLC were performed on Merck precoated 0.2 mm plates of silica gel 60 F_{254}. All reactions were carried out under an atmosphere of dry argon using oven-dried or flame-dried glassware and freshly distilled and dried solvents.

Arylsulfenyl chlorides were obtained from the corresponding thiophenols by using SO_2Cl_2.[14] Silyl enol ethers were synthesized from corresponding ketones and aldehydes by using Me_3SiCl and Et_3N in DMF.[15] Other chemicals are commercially available.

3,4,6-Tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-β-D-glucopyranosyl Chloride (β-Gluco-2) and 3,4,6-Tri-*O*-benzyl-2-

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deoxy-2-(*p*-tolylthio)-α-D-glucopyranosyl Chloride (α-Gluco-2). To a solution of 158.7 mg (1.0 mmol) of *p*-TolSCl in 10 mL of CH_2Cl_2 at room temperature was added 416.5 mg (1.0 mmol) of tri-*O*-benzyl-D-glucal. The reaction mixture was stirred for 10 min during which time the reaction mixture turned colorless. The mixture of adducts obtained was utilized in the next transformations without any purification. ^{1}H NMR for α-gluco-**2** (the spectrum was taken 4 h after the reaction of **1** with *p*-TolSCl, 200 MHz, CD_2Cl_2) δ: 2.36 (s, 3H), 3.56 (dd, J = 10.9, 2.6 Hz, 1 H), 3.72 (dd, J = 11.0, 2.4 Hz, 1 H), 3.83 (m, 1 H), 3.87 (dd, J = 11.0, 2.4 Hz, 1 H), 4.08 (dd, J = 10.9, 9.0 Hz, 1 H), 4.24 (m, 1 H), 4.60 m and 4.90 d (4 H), 4.95 and 5.08 (two d, J = 10.7 Hz), 6.24 (d, J = 2.6 Hz, 1 H), 7.35 (m, 19 H). ^{13}C NMR (50 MHz, CD_2Cl_2) δ: 21.17, 58.22, 68.96, 73.72, 74.86, 75.50, 76.42, 78.86, 81.31, 96.97 (CCl), 128.09, 128.16, 128.24, 128.43, 128.58, 128.73, 128.92, 130.19, 130.55, 131.45, 132.57, 134.15, 138.12, 138.41, 138.63, 138.67. In a separate experiment monitored by NMR in the spectrum of the mixture (taken 3 min after adding glucal **1** to *p*-TolSCl in CD_2Cl_2 at room temperature) a set of signals were identified as belonging to β-gluco-**2**: 3.41 (t, $J_{1,2} = J_{2,3}$ = 8.7 Hz, 1 H, H^2), 5.40 (d, $J_{1,2}$ = 8.7 Hz, 1 H, H^1). The broad singlet at 6.14 ppm (line width $\omega_{1/2}$ ca. 3 Hz) apparently belongs to α-manno-**2**. The NMR spectrum of the mixture prepared in CD_3NO_2 (20 °C) revealed the presence of only two components identified as α-gluco-**2** and α-manno-**2** isomers. The ratio (see Results and Discussion) of isomers was obtained by integrating of the ^{1}H signals at 6.24 (α-gluco-**2**), 5.40 (β-gluco-**2**), and 6.14 (α-manno-**2**) ppm.

2-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-β-D-glucopyranosyl)-2-methylpropanal (4a). To a solution of 158.7 mg (1.0 mmol) of *p*-TolSCl in 10 mL of CH_2Cl_2 at room temperature was added 416.5 mg (1.0 mmol) of tri-*O*-benzyl-D-glucal (the color changed from yellow to colorless). After 10 min the mixture was cooled to −78 °C, and a solution of 173 mg (1.2 mmol) of the trimethylsilyl enol ether of 2-methylpropanal (**3**) in 2 mL of CH_2Cl_2 was introduced. After that a solution of 0.14 mL (1.2 mmol) of $SnCl_4$ in 2 mL of CH_2Cl_2 was added dropwise. The mixture was stirred 30 min at −78 °C, quenched with a saturated solution of $NaHCO_3$, extracted with ether, and dried over Na_2SO_4. Preparative TLC (ether−hexane, 1:4) of the crude material after solvent removal in vacuo afforded two pure substances, **4a** and **5a**, in a ratio of 87:13 and overall yield of 73%. Data for **4a**. TLC: R_f (ether−hexane, 1:1) = 0.50. IR (neat): 1718 cm^{-1}. ^{1}H NMR (250 MHz, $CDCl_3$) δ 0.90, 1.14 (two s, 6 H), 2.32 (s, 3 H), 3.07 (t, J = 10.75 Hz, 1 H), 3.48 (ddd, J = 9.75, 4.0, 2.5 Hz, 1 H), 3.60 (d, J = 10.75 Hz, 1 H), 3.67 (m, 2 H), 3.78 (dd, J = 11.0, 4.0 Hz, 1 H), 3.77 (dd, J = 11.0, 2.5 Hz, 1 H), 4.56, 4.62 (two d, J = 12.5 Hz, 2 H), 4.67, 4.89 (two d, J = 10.5 Hz, 2 H), 4.91, 5.05 (two d, J = 10.5 Hz, 2 H), 7.28 (m, 19 H), 9.72 (s, 1 H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 15.73, 21.14, 21.99, 50.10, 54.55, 69.20, 73.52, 75.07, 76.62, 79.73, 79.89, 82.17, 85.91, 127.62, 127.69, 127.69, 127.96, 128.34, 128.41, 128.51, 128.60, 129.95, 130.73, 131.55, 137.02, 138.35, 199.74. HRMS: calcd for $C_{38}H_{42}SO_5$ (M^+) *m/e* 610.2753, found *m/e* 610.2760.

2-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-α-D-mannopyranosyl)-2-methylpropanal (5a). To a solution of 158.7 mg (1.0 mmol) of *p*-TolSCl in 10 mL of CH_3NO_2 at room temperature was added 416.5 mg (1.0 mmol) of tri-*O*-benzyl-D-glucal (the color changed from yellow to colorless). After 10 min the mixture was cooled to −25 °C and a solution of 173 mg (1.2 mmol) trimethylsilyl enol ether of 2-methylpropanal (**3**) in 2 mL of CH_3NO_2 was introduced. Then a solution of 0.14 mL (1.2 mmol) of $SnCl_4$ in 2 mL of CH_3NO_2 was added dropwise. The mixture was stirred for 3 h at room temperature, quenched with a saturated solution of $NaHCO_3$, extracted with ether, and dried over Na_2SO_4. Preparative TLC (ether−hexane, 1:4) of the crude material after solvent removal in vacuo afforded the two pure substances **4a** and **5a**. Yield of two isomers 89%, ratio 1:1. Data for **5a**. TLC: R_f (ether−hexane, 1:1) = 0.56. IR (neat): 1718 cm^{-1}. ^{1}H NMR (250 MHz, $CDCl_3$) δ: 0.995, 1.08 (two s, 6 H), 2.185 (s, 3 H), 3.52 (dd, J = 10.5, 3.0 Hz, 1 H), 3.63 (dd, J = 3.8, 2.0 Hz, 1 H), 3.69 (dd, J = 10.0, 6.4 Hz, 1 H), 3.83 (dd, J = 10.0, 7.5 Hz, 1 H), 3.90 (br. t, J = 3.8, 3.0 Hz, 1 H), 4.08 (d, J = 10.5, 1 H), 4.175 (br.t, J = 6.75 Hz, 1 H), 4.53 (m, 6 H), 7.30 (m, 19 H), 9.61 (s, 1 H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 16.04, 20.78, 21.18, 49.96, 50.18, 68.11, 71.85, 72.97, 73.80, 73.05, 73.22, 74.97, 78.26, 127.76, 127.83, 127.93, 128.05, 128.27, 128.51, 128.55, 129.55, 130.04, 131.01, 201.64. HRMS: calcd for $C_{38}H_{42}SO_5$ (M^+) *m/e* 610.2753, found *m/e* 610.2756. Anal. Calcd for $C_{38}H_{42}SO_5$: C, 74.72; H, 6.93; S, 5.25. Found: C, 74.62; H, 6.91; S, 5.33.

2-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-(mesitylthio)-β-D-glucopyranosyl)-2-methylpropanal (4b). This derivative was synthesized by the method described for **4a** with a yield 80%. TLC: R_f (ether−hexane, 1:1) = 0.53. IR (neat): 1724 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ: 1.17, 1.26 (two s, 6 H), 2.27 (s, 3 H), 2.49 (s, 6 H), 3.47 (dd, J = 6.7, 4.6 Hz, 1 H), 3.53 (dd, J = 9.0, 2.9 Hz, 1 H), 3.56 (br. t, J = 4.6, 2.9 Hz, 1 H), 3.63 (dd, J = 11.0, 5.4 Hz, 1 H), 3.68 (dd, J = 11, 2.4 Hz, 1 H), 3.76 (ddd, J = 9.0, 5.4, 2.4 Hz, 1 H), 3.84 (d, J = 6.7 Hz, 1 H), 4.10, 4.13 (two d, J = 11.7 Hz, 2 H), 4.20, 4.26 (two d, J = 11.2 Hz, 2 H), 4.58, 4.60 (two d, J = 11.2 Hz, 2 H), 6.87, 7.09, 7.28, 7.35 (four m, 17 H), 9.70 (s, 1 H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 18.50, 19.05, 21.01, 23.53, 44.96, 50.53, 70.06, 71.06, 72.31, 73.35, 78.02, 78.33, 80.40, 83.59, 127.40, 127.53, 127.57, 127.66, 127.75, 127.86, 128.04, 128.26, 128.28, 128.36, 129.35, 137.75, 137.87, 138.21, 138.42, 142.72, 203.34. HRMS: calcd for $C_{40}H_{46}SO_5$ (M^+) *m/e* 638.3066, found *m/e* 638.3082.

2-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-((*p*-chlorophenyl)thio)-β-D-glucopyranosyl)-2-methylpropanal (4c) and 2-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-((*p*-chlorophenyl)thio)-β-D-glucopyranosyl)-2-methylpropanal (5c). Both compounds were synthesized using *p*-ClC_6H_4SCl by the method dscribed for **4a** with a combined yield 84% (**4c**:**5c** = 84:16, ^{1}H NMR data). Data for **4c**: TLC: R_f (ether−hexane, 1:1) = 0.54. IR (neat): 1718 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.86, 1.13 (two s, 6 H), 3.10 (br t, J = 10.7 Hz, 1 H), 3.55 (ddd, J = 10.0, 4.0, 2.3 Hz, 1 H), 3.65 (d, J = 10.7 Hz, 1 H), 3.66 (m, 2 H), 3.72 (dd, J = 11.0, 2.3 Hz, 1 H), 3.74 (dd, J = 11.0, 4.0 Hz, 1 H), 4.62, 4.68 (two d, J = 12.5 Hz, 2 H), 4.75, 4.96 (two d, J = 11.0 Hz, 2 H), 5.00, 5.06 (two d, J = 10.5 Hz, 2 H), 7.35 (m, 19 H), 9.76 (s, 1 H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 15.37, 21.91, 50.02, 54.80, 68.90, 73.40, 75.05, 76.72, 79.59, 79.72, 81.71, 85.82, 127.47, 127.59, 127.61, 127.79, 127.83, 127.88, 128.16, 128.34, 128.37, 128.50, 129.12, 131.68, 133.00, 133.54, 138.00, 138.25, 199.30. HRMS: calcd for $C_{37}H_{39}SO_5Cl$ (M^+) *m/e* 630.2207, found *m/e* 630.2227. Data for **5c**. TLC: R_f (ether−hexane, 1:1) = 0.57. IR (neat): 1717 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.955, 1.07 (two s, 6 H), 3.50 (dd, J = 10.0, 3.0 Hz, 1 H), 3.63 (dd, J = 3.7, 1.9 Hz, 1 H), 3.68 (dd, J = 10.0, 6.2 Hz, 1 H), 3.81 (dd, J = 10.0, 7.1 Hz, 1 H), 3.90 (br. t, J = 3.7, 3.0 Hz, 1 H), 4.07 (d, J = 10 Hz, 1 H), 4.175 (br.t, J = 6.4 Hz, 1 H), 4.52 (m, 6 H), 7.30 (m, 19 H). ^{13}C NMR ($CDCl_3$, 125 MHz): 15.83, 20.73, 49.94, 50.11, 67.93, 71.86, 73.13, 73.65, 72.69, 72.94, 74.79, 78.18, 127.43, 127.63, 127.69, 127.72, 127.76, 127.80, 127.83, 127.89, 127.99, 128.17, 128.40, 128.46, 128.50, 129.28, 131.81, 133.09, 137.43, 137.93, 138.07, 201.29. HRMS: calcd for $C_{37}H_{39}SO_5Cl$ (M^+) *m/e* 630.2207, found *m/e* 630.2240.

(3,4,6-Tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-β-D-glucopyranosyl)carbonitrile (12). This derivative (contained ca. 5% of α-manno isomer ^{1}H NMR data) was synthesized by the method described for **4a** with a yield of 88% using TMSCN as the nucleophile. TLC: R_f (ether−hexane, 1:1) = 0.45. ^{1}H NMR (200 MHz, $CDCl_3$) δ: 2.38 (s, 3 H), 3.21 (br t, J = 11.2, 10.2 Hz, 1 H), 3.40 (m, 1 H), 3.53 (m, 1 H), 3.73 (m, 3 H), 4.07 (d, J = 11.2 Hz, 1 H), 4.55, 4.62 (two d, J = 9.8 Hz, 2 H), 4.64, 4.67 (two d, J = 10.8 Hz, 2 H), 4.99, 5.20 (two d, J = 10.3 Hz, 2 H), 7.40 (m, 19 H). ^{13}C NMR (50 MHz, $CDCl_3$) δ: 21.33, 54.24, 68.42, 69.75, 73.77, 75.34, 78.65, 80.18, 83.18, 116.34, 127.11, 128.02, 128.14, 128.48, 128.60, 128.65, 130.22, 134.60, 137.68, 138.11, 139.11, 139.13. HRMS: calcd for $C_{35}H_{35}SO_4N$ (M^+) *m/e* 565.2287, found *m/e* 565.2333.

3-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-β-D-glucopyranosyl)-1-propene (13). This substance (contained ca. 5% of α-manno isomer, ^{1}H NMR data) was synthesized by analogy to **4a** (using allyltrimethylsilane as the nucleophile) with yield 79%. TLC: R_f (ether−hexane) = 0.74. ^{1}H NMR (250 MHz, $CDCl_3$) δ: 2.40 (s, 3 H), 2.50 (m, 1 H), 2.98 (m, 1 H), 3.08 (t, J = 10.6 Hz, 1 H), 3.49 (m, 2 H), 3.71 (m, 2 H), 3.61 (m, 2 H), 4.66, 4.72 (two d, J = 12.4 Hz, 2 H), 4.70, 4.94

(m, 2 H), 5.00, 5.18 (m, 2 H), 5.11, 5.99 (two m, 3 H), 7.37 (m, 19 H). ^{13}C NMR ($CDCl_3$, 50 MHz) δ: 21.26, 36.85, 56.29, 69.26, 73.61, 75.10, 76.24, 79.10, 79.96, 80.08, 85.08, 117.46, 127.70, 127.86, 128.04, 128.22, 128.51, 128.61, 129.93, 131.56, 132.67, 134.77, 137.32, 138.48, 138.61, 138.76. HRMS: calcd for $C_{37}H_{40}SO_4$ (M^+) *m/e* 580.2647, found *m/e* 580.2620.

1-Cyclopropyl-2-(3,4,6-tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-*β*-D-glucopyranosyl)-1-oxoethane (14). This derivative (contained ca. 10% of α-manno isomer, ^1H NMR data) was synthesized by the method described for **4a** (using TMSEE of cyclopropyl methyl ketone as the nucleophile), yield 48%. TLC: R_f (ether–hexane, 1:1) = 0.55. ^1H NMR ($CDCl_3$, 200 MHz) δ: 0.86, 1.06 (two m, 4 H), 1.95 (m, 1 H), 2.35 (s, 3 H), 2.81 (dd, J = 16.0, 9.0 Hz, 1 H), 3.01 (t, J = 10.8 Hz, 1 H), 3.50 (dd, J = 16.0, 2.5 Hz, 1 H), 3.65 (m, 5 H), 3.97 (m, J = 10.8, 9.0, 2.5 Hz, 1 H), 4.52, 4.61 (two d, J = 12.5 Hz, 2 H), 4.63, 4.87 (two d, J = 11 Hz, 2 H), 4.93, 5.08 (two d, J = 10.25 Hz, 2 H), 7.33 (m, 19 H). ^{13}C NMR (50 MHz, $CDCl_3$) δ: 10.76, 10.89, 21.20, 21.33, 46.68, 56.70, 68.94, 73.52, 75.00, 76.12, 76.63, 78.95, 79.80, 84.71, 127.71, 127.70, 128.14, 128.42, 128.52, 129.98, 131.23, 132.50, 137.44, 138.40, 138.63, 208.22. HRMS: calcd for $C_{39}H_{42}SO_5$ (M^+) *m/e* 622.2753, found *m/e* 622.2727.

1-Phenyl-2-(3,4,6-tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-*β*-D-glucopyranosyl)-1-oxoethane (15). This derivative (contained ca. 5% of α-manno isomer, ^1H NMR data) was synthesized by the method described for **4a** (using TMSEE of methyl phenyl ketone as the nucleophile), yield 76%. TLC: R_f (ether–hexane, 1:1) = 0.59. ^1H NMR ($CDCl_3$, 200 MHz) δ: 2.32 (s, 3 H), 3.12 (t, J = 10.5 Hz, 1 H), 3.08 (dd, J = 16.0, 4.0, 8.9 Hz, 1 H), 3.45 (m, 1 H), 4.17 (m, 1 H), 3.66 (m, 4 H), 4.42, 4.52 (two d, J = 12.2 Hz, 2 H), 4.64, 4.86 (two d, J = 11.0 Hz, 2 H), 4.94, 5.09 (two d, J = 10.35 Hz, 2 H), 7.30 and 7.93 (two m, 24 H). ^{13}C NMR (50 MHz, $CDCl_3$) δ: 21.07, 42.18, 56.82, 68.78, 73.40, 74.92, 76.03, 77.02, 78.94, 79.74, 84.61, 127.53, 127.74, 127.83, 128.08, 128.34, 128.60, 129.96, 131.13, 132.55, 133.10, 137.21, 137.45, 137.50, 138.29, 138.37, 138.61, 197.90. HRMS: calcd for $C_{42}H_{42}SO_5$ (M^+) *m/e* 658.2753, found *m/e* 658.2754. Anal. Calcd for $C_{42}H_{42}SO_5$: C, 76.57; H, 6.43; S, 4.87. Found: C, 76.51; H, 6.29; S, 4.99.

4-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-*β*-D-glucopyranosyl)-2-butenal (16). This substance (contained ca. 10% of α-manno isomer, ^1H NMR data) was synthesized by analogy to **4a** (using TMSEE of crotonaldehyde as the nucleophile) with yield 31%. TLC: R_f (ether–hexane, 1:1) = 0.35. IR (neat): 1685 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$) δ: 2.31 (s, 3 H), 2.60 (m, 2 H), 2.90 (t, J = 11.6 Hz, 1 H), 3.08 (m, 1 H), 3.50 (m, 3 H), 3.53 (m, 2 H), 4.50, 4.56 (two d, J = 11.6 Hz, 2 H), 4.57, 4.82 (two d, J = 10.7 Hz, 2 H), 5.89, 5.06 (two d, J = 9.75 Hz, 2 H), 5.92 (dd, J = 15.25, 7.3 Hz, 1 H), 6.79 (m, J = 15.25, 7.1, 6.2 Hz, 1 H), 7.23 (m, 19 H), 9.38 (d, J = 7.3 Hz, 1 H). ^{13}C NMR (50 MHz, $CDCl_3$) δ: 21.08, 35.72, 56.71, 69.01, 73.51, 75.08, 76.35, 77.15, 78.92, 79.72, 84.44, 127.71, 127.91, 128.10, 128.42, 130.01, 132.55, 138.16, 154.27, 193.63. HRMS: calcd for $C_{38}H_{40}SO_5$ (M^+) *m/e* 608.2596, found for *m/e* 608.2544. Anal. Calcd for $C_{38}H_{40}SO_5$: C, 74.97; H, 6.62; S, 5.27. Found: C, 74.84; H, 6.51; S, 5.25.

Methyl 2-(3,4,6-Tri-*O*-benzyl-2-deoxy-2-(*p*-tolylthio)-*β*-D-glucopyranosyl)-2-methylpropionate (17). This derivative (contained ca. 5% of α-manno isomer, ^1H NMR data) was synthesized by the method described for **4a** (using TMS ketene acetal of methyl isobutyrate as the nucleophile) with yield 87% ($ZnCl_2$ was used as Lewis acid). TLC: R_f (ether–hexane, 1:1) = 0.52. IR (neat): 1732 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ: 1.11, 1.31 (two s, 6 H), 2.32 (s, 3 H), 3.10 (t, J = 10.69, 10.4 Hz, 1 H), 3.50 (m, J = 9.5, 4.0, 2.0 Hz, 1 H), 3.65 (t, J = 9.5, 8.5 Hz, 1 H), 3.70 (dd, J = 10.4, 8.5 Hz, 1 H), 3.73 (dd, J = 11.3, 4.0 Hz, 1 H), 3.77 (dd, J = 11.3, 2.0 Hz, 1 H), 3.89 (d, J = 10.69 Hz, 1 H), 4.58, 4.62 (two d, J = 10.8 Hz, 2 H), 4.68, 4.87 (two d, J = 11.0 Hz, 2 H), 4.88, 5.02 (two d, J = 10.5 Hz, 2 H), 7.35 (m, 19). ^{13}C NMR (50 MHz, $CDCl_3$) δ: 18.03, 21.00, 25.50, 46.65, 51.70, 53.93, 69.02, 73.27, 74.83, 76.23, 79.49, 79.94, 82.21, 86.01, 127.41, 127.44, 127.68, 128.23, 129.52, 131.52, 136.42, 138.19, 138.30, 176.85. HRMS: calcd for $C_{39}H_{44}SO_6$ (M^+) *m/e* 640.2859, found for *m/e* 640.2835. Anal. Calcd for $C_{39}H_{44}SO_6$: C, 73.10; H, 6.92; S, 5.00. Found: C, 74.07; H, 6.85; S, 5.12.

2-(3,4,6-Tri-*O*-acetyl-2-deoxy-2-(*p*-tolylthio)-*β*-D-glucopyranosyl)-2-methylpropanal (22) and 2-(3,4,6-Tri-*O*-acetyl-2-deoxy-2-(*p*-tolylthio)-α-D-mannopyranosyl)-2-methylpropanal (23). To a solution of 158.7 mg (1.00 mmol) of *p*-TolSCl in 3 mL of CH_3CN at 0 °C was added 272 mg (1.00 mmol) of 3,4,6-tri-*O*-acetyl-D-glucal (**18**) (the color changed from yellow to colorless). After 10 min the solvent was evaporated and the residue was dissolved in 20 mL of CH_2Cl_2. This solution was cooled down to −78 °C, and 173 mg (1.2 mmol) TMSEE of 2-methylpropanal (3) in 2 mL of CH_2Cl_2 was introduced. After that a solution of 0.14 mL (1.2 mmol) of $SnCl_4$ in 2 mL of CH_2Cl_2 was added dropwise. The mixture was stirred for 30 min at 0 °C, quenched with a saturated solution of $NaHCO_3$ in water, extracted with ether, and dried over Na_2SO_4. Preparative TLC (ether–hexane, 1:2) of the crude material after solvent removal in vacuo afforded the pure substances **22** and **23** with a ratio of 83:17 and yield 61%. Data for **22**. TLC: R_f (hexane–ether, 1:1) = 0.25. IR (neat): 1748 cm^{-1}. ^1H NMR (250 MHz, $CDCl_3$) δ: 0.96, 1.11 (two s, 6 H), 1.92, 2.03, 2.07 (three s, 9 H), 2.31 (s, 3 H), 3.15 (t, J = 10.75 Hz, 1 H), 3.66 (d, J = 10.75 Hz, 1 H), 3.68 (m, J = 9.5, 5.25, 2.6 Hz, 1 H), 4.12 (dd, J = 12.2, 2.6 Hz, 1 H), 4.22 (dd, J = 12.2, 5.25 Hz, 1 H), 4.97 (t, J = 9.5 Hz, 1 H), 5.23 (dd, J = 10.75, 9.5 Hz, 1 H), 7.16 (m, 4 H), 9.66 (s, 1 H). ^{13}C NMR ($CDCl_3$, 50 MHz) δ: 15.31, 20.56, 20.58, 20.65, 20.94, 21.47, 49.85, 51.90, 62.24, 69.73, 75.45, 75.74, 81.34, 129.91, 130.45, 132.58, 137.43, 169.44, 169.77, 170.45, 199.18. HRMS: calcd for $C_{23}H_{30}O_8S$ (M^+) *m/e* 466.1661, found *m/e* 466.1673. Data for **23**. TLC R_f (hexane–ether, 1:1) = 0.28. IR (neat): 1745 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ: 1.11, 1.13 (two s, 6 H), 2.055, 2.058, 2.077 (3 s, 9 H), 2.32 (s, 3 H), 3.43 (dd, J = 9.5, 3.7 Hz, 1 H), 4.08 (d, J = 9.5 Hz, 1 H), 4.12 (m, 2 H), 4.75 (m, J = 11.6, 4.0, 1.5 Hz, 1 H), 4.88 (dd, J = 4.9, 1.5 Hz, 1 H), 5.22 (br.t, J = 4.9, 3.7 Hz, 1 H), 7.19 (m, 4 H), 9.61 (s, 1 H). ^{13}C NMR (125 MHz, $CDCl_3$) δ: 16.35, 19.53, 20.62, 20.68, 20.82, 21.06, 48.03, 50.09, 60.05, 67.66, 69.80, 72.55, 74.23, 130.03, 132.60, 138.40, 170.40, 169.43, 169.43, 201.53. HRMS: calcd for $C_{23}H_{30}O_8S$ (M^+) *m/e* 466.1661, found *m/e* 466.1671.

2-(3,4-Di-*O*-acetyl-2,6-deoxy-2-(*p*-tolylthio)-α-L-mannopyranosyl)-2-methylpropanal (24) and 2-(3,4-Di-*O*-acetyl-2,6-deoxy-2-(*p*-tolylthio)-*β*-L-glucopyranosyl)-2-methylpropanal (25). This mixture of isomers (**24**:**25** = 57:43, ^1H NMR data) was obtained from **19** by the method described for **22** and **23** with a yield 87% ($ZnCl_2$ was used as Lewis acid). ^1H NMR for **24** (taken from the spectra of the mixture of **24** and **25**, 300 MHz, $CDCl_3$) δ: 1.135, 1.145 (two s, 6 H), 1.425 (d, J = 7.0 Hz, 1 H), 1.93, 2.045, 2.055 (three s, 9 H), 2.32 (s, 3 H), 3.43 (dd, J = 9.5, 3.75 Hz, 1 H), 4.04 (m, J = 7.0, 2.0 Hz, 1 H), 4.805 (dd, J = 5.0, 2.0 Hz, 1 H), 5.20 (br *t*, J = 4 Hz, 1 H), 7.20 (m, 4 H), 9.66 (s, 1 H). ^1H NMR for **25** (taken from the spectra of the mixture of **24** and **25**, 300 MHz, $CDCl_3$) δ: 0.93, 1.10 (two s, 6 H), 1.425 (d, J = 6.4 Hz, 1 H), 2.04, 2.045, 2.055 (three s, 9 H), 2.31 (s, 3 H), 3.135 (dd, $J_1 = J_2$ = 11.0 Hz, 1 H), 3.53 (m, J = 9.5, 6.4 Hz, 1 H), 4.77 (t, J = 9.5 Hz, 1 H), 5.185 (dd, J = 11.0, 9.5 Hz, 1 H), 7.20 (m, 4 H), 9.665 (s, 1 H). HRMS: calcd for $C_{21}H_{28}O_6S$ (M^+) *m/e* 408.1607, found *m/e* 408.1596.

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Supplementary Material Available: ^1H NMR spectra for compounds **4a**, **4b**, **12**, **22**, and the mixture of **24** and **25** and ^{13}C NMR spectra for compounds **4c**, **5c**, **13**, **14**, and **23** (9 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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