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Synthesis and Enzyme Inhibitory Activity of Novel Glycosidase Inhibitors Containing Sulfur and Selenium

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Abstract: The syntheses of novel methyl maltoside analogues containing sulfur in the nonreducing ring and either oxygen, sulfur, or selenium atoms in the interglycosidic linkage are described. The compounds are substrate analogues for glucosidases and are of interest as potential inhibitors of these enzymes. The syntheses rely on the use of the 3,4,5,6-tetra-*O*-acetyl-5-thio-α-D-glucopyranosyl trichloroacetimidate **6** as a glycosyl donor and methyl 2,3,6-tri-*O*-benzoyl-4-X-α-D-glucopyranoside (X = OH, SH, SeH) as glycosyl acceptors. The glycosylation reactions are catalyzed by triethylsilyl triflate. The 5′-thio-4-X-disaccharides are obtained as α:β mixtures of 100:0 (X = O **8**), 36:1 (X = S **17**, **18**), and 4.5:1 (X = Se **23**, **24**), in yields of 85%, 55%, and 57%, respectively. The notable α-selectivity is attributed to the greater thermodynamic stability of the α-isomers. In accordance with this conclusion, rearrangement of the orthoester **12**, formed as a side product in the reaction to give the 5′-thiomaltoside, under acid catalysis affords the α-disaccharide. A reaction employing **6** and methyl 2,3,6-tri-*O*-benzyl-α-D-glucopyranoside **13** leads to a loss of stereoselectivity and gives a 1:1.2 α:β mixture of the disaccharides **14** and **15**. Deprotection of **8**, **17**, and **23** by transesterification gives the pure methyl maltoside heteroanalogues **1**, **2**, and **3**, respectively. Kinetic studies indicate that **1**, **2**, and **3** are competitive inhibitors of the binding of maltose by glucoamylase G2, with K_i values of 1.34, 2.04, and 0.80 mM, respectively. The K_i values for the phenyl selenoglycosides of α-D-glucose **4** and α-D-5-thioglucose **5** are 5.88 and 4.01 mM, respectively, and the K_m values for the substrates maltose and 4-nitrophenyl α-D-glucopyranoside are 1.2 and 3.7 mM, respectively.

Introduction

Glycosidases may be grouped according to substrate specificity, but the key feature of the respective transition states, shape or charge, remains to be identified.[1] Numerous transition-state mimics and potent carbohydrase inhibitors have been synthesized. Although few are used in therapy, most illustrate features of intermediates in enzyme mechanisms. In enzyme technology, there is a need for improvement of specificity and catalytic efficiency. A preferred approach involves directed mutagenesis based on the crystal structure of enzyme-inhibitor complexes and the proposed mechanism.[2] Novel inhibitors can assist the design of mutants by highlighting roles of individual side chains, as deduced from modeled enzyme-complexes and the inhibition kinetics.[3-5] Access to a selection of glycosidases, with different acid-catalytic mechanisms for hydrolysis of glycosidic bonds and producing, for example, products with either inverted or

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Table 1. Results of Glycosylation Reactions

entry	donor	acceptor	molar ratio[a]	reaction conditions[b]	products	yield, %
1	**6**	**7**[33]	1:1:0.1	−78 °C for 1 h, rt[c] for 45 min	**8**	50
					9, 10, 11	30
					7	
2	**6**	**7**	1:0.7:0.1	−78 °C for 6 h	**12**	43
					8	7
					6, 7	
					(**12:8** = 6:1)	
3	**6**	**7**	1:1:0.1	−78 °C for 1 h, −50 °C for 1.5 h	**12**	83
					8	5
					(**12:8** = 15:1)	
4	**6**	**7**	1:1:0.2	−78 °C for 1 h, rt for 1 h	**8**	50
					9, 10, 11	40
					7	
5	**6**	**7**	2:1:0.1	−78 °C for 1 h, rt for 1 h	**8**	45
					9, 10, 11	
					7	
6	**6**	**7**	1:2:0.1	−78 °C for 1 h, rt for 1 h	**8**	85
					9, 10	6
					11	4
7	**6**	**13**[13]	1:2:0.1	−78 °C for 1 h, rt for 1 h	**14**	45
					15	45
8	**6**	**16**[14]	1:2:0.25	−78 °C to −50 °C in 1 h	**17**	53
					18	1.5
9	**6**	**21**	1:2:0.1	−78 °C for 10 min, rt for 1 h	**23**	46
					24	11

[a] Donor:acceptor:triethylsilyl triflate. [b] All reactions mixtures were cooled to −78 °C prior to quenching with collidine. [c] Room temperature = rt.

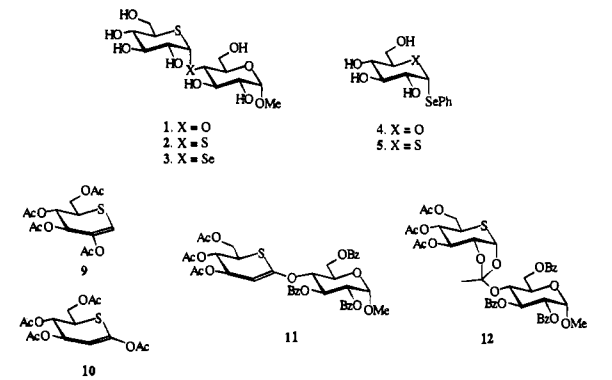
retained anomeric configuration, together with a selection of glycosidase inhibitors will allow optimal progress in this field.

As part of a program to develop carbohydrase inhibitors for therapy and a gain of insight of subtle events in the catalytic mechanism, we have recently communicated the synthesis of novel heteroanalogues of methyl α-D-maltoside containing heteroatoms in the nonreducing ring and/or the interglycosidic linkage.[6] We now report full details of the syntheses together with the evaluation of these candidates and the phenyl selenoglycosides of glucose **4** and 5-thioglucose **5** as inhibitors of glucoamylase G2. Oligosaccharides with sulfur in the interglycosidic linkage have been reported to be resistant to hydrolysis by glycosidases.[7] It is of interest in the present work to evaluate the role of a sulfur atom in the sugar ring as well as the role of different chalcogen atoms in the interglycosidic linkage. We note that the sulfur-in-the-ring analogue of a glycoside of *N*-acetyllactosamine has been reported to be 200 times more stable to hydrolysis by a galactosidase,[8] and 5-thio-α-L-fucose has recently been reported to show excellent inhibitory activity (30 μM) against α-L-fucosidase.[9]

Results and Discussion

Synthesis. The synthesis of methyl 5′-thiomaltoside **1** required a suitably blocked sugar with a free hydroxyl group at the C-4 position to function as the glycosyl acceptor. Earlier results[10] had revealed that the removal of benzyl substituents on thioglucose derivatives was problematic. Therefore, a unit was desired that could be deprotected in a convenient manner and could be obtained with minimum protecting group manipulations. These requirements were met by the glycosyl acceptor **7** which was obtained in one step, by the selective benzoylation of methyl α-D-glucopyranoside with benzoyl chloride at −60 °C. The glycosylation of the acceptor **7** with the trichloroacetimidate **6**[10] was attempted under varying conditions of promoter concentration, reactant concentration, and temperature. The results are shown in Table 1 and are briefly discussed below.

Chart 1



Initial glycosylations employed 0.1 equiv of triethylsilyl triflate (TESOTf) as the catalyst which was added to a mixture of the reactants at −78 °C. Different reactions were quenched at different temperatures, and their outcomes were examined. When the temperature of the reaction mixture was allowed to rise to room temperature, a complex mixture of products was formed (Table 1, entry 1). Most significantly, the desired (1−4) linked disaccharide **8** was obtained in exclusively an α-configuration and the corresponding β-disaccharide was not detected. In addition, a mixture of the glucals **9** and **10** was obtained in 30% yield. Another elimination product **11** and the unreacted acceptor **7** were also isolated. In another reaction, the temperature was maintained below −70 °C (Table 1, entry 2). In this case, the side products **9**, **10**, and **11** were avoided. However, the major product in this reaction was the orthoester **12**, and a mixture of **12** and the α-disaccharide **8** was obtained in a 6:1 ratio, in a combined yield of 50%. Isolation of unreacted donor and acceptor indicated that the reaction had

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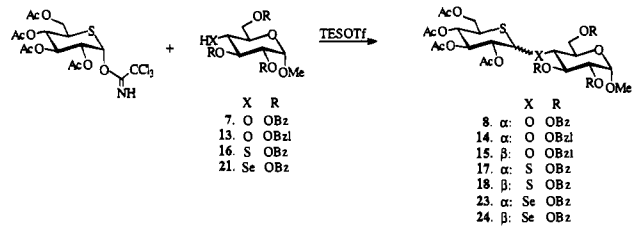
Scheme 1



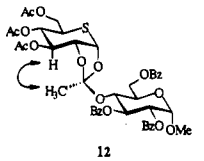
not proceeded to completion. Therefore, in a subsequent experiment, the reaction was quenched at −50 °C. In this case a 15:1 mixture of the orthoester to disaccharide was isolated in a combined yield of 88%. Minor amounts of glycal and acceptor were detectable by TLC (Table 1, entry 3). These were the best experimental conditions for the formation of the orthoester. However, optimal reaction conditions for the synthesis of the disaccharide remained to be achieved. An increased concentration of the catalyst (0.2 equiv with respect to the donor) did not prove to be advantageous, and substantial amounts of the elimination side products were again isolated, in addition to the disaccharide (40%) (Table 1, entry 4). The use of 2 equiv of the glycosyl donor **6** with respect to the acceptor was contemplated (Table 1, entry 5). However, the yield of the disaccharide remained below 50%, and unreacted acceptor was again recovered. It is noteworthy that all these experiments were stereoselective for the formation of the α-disaccharide, and no β-anomer was detected.

Until this point we were of the opinion that inefficient reactions were a consequence of the low reactivity of the glycosyl donor **6**. However, we hypothesized that a complexation of the acceptor with the trichloroacetamide produced in the reaction or primary attack of the acceptor on the trichloroacetimidate to give a tetrahedral intermediate may have prevented complete reaction of the acceptor to give the disaccharide. Therefore, in the next experiment, a 2-fold excess of the acceptor was employed (Table 1, entry 6). The yield of the disaccharide **8** increased to 85%, with minor amounts of glucals **9** and **10**, compound **11**, and unreacted acceptor **7** being isolated.

The following conclusions can be drawn from the results presented in the foregoing sections. The glycosylations with the trichloroacetimidate **6** and an unreacted acceptor such as **7** occur stereoselectively in favor of the α-product. The temperature at which this reaction is quenched is of great significance in controlling its outcome, the orthoester **12** being isolated at lower temperatures. Higher temperatures lead to the formation of the side products **9**, **10**, and **11** as a result of elimination, as does the use of a higher concentration (0.2 equiv) of the catalyst. The optimum condition for this glycosylation reaction is realized with the use of an excess of the acceptor rather than the donor.

In our opinion, the exceptional behavior of 5-thiohexopyranosyl donors to afford preferentially the α-product, despite the presence of a participating acetate at the 2-position of the glycosyl donor, is due to the greater thermodynamic stability of the axially oriented aglycon in these compounds as compared to their 5-oxa-counterparts.[10,11]

The formation of the orthoester **12** was confirmed by the use of ^1H and ^{13}C NMR spectroscopy. The singlet corresponding to the protons of the C-methyl was observed at a higher field than the signals attributed to the other acetoxy methyl groups and the ^{13}C chemical shift of the C-methyl was separated and downfield as compared to the signals of the acetoxy methyls. This is usually an indication of orthoester formation.[12] This was further confirmed in the $^{13}C-^1H$ chemical-shift correlated spectrum in which correlation was observed between the peak attributed to the protons and the carbon of the C-methyl group. A ^{13}C signal in the region of 122 ppm (due to the orthoester carbon) was observed in the ^{13}C spectrum of compound **12** (122.4 ppm), and it did not correlate with any peak in the ^1H spectrum. The configuration of the orthoester **12** was determined by a NOESY experiment; an NOE contact between the C-methyl group and the H-3 of the nonreducing sugar residue indicated the presence of an *exo*- configuration.



12

We speculated that the α-disaccharides might arise from the rearrangement of the orthoesters. To verify this postulate, the orthoester **12** that was isolated at below −50 °C was reintroduced into the same initial reaction conditions, but the reaction mixtures were warmed to room temperature. The orthoester **12** rearranged to afford only the α-disaccharide **8** in a 40% yield. Also isolated were the acceptor **7** and the glucals **9** and **10**. Thus, the results of the rearrangement of these orthoesters is reflective of results obtained in reactions that were conducted without their isolation. We suggest that the preferential α-disaccharide formation is preceded by orthoester formation. We suggest further that the rearrangement of **12** to give the thioglucals **9** and **10** might be a general reaction with 5-thio sugars.

In order to ascertain the effect of an increase in the reactivity of the reacting partners on the stereochemical outcome of the reaction, we examined the glycosylation of a more reactive, benzylated acceptor **13**.[13] In this case, a loss in stereoselectivity was observed, as expected with the more reactive acceptor, and a 1:1 mixture of the α and β disaccharide **14** and **15** was obtained (Table 1, entry 7).

The synthesis of 4-thio-5′-thiomaltoside **2** was achieved by the glycosylation of methyl 2,3,6-tri-*O*-benzoyl-α-D-glucopyranoside **16**[14] with 5-thioglucopyranosyl trichloroacetimidate **6** in the presence of triethylsilyl triflate. As observed for the glycosylations of the 4-OH acceptor **7**, the use of equimolar proportions of the donor **6** and the acceptor **16**, in glycosylation reactions, led to the isolation of significant quantities of the glucal **9** and low yields of the disaccharides. However, the glycosylation of donor **6** with a 2-fold excess of the acceptor **16** in the presence of 2.5 equiv of triethylsilyl triflate as catalyst afforded predominantly the α-disaccharide **17** in 53% yield and a minor amount of the corresponding β-isomer **18** (1.5%, α/β = 36/1) (Table 1, entry 8). The stereochemical integrity of compounds **17** and **18** was confirmed by observation of the $^1J_{H1',H2'}$ coupling constants (4.8 and 11.0 Hz, respectively) and the $^1J_{C1',H1'}$ coupling constants (158 and 155 Hz, respectively).

The strategy for the synthesis of 4-seleno-5′-thiomaltoside **3** was similar to that of the 4-*O*- and the 4-*S*-5′-thiomaltopyranoside. It necessitated the synthesis of the selectively protected 4-selenoglucopyranoside acceptor. The synthesis of this compound was performed by the initial displacement of the 4-*O*-trifluoromethanesulfonate of methyl 2,3,6-tri-*O*-benzoyl-α-D-galactopyranoside **19** by potassium selenocyanate[14] to afford

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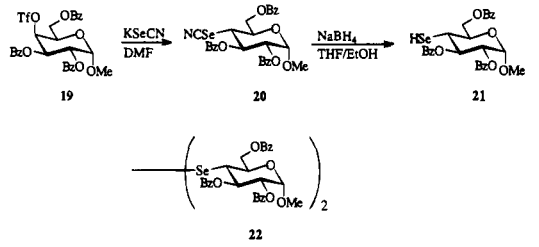
the selenocyanate **20** (Scheme 2). This was reduced with sodium borohydride[15] to provide the 4-selenol **21**. Attempted column purification and/or crystallization resulted in the oxidation of the selenol to the diselenide **22**. Although the selenol showed appreciable air stability, slow oxidation to the corresponding diselenide occurred over a period of days. The diselenide was crystallized and fully characterized. Thus, the crude selenol was used for subsequent glycosylation reactions immediately after its preparation.

Scheme 2



19 20 21 22

The acceptor **21** was glycosylated with the glycosyl donor **6** in the presence of 0.2 equiv of TESOTf. At −78 °C no coupling of the above reactants was observed. When the temperature was allowed to rise to room temperature, a 4.5:1, α/β mixture of the disaccharides **23** and **24** was obtained in a combined yield of 57% (Table 1, entry 9). When the effect of a reduced amount of catalyst was examined, the stereoselectivity of the reaction remained unchanged, but the yield of the reaction dropped to 40%.

Deprotection of the disaccharides **8**, **17**, and **23** was performed under Zemplen conditions with a 0.2 M sodium methoxide solution in methanol, to afford the target disaccharides **1**, **2**, and **3** in yields of 74%, 89%, and 75%, respectively. Compound **2** was crystallized from hot ethanol.

Enzyme Inhibition. Glucoamylase from *Aspergillus niger* catalyzes the hydrolysis of maltose and related compounds with release of β-D-glucose.[16] The inhibitory action of the novel heteroanalogues containing sulfur and selenium of methyl α-maltoside **1**−**3** and of phenyl α-D-glucopyranoside **4** and **5** has been tested.

Methyl α-5′-thiomaltoside **1** was a very poor substrate with a $t_{1/2}$ of 28 h compared to 1.5 h for the substrate methyl β-D-maltoside under the same conditions. The lower rate of hydrolysis of the sulfur-in-the-ring compound is in accord with recent observations by Yuasa *et al.*[8] who reported that the stability of a glycoside of 5′-thio-*N*-acetyllactosamininide to hydrolysis by a β-galactosidase was 200 times greater than that of its counterpart with oxygen in the ring. The results are also consistent with the analysis of Jagannadham *et al.*[17] which shows that the thermodynamically more stable α-thia-stabilized carbocation (the presumptive intermediate in the glycoside hydrolysis reaction) is nevertheless formed more slowly than its oxygen counterpart because of a higher intrinsic barrier.

The compounds **1**−**5** were tested, therefore, as inhibitors of the hydrolysis of maltose. All of the heteroanalogues examined were competitive inhibitors with inhibition constants (K_i) of the same order of magnitude as the K_m values for maltose and 4-nitrophenyl α-D-glucopyranoside of 1.2 and 3.7 mM, respectively (Table 2). Methyl α-4-thiomaltoside (the analogue with O in the ring and S in the interglycosidic linkage) is also a competitive inhibitor, with a K_i value of 0.35 ± 0.04 mM.[19] We assume, therefore, that the binding interactions of these heteroanalogues with the enzyme correspond to those seen for the two rings at the nonreducing end of acarbose and D-*gluco*-dihydroacarbose in complexes with a very closely related glucoamylase.[20,21] Indeed, a transferred NOE NMR study of methyl 4,5′-dithiomaltoside **2** bound to glucoamylase G2[22] showed a similar orientation of the two rings as the A and B rings of D-*gluco*-dihydroacarbose.

Table 2. Inhibition of Glucoamylase by Heteroanalogues of Methyl α-D-Maltoside and Phenyl α-D-Glucopyranoside

inhibitor	K_i (mM)
methyl α-5′-thiomaltoside (**1**)	1.34 ± 0.06[a]
methyl α-4-*S*-5′-thiomaltoside (**2**)	2.04 ± 0.42
methyl α-4-*Se*-5′-thiomaltoside (**3**)	0.796 ± 0.03
phenylseleno α-D-glycopyranoside (**4**)[18]	5.88 ± 0.35
phenylseleno α-D-5-*S*-glucopyranoside (**5**)[10]	4.01 ± 1.5

[a] Standard deviation.

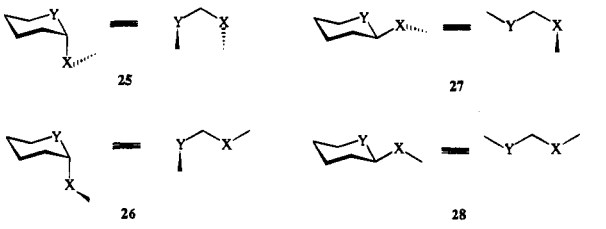


Figure 1. Conformations of $RXCH_2YR'$ molecules and their relationships to the conformations of 2-substituted heterocyclohexanes.

It is tempting to speculate that the lower K_i value for the S/Se compound **3** than the S/S compound **2** might be a function of the greater tolerance for alternative conformations about the acetal center. The conformational preferences about the acetal center are dictated by the anomeric effect which refers to the torsional preferences about the C−X and C−Y bonds in $RXCH_2YR'$ molecules. In axially oriented compounds, the gauche,gauche **25** is favored over the gauche,anti conformation **26**, and in equatorially oriented compounds, the anti,gauche **27** is favored over the anti,anti conformation **28** (Figure 1).[23] The conformational preferences and associated geometrical variations have been rationalized in terms of stabilizing orbital interactions between the p-type nonbonding orbitals on X and Y, n_X and n_Y, with the acceptor orbitals, σ^*_{C-Y} and σ^*_{C-X}, respectively.[23] These hyperconjugative interactions account for the existence of the endo and exo anomeric effect when the $RXCH_2YR'$ moiety is incorporated into a heterocyclohexane (Figure 1).[23] The gauche,gauche conformation is the global minimum when X and Y are first or second row elements. However, the stabilization of the gauche,anti conformation **26** becomes as significant or more significant with elements of the third and fourth row owing to the importance of other stabilizing orbital interactions.[24] The population of this alternative conformation in **3** would thus still provide anomeric stabilization and would

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allow greater ligand flexibility for accommodating complementary contact residues on the enzyme. It is noteworthy that a conformational study in solution by NOE spectroscopy has indicated greater flexibility in **3** than in **2** or **1**.[25]

As a final point of interest, we comment on the thermodynamics of binding of the methyl α-4,5′-dithiomaltoside **2**. Titration microcalorimetry[26] has given a K_a of $3.0 \pm 1.6 \times 10^3$ M^{-1}; at 300 K this K_a corresponds to a free energy of interaction of -20.0 ± 1.4 kJ mol^{-1}. The enthalpy of interaction was 5.7 $\pm$ 1.7 kJ mol^{-1} and the $T\Delta S$ term was 14.3 $\pm$ 2.2 kJ mol^{-1}. The binding is thus dominated by the entropic contribution. The positive entropic term must result from the efficient release of water molecules to bulk solvent from the interacting complementary surfaces since a negative contribution would result from restrictions in translational, rotational, vibrational, and conformational degrees of freedom.[26] It is worth noting that an NMR and molecular mechanics study of the conformations of the free ligand **2**[25] together with a transferred NOE NMR study of the ligand bound to glucoamylase G2[22] indicate a restriction of conformations upon binding.

General Experimental

Synthesis. Melting points were determined on a Fisher-Johns melting-point apparatus and are uncorrected. Optical rotations were measured with a Rudolph Research Autopol II automatic polarimeter. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker AMX-400 NMR spectrometer at 400.13 and 100.6 MHz, for proton and carbon, respectively, unless otherwise stated. The spectra were recorded in deuterochloroform or deuterium oxide. Chemical shifts are given in ppm downfield from TMS for those spectra measured in deuterochloroform and downfield from 2,2-dimethyl-2-silapentane-5-sulfonate (DSS) for those spectra measured in deuterium oxide. Chemical shifts and coupling constants were obtained from a first-order analysis of the spectra. All new compounds were characterized by either microanalysis or electrospray mass spectrometry.

All new compounds were also fully characterized by the use of routine ^{1}H, ^{13}C, ^{1}H-homonuclear, and ^{1}H-^{13}C inverse-detected NMR spectra. The ^{1}H-homonuclear chemical-shift correlated (COSY) spectra[27] were acquired using a pulse sequence d1-90°-d0-45°-FID with quadrature detection in both dimensions. The initial data sets of 1024 × 512 data points were zero-filled once in the F_1 direction to give a final data set of 1024 × 1024 real data points. For the inverse detection experiments a four-pulse sequence was used for the ^{1}H{^{13}C}−^{13}C correlation.[28] The data sets of 2048 × 512 data points were zero-filled once in the F_1 direction, to give a final data set of 1024 × 1024 real data points.

Analytical thin-layer chromatography (TLC) was performed on aluminum plates precoated with Merck silica gel 60F-254 as the adsorbent. The developed plates were air-dried, exposed to UV light, and/or sprayed with 5% sulfuric acid in ethanol, and heated at 150 °C. All compounds were purified by medium-pressure column chromatography on Kieselgel 60 (230−400 mesh).

Solvents were distilled before use and were dried, as necessary, by literature procedures. Solvents were evaporated under reduced pressure and below 40 °C.

Reactions performed under nitrogen were also carried out in deoxygenated solvents. Transfers under nitrogen were effected by means of standard Schlenk-tube techniques.

Enzyme Inhibition Assays. The initial rates of glucoamylase (*Aspergillus niger* glucoamylase) G2[29]-catalyzed hydrolysis of maltose (up to 11 different substrate concentrations in the range 0.2−26 mM) were followed in the presence of the different inhibitors (five different concentrations in the range 0.3−8 mM) in 0.1 M sodium acetate pH 4.5 at 45 °C and a final enzyme concentration in the range 15−90 nM. The glucose released was analyzed in aliquots removed at appropriate time intervals using a glucose oxidase assay adapted to microtiter plate reading and using a total reaction volume for the enzyme reaction mixtures of 150 or 300 μL.[30−32] The inhibitors were all competitive, and the constant of inhibition was calculated from $K_m' = K_m(1 + ([I]/K_i))$, where K_m' and K_m are the Michaelis−Menten constants determined in the presence and the absence of inhibitor, using the software ENZFITTER,[33] and [I] is the concentration of inhibitor. With 5-thio-D-glucose, the glucose oxidase had ≤1% of the activity toward D-glucose and neither 5-thio-D-glucose or the glucoamylase inhibitors tested were inhibitors of the glucose oxidase. Using a reported technique for analysis of the progress of substrate hydrolysis by NMR spectroscopy,[34,35] 5.6 mM methyl α-5′-thiomaltoside was hydrolyzed by 26 μM *A. niger* glucoamylase in 0.1 M CD_3COONa buffer, pD 4.5 at 27 °C.

Methyl 2,3,6-Tri-*O*-benzoyl-α-D-glucopyranoside (7).[36] Methyl α-D-glucopyranoside (1.5 g, 7.7 mmol) was treated with pyridine (40 mL), and the reaction mixture was cooled to −60 °C. Benzoyl chloride (5 mL, 43 mmol) was added dropwise. The reaction mixture was warmed up slightly when it stopped stirring and was subsequently recooled. After 3 h the starting material had completely reacted, as determined by TLC. The reaction mixture was quenched with excess methanol and warmed up to room temperature. The reaction mixture was washed successively with H_2O, HCl (2 N), and $NaHCO_3$. The organic extracts were dried over magnesium sulfate and concentrated. The resulting syrup was purified by column chromatography with toluene−ethyl acetate (8:1) as eluant [R_f 0.32] to afford the *title compound* (**7**) as a foam (2.5 g, 64%): $[\alpha]_D^{21}$ 146.0° (*c* 1.0 in CH_2Cl_2), lit.[36] 173° $[\alpha]_D^{20}$ 144.0° (*c* 1.0 in $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 3.36 (1H, d, $J_{4,OH}$ = 4.8 Hz, O*H*), 3.45 (3H, s, OC*H*$_3$), 3.87 (1H, dt, $J_{3,4+4,5}$ = 19.0 Hz, $J_{4,OH}$ = 4.8 Hz, H-4), 5.14 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 5.27 (1H, dd, $J_{1,2}$ = 3.5 Hz, $J_{2,3}$ = 10.0 Hz, H-2), 5.78 (1H, dd, $J_{2,3}$ = 10.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3), 7.20−8.20 (15H, m, Ar).

Methyl 2,3,6-Tri-*O*-benzoyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-5′-thio-α-D-glucopyranosyl)-α-D-glucopyranoside (8). A mixture of *O*-(2,3,4,6-tetra-*O*-acetyl-5-thio-α-D-glucopyranosyl) trichloroacetimidate (**6**) (0.15 g, 0.3 mmol), methyl 2,3,6-tri-*O*-benzoyl-α-D-glucopyranoside (**7**) (0.3 g, 0.6 mmol), and dry 4Å molecular sieves in anhydrous dichloromethane (3 mL) was stirred under nitrogen for 1 h. The reaction mixture was cooled to −78 °C, and triethylsilyl triflate (0.007 mL, 0.03 mmol) was added. The reaction mixture was stirred at −78 °C for 1 h. An aliquot of the reaction mixture was taken and quenched with triethylamine. A TLC of this aliquot indicated the presence of starting materials in addition to a product. The reaction mixture was then warmed to room temperature and stirred for 1 h. A TLC at this point indicated that the reaction was complete. The reaction mixture was again cooled to −78 °C and neutralized with collidine. The reaction mixture was then filtered and washed successively with hydrochloric acid (5%) and aqueous sodium hydrogen carbonate. The organic extracts were dried over magnesium sulfate and concentrated to give a foam that was chromatographed with hexane−ethyl acetate (1.5:1) as eluant [R_f 0.32]. The *title compound* (**8**) was obtained as a white foam (0.21 g, 87%): $[\alpha]_D^{20}$ +218.7° (*c* 12.3 in CH_2Cl_2); ^{13}C NMR ($CDCl_3$) δ 20.4, 20.5 (4CO*C*H$_3$), 37.5 (C-5′), 55.6 (O*C*H$_3$), 60.7

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(C-6′), 63.2 (C-6), 67.9 (C-5), 70.3 (C-3′), 71.7 (C-4′), 72.4 (C-4, C-2), 73.1 (C-3, C-2′), 80.1 (C-1′), 96.9 (C-1), 128.4−133.5 (Ar), 165.4, 165.9, 166.3 ($3COC_6H_5$) 169.3, 169.5, 169.7 ($4COCH_3$); ^{1}H NMR ($CDCl_3$) δ 1.95, 1.99 (12H, 2s, $4COCH_3$), 3.36 (1H, dt, $J_{4',5'}$ = 10.7 Hz, $J_{5',6'a}$ = 2.6 Hz, $J_{5',6'b}$ = 4.1 Hz, H-5′), 3.47 (3H, s, OCH_3), 3.79 (1H, dd, $J_{5',6'a}$ = 2.6 Hz, $J_{6'a,6'b}$ = 12.2 Hz, H-6′a), 4.23−4.33 (2H, m, H-5, H-6′b), 4.40 (1H, t, $J_{3,4+4,5}$ = 18.6 Hz, H-4), 4.60−4.68 (2H, m, H-6a, H-6b), 5.03 (1H, dd, $J_{1',2'}$ = 3.3 Hz, $J_{2',3'}$ = 10.4 Hz, H-2′), 5.12 (1H, dd, $J_{1,2}$ = 3.4 Hz, $J_{2,3}$ = 9.8 Hz, H-2), 5.14 (1H, d, $J_{1,2}$ = 3.4 Hz, H-1), 5.15 (1H, d, $J_{1',2'}$ = 3.3 Hz, H-1′), 5.21 (1H, dd, $J_{3',4'}$ = 9.7 Hz, $J_{4',5'}$ = 10.7 Hz, H-4′), 5.39 (1H, t, $J_{2',3'+3',4'}$ = 20.1 Hz, H-3′), 6.15 (1H, dd, $J_{2,3}$ = 9.8 Hz, $J_{3,4}$ = 9.1 Hz, H-3), 7.3−8.2 (15H, Ar). Anal. Calcd for $C_{42}H_{44}O_{17}S$: C, 59.15; H, 5.20. Found: C, 59.40; H, 5.25.

Methyl 4-O-(5′-thio-α-D-glucopyranosyl)-α-D-glucopyranoside (1). A freshly prepared solution of sodium methoxide in methanol (0.2 N, 2 mL) was added to disaccharide **8** (0.75 mg, 0.09 mmol), and the mixture was stirred under nitrogen for 3 h. The solution was acidified to a pH of 3 with Rexyn (H^+) resin and filtered. The filtrate was neutralized with Amberlite basic ion exchange resin, filtered, and concentrated. The residue was purified by column chromatography with hexane−dichloromethane−methanol (1.2:1:1) as eluant [R_f 0.32]. The *title compound* **1** was obtained as a syrup (25 mg, 74%): $[\alpha]_D^{20}$ + 102° (*c* 0.5 in CH_3OH); ^{13}C NMR (D_2O) δ 46.5 (C-5′), 57.8 (OCH_3), 62.6, 62.8 (C-6, 6′), 74.0 (C-2), 72.8, 76.0, 76.5, 76.7, 78.1, 78.2 (C-2′, 3′, 4′, 3, 4, 5), 85.5 [$^1J(^{13}C,^1H)$ 163 Hz, (C-1′)], 101.8 [$^1J(^{13}C,^1H)$ 167 Hz, (C-1)]; ^{1}H NMR (D_2O) δ 2.98 (1H, ddd, $J_{4',5'}$ = 10.0 Hz, $J_{5',6'a}$ = 3.5 Hz, $J_{5',6'b}$ = 5.1 Hz, H-5′), 3.35 (3H, s, OCH_3), 3.53 (1H, dd, $J_{1,2}$ = 3.8 Hz, $J_{2,3}$ = 9.8 Hz, H-2), 3.55−3.88 (9H, m, H-2′, 3′, 4′, 6′a, 6′b, 4, 5, 6a, 6b), 3.89 (1H, t, $J_{2,3}$ = 9.8, $J_{3,4}$ = 8.3 Hz, H-3), 4.77 (1H, d, $J_{1,2}$ = 3.8 Hz, H-1), 5.30 (1H, d, $J_{1',2'}$ = 3.3 Hz, H-1′); ES-MS calcd for $C_{13}H_{24}O_{10}S$ M^+ 372, found 395 $(M + Na)^+$.

Methyl 2,3,6-Tri-O-benzoyl-4-O-(2,3,4,6-tetra-O-acetyl-5′-thio-α-D-glucopyranosyl)-α-D-glucopyranoside (8), Glucals (9 and 10), and (11). A mixture of *O*-(2,3,4,6-tetra-*O*-acetyl-5-thio-α-D-glucopyranosyl) trichloroacetimidate (**6**) (0.25 g, 0.5 mmol), methyl 2,3,6-tri-*O*-benzoyl-α-D-glucopyranoside (**7**) (0.13 g, 0.25 mmol), and dry 4Å molecular sieves in anhydrous dichloromethane (5 mL) was stirred under nitrogen for 1 h. The reaction mixture was cooled to −78 °C, and triethylsilyl triflate (0.011 mL, 0.05 mmol) was added. The reaction mixture was stirred at −78 °C for 1 h. An aliquot of the reaction mixture was taken and quenched with triethylamine. A TLC of this aliquot indicated the presence of starting materials in addition to a product. The reaction mixture was then warmed to room temperature and stirred for 1 h. A TLC at this point indicated that the trichloroacetimidate donor **6** had been consumed. The reaction mixture was again cooled to −78 °C and neutralized with triethylamine. The reaction mixture was then filtered through Celite and concentrated to give a foam that was chromatographed with hexane−ethyl acetate (1.5:1) as eluant. The disaccharide **8** was isolated as a white foam (0.09 g, 45%). In addition, a mixture of glycals **9** and **10** and compound **11** were isolated (0.11 g). Compounds **9** and **10** were separated from **11** by column chromatrography with hexane−ethyl acetate (2:1) as eluant [R_f **9** and **10** = 0.32; **11** = 0.30]. **9:** ^{13}C NMR ($CDCl_3$) δ 20.66, 20.7, 20.73 ($4COCH_3$), 40.0 (C-5), 62.4 (C-6), 67.0 (C-3), 68.9 (C-4), 113.5 (C-2), 136.2 (C-1), 169.8, 170.4 ($4COCH_3$); ^{1}H NMR ($CDCl_3$) δ 2.05, 2.08, 2.10, 2.12 (12H, 4s, $4COCH_3$), 3.36 (1H,bq, $J_{4,5+5,6a+5,6b}$ = 20.0 Hz, H-5), 4.31 (1H, dd, $J_{5,6a}$ = 7.4 Hz, $J_{6a,6b}$ = 11.7 Hz, H-6a), 4.38 (1H, dd, $J_{5,6b}$ = 7.2 Hz, $J_{6a,6b}$ = 11.7 Hz, H-6b), 5.41 (1H, dd, $J_{3,4}$ = 4.2 Hz, $J_{4,5}$ = 4.2 Hz, $J_{4,5}$ = 5.5 Hz, H-4), 5.50 (1H, d, $J_{3,4}$ = 4.2 Hz, H-3), 6.10 (1H, s, H-1). **10:** ^{13}C NMR ($CDCl_3$) δ 20.6−20.7 ($4COCH_3$), 37.2 (C-5), 61.6 (C-6), 66.3 (C-3), 69.7 (C-4), 114.8 (C-2), 136.0 (C-1), 168.0−170.0 ($4COCH_3$); ^{1}H NMR ($CDCl_3$): δ 2.01−2.12 (12H, 4s, $4COCH_3$), 3.76 (1H, ddd, $J_{4,5}$ = 11.0 Hz, $J_{5,6a}$ = 6.5 Hz, $J_{5,6b}$ = 3.5 Hz, H-5), 4.30−4.38 (2H, m, H-6a, H-6b), 5.34 (1H, dd, $J_{3,4}$ = 3.5 Hz, $J_{4,5}$ = 11.5 Hz, H-4), 5.69 (1H, d, $J_{3,4}$ = 3.5 Hz, H-3), 6.14 (1H, s, H-2). Anal. Calcd for a mixture of **9** and **10** $C_{14}H_{18}O_8S$: C, 48.55; H, 5.24. Found: C, 48.72; H, 5.44. **11:** mp 196° C; ^{13}C NMR ($CDCl_3$) δ 20.5, 20.7, 20.8 ($3COCH_3$), 37.0 (C-5′), 55.5 (OCH_3), 61.2 (C-6′), 63.2 (C-6), 68.3 (C-5), 68.9 (C-4′), 72.4 (C-2), 73.1 (C-3), 73.4 (C-4), 77.3 (C-1′), 96.8 (C-1), 120.8 (C-2′), 128.4−133.5 (Ar), 144.5 (C-3′) 165.5, 165.9, 166.4 ($3COC_6H_5$) 168.6, 170.0, 170.4 ($3COCH_3$); ^{1}H NMR ($CDCl_3$) δ 1.99, 2.04, 2.06 (9H, 3s, $3COCH_3$), 3.41 (1H, ddd, $J_{4',5'}$ = 10.5 Hz, $J_{5',6'a}$ = 3.1 Hz, $J_{5',6'b}$ = 4.2 Hz, H-5′), 3.44 (3H, s, OCH_3), 4.14 (1H, dd, $J_{5',6'a}$ = 3.1 Hz, $J_{6'a,6'b}$ = 12.0 Hz, H-6′a), 4.17−4.24 (2H, m, H-5, H-4), 4.38 (1H, dd, $J_{5',6'b}$ = 4.2 Hz, $J_{6'a,6'b}$ = 12.0 Hz, H-6′b), 4.61−4.70 (2H, m, H-6a, H-6b), 5.12 (1H, dd, $J_{1,2}$ = 3.4 Hz, $J_{2,3}$ = 10.0 Hz, H-2), 5.14 (1H, s, H-1′), 5.16 (1H, d, $J_{1,2}$ = 3.4 Hz, H-1), 5.52 (1H, dd, $J_{2',4'}$ = 2.0 Hz, H-2′), 5.56 (1H, ddd, $J_{1',4'}$ = 0.9 Hz, $J_{2',4'}$ = 2.0 Hz, $J_{4',5'}$ = 10.5 Hz, H-4′), 6.13 (1H, dd, $J_{2,3}$ = 10.0 Hz, $J_{3,4}$ = 8.4 Hz, H-3), 7.2−8.2 (15H, Ar). Anal. Calcd for $C_{40}H_{40}O_{15}S$: C, 60.60; H, 5.09. Found: C, 60.29; H, 5.02.

3,4,6-Tri-O-acetyl-1,2-(methyl 2,3,6-tri-O-benzoyl-α-D-glucopyranos-4-yl)-α-D-5′-thioglucopyranose Orthoacetate (12). A mixture of *O*-(2,3,4,6-tetra-*O*-acetyl-5-thio-α-D-glucopyranosyl) trichloroacetimidate (**6**) (0.10 g, 0.20 mmol), methyl 2,3,6-tri-*O*-benzoyl-α-D-glucopyranoside (**7**) (0.09 g, 0.17 mmol), and dry 4Å molecular sieves in anhydrous dichloromethane (2 mL) was stirred under nitrogen for 1 h. The reaction mixture was cooled to −78 °C and triethylsilyl triflate (0.005 mL, 0.02 mmol) was added. The reaction mixture was stirred at −78 °C for 1 h, warmed to −50 °C, and stirred for another 1.5 h. An aliquot of the reaction mixture was taken and quenched with collidine at −78 °C. A TLC of this aliquot indicated that the reaction was complete. The reaction mixture was again cooled to −78 °C and neutralized with collidine. The mixture was filtered and washed successively and hydrochloric acid (5%) and aqueous sodium hydrogen carbonate. The organic extracts were dried over magnesium sulfate and concentrated to give a foam that was chromatographed with hexane−ethyl acetate (1.5:1) as eluant [R_f 0.32]. A mixture of the orthoester (**12**) and the disaccharide (**8**) was isolated in a combined yield of 88% (0.12 g, **12:8** = 15:1, 83% of **12**, 5% of **8**). **12:** ^{13}C NMR ($CDCl_3$) δ 20.4, 20.5 ($3COCH_3$), 24.4 ($CCH3$), 39.7 (C-5), 55.4 (OCH_3), 61.2 (C-6), 63.1 (C-6′), 68.6 (C-5′), 70.1 (C-4), 70.7 (C-4′), 71.5 (C-3′), 71.8 (C-2′), 72.7 (C-3), 77.4 (C-1), 79.1 (C-2), 96.8 (C-1′), 122.4 (CCH_3), 128.3−133.3 (Ar), 165.5, 166.0, 166.3 ($3COC_6H_5$) 169.3, 169.4, 170.3 ($4COCH_3$); ^{1}H NMR ($CDCl_3$) δ 1.62 (3H, s, CCH_3), 1.75, 1.93, 2.02 (9H, 3s, $3COCH_3$), 3.23 (1H, ddd, $J_{4',5'}$ = 10.2 Hz, $J_{5',6'a}$ = 3.2 Hz, $J_{5',6'b}$ = 5.7 Hz, H-5′), 3.41 (3H, s, OCH_3), 3.93 (1H, dd, $J_{5',6'a}$ = 3.2 Hz, $J_{6'a,6'b}$ = 12.1 Hz, H-6′a), 4.08−4.20 (3H, m, -6′, -4, -5), 4.32 (1H, dd, $J_{1',2'}$ = 5.5 Hz, $J_{2',3'}$ = 7.5 Hz, H-2′), 4.53 (1H, dd, $J_{5,6}$ = 3.9 Hz, $J_{6a,6b}$ = 12.1 Hz, H-6a), 4.63 (1H, dd, $J_{5,6b}$ = 2.0 Hz, $J_{6a,6b}$ = 12.1 Hz, H-6b), 4.88 (1H, dd, $J_{2',3'}$ = 7.5 Hz, $J_{3',4'}$ = 9.2 Hz, H-3′), 4.97 (1H, t, $J_{3',4'+4',5'}$ = 19.7 Hz, H-4′), 5.12 (1H, d, $J_{1,2}$ = 3.9 Hz, H-1), 5.21 (1H, dd, $J_{1,2}$ = 3.9 Hz, $J_{2,3}$ = 10.2 Hz, H-2), 5.36 (1H, d, $J_{1',2'}$ = 5.4 Hz, H-1′), 5.93 (1H, dd, $J_{2,3}$ = 10.2 Hz, $J_{3,4}$ = 8.2 Hz, H-3), 7.3−8.2 (15H, Ar). Anal. Calcd for $C_{42}H_{44}O_{17}S$: C, 59.15; H, 5.20. Found: C, 59.28; H, 5.17.

Methyl 2,3,6-Tri-O-benzyl-4-O-(2,3,4,6-tetra-O-acetyl-5′-thio-α/β-D-glucopyranosyl)-α-D-glucopyranoside (14 and 15). A mixture of *O*-(2,3,4,6-tetra-*O*-acetyl-5-thio-α-D-glucopyranosyl) trichloroacetimidate (**6**) (0.08 g, 0.15 mmol), methyl 2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (**13**) (0.14 g, 0.30 mmol), and dry 4Å molecular sieves in anhydrous dichloromethane (1.5 mL) was stirred under nitrogen for 1 h. The reaction mixture was cooled to −78 °C, and triethylsilyl triflate (0.0034 mL, 0.015 mmol) was added. The reaction mixture was stirred at −78 °C for 1 h, then warmed to room temperature, and stirred for 1 h. A TLC at this point indicated that the reaction was complete. The reaction mixture was again cooled to −78 °C and neutralized with collidine. The reaction mixture was then filtered and washed successively with hydrochloric acid (5%) and sodium hydrogen carbonate. The organic extracts were dried over magnesium sulfate and concentrated to give a foam that was chromatographed with hexane−ethyl acetate (1.3:1) as eluant [R_f α-isomer **14** = 0.36; β-isomer **15** = 0.32]. The *title compounds* **14** and **15** were obtained as syrups (α: 51 mg, 43%, β: 54 mg, 45%). α-Isomer **14:** $[\alpha]_D^{20}$ +131.5° (*c* 0.73 in CH_2Cl_2); ^{13}C NMR ($CDCl_3$) δ 20.5 ($4COCH_3$), 38.7 (C-5′), 55.3 (OCH_3), 61.0 (C-6′), 69.2 (C-5), 69.4 (C-6), 70.7 (C-3′), 72.1 (C-4′), 72.4 (C-4), 73.2 ($CH_2C_6H_5$), 73.5 ($CH_2C_6H_5$), 74.0 (C-2′), 74.5 ($CH_2C_6H_5$), 79.2 (C-1′), 80.9 (C-2), 81.8 (C-3), 97.5 (C-1), 127.3−138 (Ar), 169.3, 169.7, 170.4 ($4COCH_3$); ^{1}H NMR ($CDCl_3$) δ (1.97, 1.99, 2.01, 2.02, 12H, 4s, $4COCH_3$), 3.24 (1H, dt, $J_{4',5'}$ = 10.8 Hz, $J_{5',6'a+5',6'b}$ = 6.8 Hz, H-5′), 3.40 (3H, s, OCH_3), 3.59 (1H, dd, $J_{1,2}$ = 3.5 Hz, $J_{2,3}$ = 10.1 Hz, H-2), 3.62 (1H, dd, $J_{5',6'a}$ = 2.8 Hz, $J_{6'a,6'b}$ = 12.0 Hz, H-6′a), 3.68 (1H, dd, $J_{5,6a}$ = 1.5 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6a),

3.78 (1H, dd, $J_{5,6b}$ = 4.2 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6b), 3.88 (1H, ddd, $J_{4,5}$ = 9.6 Hz, $J_{5,6a}$ = 1.5 Hz, $J_{5,6b}$ = 4.2 Hz, H-5), 4.0 (1H, t, $J_{2,3+3,4}$ = 17.8 Hz, H-3), 4.05−4.15 (2H, m, H-4, H-6'b), 4.51 (1H, d, J = 10.5 Hz, C*H*HC$_6$H$_5$), 4.54−5.42 (4H, m, 3C*H*HC$_6$H$_5$, H-1), 4.70 (1H, d = 11.7 Hz, CH*H*C$_6$H$_5$), 5.01 (1H, d, J = 10.5 Hz, CH*H*C$_6$H$_5$), 5.22 (1H, t, $J_{3',4'+4',5'}$ = 20.3 Hz, H-4'), 5.25 (1H, dd, $J_{1',2'}$ = 3.0 Hz, $J_{2',3'}$ = 10.2 Hz, H-2'), 5.38 (1H, t, $J_{2',3'+3',4'}$ = 19.8 Hz, H-3'), 5.61 (1H, d, $J_{1',2'}$ = 3.0 Hz, H-1'), 7.1−7.4 (15H, m, Ar). Anal. Calcd for $C_{42}H_{50}O_{14}S$: C, 62.20; H, 6.22. Found: C, 62.29; H, 6.39. β-Isomer **15:** $[\alpha]_D^{20}$ +33° (c 0.84 in CH_2Cl_2); ^{13}C NMR ($CDCl_3$) δ 20.6, 20.7 (4CO*C*H$_3$), 40.6 (C-5'), 55.5 (O*C*H$_3$), 61.4 (C-6'), 68.1 (C-6), 70.1 (C-5), 71.9 (C-4'), 73.6, 73.9 (C-3', 2*C*H$_2$C$_6$H$_5$), 75.2 (C-2'), 76.2 (*C*H$_2$C$_6$H$_5$), 76.9 (C-4), 79.86, 79.9 (C-2. C-3), 81.3 (C-1'), 98.5 (C-1), 127.5−138.6 (Ar), 169.0, 169.3, 169.8, 170.5 (4*C*OCH$_3$); ^{1}H NMR ($CDCl_3$) δ (1.96, 1.97, 1.99, 2.05, 12H,.4s, 4COC*H*$_3$), 2.46 (1H, m, H-5'), 3.35 (3H, s, OC*H*$_3$), 3.49 (1H, dd, $J_{1,2}$ = 3.7 Hz, $J_{2,3}$ = 9.7 Hz, H-2), 3.57 (1H, m, H-5), 3.66 (1H, dd, $J_{5,6a}$ = 1.0 Hz, $J_{6a,6b}$ = 10.8 Hz, H-6a), 3.73 (1H, t, $J_{2,3+3,4}$ = 18.7 Hz, H-3), 3.81 (1H, dd, $J_{5,6b}$ = 2.8 Hz, $J_{6a,6b}$ = 10.8 Hz, H-6b), 3.84−3.92 (2H, m, H-6'a, H-4), 4.19 (1H, dd, $J_{5',6'b}$ = 4.0 Hz, $J_{6'a,6'b}$ = 11.8 Hz, H-6'b), 4.43 (1H, d, J = 12.0 Hz, C*H*HC$_6$H$_5$), 4.52 (1H, d, $J_{1,2}$ = 3.7 Hz, H-1), 4.51 (1H, d, J = 12.2 Hz, C*H*HC$_6$H$_5$), 4.65 (1H, d, $J_{1',2'}$ = 9.3 Hz, H-1'), 4.74−4.87 (5H, m, C*H*HC$_6$H$_5$, 3CH*H*C$_6$H$_5$, H-3'), 5.19 (1H, t, $J_{3',4'+4',5'}$ = 20.3 Hz, H-4'), 5.29 (1H, t, $J_{1',2'+2',3'}$ = 19.0 Hz, H-2'), 7:1−7.5 (15H, m, Ar). Anal. Calcd for $C_{42}H_{50}O_{14}S$: C, 62.20; H, 6.22. Found: C, 62.22; H, 6.27.

Methyl 2,3,6-Tri-*O*-benzoyl-4-thio-(2',3',4',6',-tetra-*O*-acetyl-5'-thio-α-D-glucopyranosyl)-α-D-glucopyranoside (17). A mixture of *O*-(2,3,4,6-tetra-*O*-acetyl-5-thio-α-D-glucopyranosyl)trichloroacetimidate (**6**) (0.15 g, 0.29 mmol) and the thiol (**16**)[14] (0.31 g, 0.59 mmol) in dry CH_2Cl_2 (2 mL) containing 4Å molecular sieves in a Schlenk tube under nitrogen. Triethylsilyl triflate (16.7 mL, 0.07 mmol) was added to the stirred solution at −50 °C. The reaction mixture was heated to −10 °C over 1 h at which time TLC indicated that the reaction was complete. The reaction mixture was heated to 20 °C for 10 min, then cooled to −78 °C, and quenched with collidine (60 mL). The reaction was filtered, excess collidine was removed by repeated codistillation with toluene, and the resulting syrup was purified by column chromatography with hexane−ethyl acetate (3:2) as eluant [R_f 0.28) to yield the *title compound* **17** (0.14 g, 53%) and the β-disaccharide **18** (3.8 mg) (α/β = 36/1). In addition, 0.02 g of the glucal **5** and 0.2 g of unreacted thiol **2** were also isolated. α-Isomer **17:** $[\alpha]_D^{21}$ +265.0° (c 0.6 in CH_2Cl_2); ^{13}C NMR($CDCl_3$) δ 20.0, 20.5 (4 CO*C*H$_3$), 40.2 (C-5'), 46.8 (C-4), 51.9 (C-1', $^1J_{C,H}$ = 158 Hz), 55.6 (O*C*H$_3$), 60.8 (C-6'), 64.3 (C-6), 68.4 (C-5), 70.8, 71.8, 73.0, 73.3 (C-2, C-2', C-3', C-4'), 73.2 (C-3), 97.2 (C-1, $^1J_{C,H}$ = 174 Hz), 128.3, 128.6, 129.0, 129.6, 129.8, 129.9, 133.3, 133.5 (3 CO*C*$_6$H$_5$), 165.3, 165.9, 166.2, 169.0, 169.4, 170.3 (3 *C*OCH$_3$, 3 *C*OC$_6$H$_5$); ^{1}H NMR($CDCl_3$) δ 1.65, 1.91, 1.99, 2.02 (3H, s, CO*C*H$_3$), 3.39 (1H, dd, $J_{3,4+4,5}$ = 22.0 Hz, H-4), 3.45 (3H, s, OC*H*$_3$), 3.61 (1H, ddd, $J_{5',6'a}$ = 2.9 Hz, $J_{5',6'b}$ = 2.5 Hz, H-5'), 3.95 (1H, dd, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.19 (1H, ddd, $J_{5,6a}$ = 5.5 Hz, $J_{5,6b}$ = 2.5 Hz, H-5), 4.39 (1H, dd, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 4.60 (1H, d, $J_{1',2}$ = 4.8 Hz, H-1'), 4.72 (1H, dd, $J_{6a,6b}$ = 12.0 Hz, H-6a), 4.80 (1H, dd, $J_{6a,6b}$ = 12.0 Hz, H-6b), 5.08−5.23 (5H, complex m, H-1, H-2, H-2', H-3', H-4'), 6.16 (1H, dd, $J_{2,3+3,4}$ = 20.5 Hz, H-3), 7.14−8.12 (15H, complex m, 3 COC$_6$*H*$_5$). Anal. Calcd for $C_{42}H_{44}O_{16}S_2$: C, 58.06; H, 5.10. Found: C, 58.20; H, 5.12. β-Isomer **18:** $[\alpha]_D^{22}$ +132.4° (c 1.28 in CH_2Cl_2); ^{13}C NMR ($CDCl_3$) δ 43.1 (C-5'), 46.6 (C-4), 47.3 (C-1', $^1J_{C,H}$ = 155 Hz), 60.6 (C-6'), 63.8 (C-6), 68.5 (C-3), 69.8 (C-5), 71.2 (C-4'), 73.0 (C-2), 73.2 (C-2'), 74.4 (C-3'), 97.0 (C-1); ^{1}H NMR ($CDCl_3$) δ 1.87, 1.91, 1.95, 2.0 (3H, s, COC*H*$_3$), 2.74 (1H, ddd, $J_{5',6'a}$ = 3.0 Hz, $J_{5',6'b}$ = 4.5 Hz, H-5'), 3.44 (3H, s, OC*H*$_3$), 3.44 (1H, dd, $J_{3,4+4,5}$ = 22.5 Hz, H-4), 3.79 (1H, dd, $J_{6'a,6'b}$ = 12.0 Hz, H-6'a), 4.06 (1H, dd, $J_{6'a,6'b}$ = 12.0 Hz, H-6'b), 4.07 (1H, d, $J_{1',2'}$ = 11.0 Hz, H-1'), 4.31 (1H, ddd, $J_{5,6a}$ = 4.2 Hz, $J_{5,6b}$ = 1.8 Hz, H-5), 4.71 (1H, dd, $J_{6a,6b}$ = 12.0 Hz, H-6a), 4.80 (1H, dd, $J_{2',3'} + J_{3',4'}$ = 18.8 Hz, H-3'), 4.86 (1H, dd, $J_{6a,6b}$ = 12.0 Hz, H-6b), 4.98 (1H, dd, $J_{2',3'}$ = 9.9 Hz, H-2'), 5.11 (1H, dd, $J_{3',4'} + J_{4',5'}$ = 20.5 Hz, H-4'), 5.18 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 5.24 (1H, dd, $J_{2,3}$ = 9.8 Hz, H-2), 5.88 (1H, dd, $J_{3,4}$ = 11.0 Hz, H-3), 7.35−8.15 (15H, m, 3 OC(O)C$_6$*H*$_5$). Anal. Calcd for $C_{42}H_{44}O_{16}S_2$: C, 58.06; H, 5.10. Found: C, 58.30; H, 5.21. ES-MS calcd for $C_{42}H_{44}O_{16}S_2$ 868, found 891 $(M + Na)^+$.

Methyl 4-Thio-(5'-thio-α-D-glucopyranosyl)-α-D-glucopyranoside (2). The disaccharide (**17**) (0.091 g, 0.1051 mmol) was dissolved in 0.2 M NaOMe in MeOH (4 mL) and stirred at room temperature under nitrogen. After 2.5 h TLC (EtOAc/MeOH/H_2O 6:2.5:1.0) indicated that the reaction was complete. The reaction mixture was diluted with methanol (20 mL) and neutralized with Rexyn (H^+) resin, filtered, concentrated, and purified by column chromatography (silica gel) with EtOAc/MeOH/H_2O 6:2:0.9 as eluant. Further purification by Sephadex LH20 filtration yielded 0.036 g of the *title compound* **2** (89%) which was crystallized from hot methanol (mp 217−220 °C): $[\alpha]_D^{22}$ +361.5° (c 1.0 in MeOH). Anal. Calcd for $C_{13}H_{24}O_9S_2$: C, 40.20; H, 6.23. Found: C, 40.47; H, 6.21. ES-MS calcd for $C_{13}H_{24}O_9S_2$ 388, found 411 $(M + Na)^+$; ^{13}C NMR (D_2O) δ 47.4 (C-5'), 51.1 (C-4), 56.0 (C-1', $^1J_{C,H}$ = 155 Hz), 57.8 (O*C*H$_3$), 62.7 (C-6'), 64.5 (C-6), 73.5 (C-5), 75.0 (C-2), 75.9 (C-3), 76.3 (C-4'), 77.3 (C-3'), 77.7 (C-2'), 102.1 (C-1); ^{1}H NMR (D_2O) δ 2.91 (1H, dd, $J_{3,4+4,5}$ = 22.5 Hz, H-4), 3.22 (1H, ddd, $J_{5',6'a} = J_{5',6'b}$ = 3.22 Hz, H-5'), 3.37 (3H, s, OCH_3), 3.50 (1H, dd, $J_{2',3'+3',4'}$ = 19.0 Hz, H-3'), 3.54 (1H, dd, $J_{2,3}$ = 9.6 Hz, H-2), 3.57 (1H, dd, $J_{3',4'+4',5'}$ = 20.0 Hz, H-4'), 3.77 (1H, ddd, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 5.0 Hz, H-5), 3.85−3.92 (4H, m, 3.88, H-3; 3.89, H-6'a, H-6a; 3.90, H-6'b), 3.98 (1H, dd, $J_{6a,6b}$ = 12.0 Hz, H-6b), 4.01 (1H, dd, $J_{2',3'}$ = 9.5 Hz, H-2'), 4.56 (1H, d, $J_{1',2'}$ = 4.5 Hz, H-1'), 4.82 (1H, d, $J_{1,2}$ = 3.8 Hz, H-1).

Methyl 2,3,6-Tri-*O*-benzoyl-4-selenocyanato-α-D-glucopyranoside (20). Methyl 2,3,6-tri-*O*-benzoyl-α-D-galactopyranoside[14] (5.18 g, 10.0 mmol) was dissolved in a mixture of dichloromethane (50 mL) and pyridine (2.0 mL, 25 mmol) and cooled to −30 °C. Triflic anhydride (2.5 mL, 15 mmol) was added dropwise over 10 min. The mixture was warmed to room temperature over 0.5 h and then recooled in an ice bath. Cold, saturated, aqueous sodium hydrogen carbonate (30 mL) was added, and the mixture was stirred for 10 min. The organic phase was separated, and the aqueous phase was extracted with dichloromethane (30 mL). The combined organic extracts were washed with cold, 5% aqueous HCl (30 mL), and sodium hydrogen carbonate (30 mL), and dried over magnesium sulfate. Removal of the solvent afforded the methyl 2,3,6-tri-*O*-benzoyl-4-*O*-trifluoromethanesulfonyl-α-D-galactopyranoside (**19**) (6.47 g) as a light yellow foam. The crude triflate was dissolved in *N*,*N*-dimethylformamide (55 mL) and treated with potassium selenocyanate (1.75 g, 12.1 mmol) at 50 °C and stirred for 3 h. The mixture was cooled, poured into ice water (850 mL) and stirred until a solid was formed. This was collected by filtration and washed with water. The crystals were dissolved in CH_2Cl_2 and dried over magnesium sulfate. Solvent removal afforded the *title compound* (**20**) as a pale yellow solid. Recrystallization from chloroform/hexane gave the pure product (4.77 g, 80%): mp 198−199 °C (slight decomposition above 195 °C); $[\alpha]_D^{27}$ 65.0° (c 2.0 in $CHCl_3$); ^{13}C NMR ($CDCl_3$) δ 45.8 (C-4), 56.0 (O*C*H$_3$), 64.0 (C-6), 69.4 (C-5), 69.6 (C-3), 72.9 (C-2), 97.4 (C-1), 98.1 (*C*N); ^{1}H NMR ($CDCl_3$) δ 3.48 (3H, s, OC*H*$_3$), 3.59 (1H, t, $J_{3,4+4,5}$ = 22 Hz, H-4), 3.47 (1H, ddd, $J_{4,5}$ = 5.5 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 1.3 Hz, H-5), 4.83 (1H, dd, $J_{5,6a}$ = 1.3 Hz, $J_{6a,6b}$ = 6.5 Hz, H-6a), 4.88 (1H, dd, $J_{5,6b}$ = 2.0 Hz, $J_{6a,6b}$ = 6.5 Hz, H-6b), 5.23 (1H, d, $J_{1,2}$ = 1.8 Hz, H-1), 5.27 (1H, dd, $J_{1,2}$ = 1.8 Hz, $J_{2,3}$ = 6.8 Hz, H-2), 6.11 (1H, dd, $J_{2,3}$ = 6.8 Hz, $J_{3,4}$ = 5.5 Hz, H-3), 7.33−8.13 (15H, *m*, Ar). Anal. Calcd for $C_{29}H_{25}NO_8Se$: C, 58.59; H, 4.24; N, 2.36. Found: C, 58.67; H, 4.22; N, 2.23.

Methyl 2,3,6-Tri-*O*-benzoyl-4-seleno-α-D-glucopyranoside (21). Methyl 2,3,6-tri-*O*-benzoyl-4-selenocyanato-α-D-glucopyranoside (**20**) (0.6 g, 1.0 mmol) was dissolved in THF:EtOH, 5:1 (24 mL) and cooled in an ice bath, while sodium borohydride (0.18 g, 4.8 mmol) was added in small portions over 15 min. The reaction mixture was warmed to room temperature and stirred for 40 min. After recooling in an ice bath, Et_2O (100 mL) was added, and excess $NaBH_4$ was hydrolyzed by the cautious addition of 5% aqueous HCl solution (10 mL). The mixture was stirred for 5 min. The ether phase was separated and washed with H_2O (2 × 10 mL) and saturated aqueous NaCl solution (10 mL). The organic phase was dried over magnesium sulfate and concentrated to yield the *title compound* (**21**) (0.57g) as a colorless foam which solidified on cooling: ^{13}C NMR (100 MHz, $CDCl_3$) δ 36.2 (C-4), 55.6 (O*C*H$_3$), 65.0 (C-6), 71.8 (C-5), 72.7 (C-3), 73.2 (C-2), 97.5 (C-1); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.07 (1H, d, $^1J_{Se,H}$ = 45.5 Hz, $^3J_{SeH,4}$ = 7.9 Hz, Se*H*), 3.62 (1H, dt, $J_{3,4+4,5}$ = 22.0 Hz, $^3J_{SeH,4}$ = 7.9 Hz, H-4), 3.94 (3H, s, OCH_3), 4.24 (1H, ddd, $J_{4,5}$ = 11.0 Hz,

$J_{5,6a}$ = 4.4 Hz, $J_{5,6b}$ = 2.7 Hz, H-5), 4.80 (1H, dd, $J_{5,6a}$ = 4.4 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6a), 4.83 (1H, dd, $J_{5,6b}$ = 2.7 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6b), 5.18 (1H, dd, $J_{1,2}$ = 3.6 Hz, $J_{2,3}$ = 9.8 Hz, H-2), 5.22 (1H, d, $J_{1,2}$ = 3.6 Hz, H-1), 5.89 (1H, dd, $J_{2,3}$ = 9.8 Hz, $J_{3,4}$ = 11.0 Hz, $^3J_{H,Se}$ = 5.0 Hz, H-3), 7.30−8.15 (15H, m, Ar). The air oxidation of methyl 2,3,6-tri-*O*-benzoyl-4-seleno-α-D-glucopyranoside (**21**) afforded the corresponding diselenide **22** that was recrystallized from ethanol: mp 118−120 °C; $[\alpha]_D^{24}$ 59.2° (*c* 1.2 in $CHCl_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 44.8 (C-4), 55.6 (OCH_3), 65.0 (C-6), 70.0 (C-5), 70.8 (C-3), 73.2 (C-2), 97.3 (C-1). ^1H NMR (400 MHz, $CDCl_3$) δ 3.34 (3H, s, OCH_3), 3.48 (1H, t, $J_{3,4+4,5}$ = 22.2 Hz, H-4), 4.28 (1H, ddd, $J_{4,5}$ = 11.8 Hz, $J_{5,6a}$ = 1.9 Hz, $J_{5,6b}$ = 6.1 Hz, H-5), 4.67 (1H, dd, $J_{5,6a}$ = 1.9 Hz, $J_{6a,6b}$ = 11.8 Hz, H-6a), 4.98 (1H, dd, $J_{5,6b}$ = 6.1 Hz, $J_{6a,6b}$ = 11.8 Hz, H-6b), 5.13 (1H, d, $J_{1,2}$ = 3.4 Hz, H-1), 5.18 (1H, dd, $J_{1,2}$ = 3.4 Hz, $J_{2,3}$ = 10.0 Hz, H-2), 5.96 (1H, t, $J_{2,3+3,4}$ = 20.5 Hz, H-3), 7.15−8.15 (15H, m, Ar). Anal. Calcd for $C_{56}H_{56}O_{16}Se_2$: C, 59.16; H, 4.43. Found: C, 59.12; H, 4.38.

Methyl 2,3,6-Tri-*O*-benzoyl-4-seleno-(2,3,4,6-tetra-*O*-acetyl-5′-thio-α/β-D-glucopyranosyl)-α-D-glucopyranoside (23 and 24). A mixture of *O*-(2,3,4,6-tetra-*O*-acetyl-5-thio-α-D-glucopyranosyl) trichloroacetimidate (**6**) (0.05 g, 0.1 mmol), methyl 2,3,6-tri-*O*-benzoyl-4-seleno-α-D-glucopyranoside (**21**) (0.1 g, 0.18 mmol), and dry 4Å molecular sieves in anhydrous dichloromethane (1 mL) was stirred under nitrogen for 1 h. The reaction mixture was cooled to −78 °C, and triethylsilyl triflate (0.002 mL, 0.01 mmol) was added. The reaction mixture was stirred at −78 °C for 1 h. An aliquot of the reaction mixture was taken and quenched with Et_3N at −78 °C. A TLC indicated that no reaction had occurred. The reaction mixture was then warmed to room temperature and stirred for another 1.5 h. A TLC indicated that the reaction was complete. The reaction mixture was again cooled to −78 °C and neutralized with collidine. The reaction mixture was then filtered and washed successively with hydrochloric acid (5%) and aqueous sodium hydrogen carbonate. The organic extracts were dried over magnesium sulfate and concentrated to give a foam that was chromatographed with hexane−ethyl acetate (1.3:1) as eluant [R_f α-isomer **23** = 0.33; β-isomer **24** = 0.23]. The *title compounds* **23** and **24** were obtained as foams and were crystallized from ethanol (α:40 mg, 45%, β:10 mg, 11%). α-Isomer **23:** mp 184 °C; $[\alpha]_D^{20}$ +292° (*c* 1.0 in CH_2Cl_2); ^{13}C NMR ($CDCl_3$) δ 19.9, 20.3, 20.4, 20.5 ($4COCH_3$), 41.4 (C-5′), 42.8 (C-4), 44.9 [$^1J(^{13}C,^1H)$ 156 Hz, (C-1)], 55.6 (OCH_3), 60.8 (C-6′), 65.0 (C-6), 68.7 (C-5), 71.6 (C-3′), 71.7 (C-4), 72.1 (C-3), 73.4 (C-2), 73.9 (C-2′), 97.3 [$^1J(^{13}C,^1H)$ 173 Hz, (C-1)], 128.3−133.4 (Ar), 165.2, 165.8, 166.2 ($3COC_6H_5$) 168.9, 169.3, 169.35, 170.4 ($4COCH_3$); ^1H NMR ($CDCl_3$) δ 1.59, 1.91, 2.0, 2.04 (12H, 4s, $4COCH_3$), 3.36 (1H, t, $J_{3,4+4,5}$ = 22.6 Hz, H-4), 3.44 (3H, s, OCH_3), 3.61 (1H, ddd, $J_{4',5'}$ = 10.5 Hz, $J_{5',6'a}$ = 4.6 Hz, $J_{5',6'b}$ = 2.9 Hz, H-5′), 4.03 (1H, dd, $J_{5',6'a}$ = 2.9 Hz, $J_{6'a,6'b}$ = 12.3 Hz, H-6′a), 4.28 (1H, ddd, $J_{4,5}$ = 9.4 Hz, $J_{5,6a}$ = 2.2 Hz, $J_{5,6b}$ = 6.3 Hz, H-5), 4.43 (1H, dd, $J_{5'6'b}$ = 4.6 Hz, $J_{6'a,6'b}$ = 12.3 Hz, H-6′b), 4.68 (1H, dd, $J_{5,6a}$ = 6.3 Hz, $J_{6a,6b}$ = 11.8 Hz, H-6a), 4.75 (1H, d, $J_{1',2'}$ = 5.6 Hz, H-1′), 4.90 (1H, dd, $J_{5,6b}$ = 2.2 Hz, $J_{6a,6b}$ = 11.8 Hz, H-6b), 5.01 (1H, dd, $J_{1',2'}$ = 5.6 Hz, $J_{2',3'}$ = 10.0 Hz, H-2′), 5.12 (1H, t, $J_{2',3'+3',4'}$ = 19.3 Hz, H-3′), 5.14 (1H, dd, $J_{1,2}$ = 3.5 Hz, $J_{2,3}$ = 10.0 Hz, H-2), 5.21 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 5.22 (1H, dd, $J_{3',4'}$ = 9.1 Hz, $J_{4',5'}$ = 10.5 Hz, H-4′), 6.20 (1H, dd, $J_{2,3}$ = 10.0 Hz, $J_{3,4}$ = 10.8 Hz, H-3), 7.2−8.2 (15H, Ar). Anal. Calcd for $C_{42}H_{44}O_{16}SSe$: C, 55.08; H, 4.84. Found: C, 54.94; H, 4.86. β-Isomer **24:** mp 175 °C; ^{13}C NMR ($CDCl_3$) δ 19.9, 20.3, 20.4, 20.5 ($4COCH_3$), 39.3 (C-1′), 43.0 (C-4), 45.9 (C-5′), 55.6 (OCH_3), 60.8 (C-6′), 64.8 (C-6), 69.0 (C-3), 70.6 (C-5), 71.5 (C-4′), 73.3 (C-2), 73.8 (C-2′), 74.5 (C-3′), 97.4 (C-1), 128.2−133.3 (Ar), 165.2, 165.8, 166.2 ($3COC_6H_5$) 168.9, 169.3, 169.35, 170.4 ($4COCH_3$); ^1H NMR ($CDCl_3$) δ 1.86, 1.92, 1.96, 2.02 (12H, 4s, $4COCH_3$), 2.71 (1H, ddd, $J_{4',5'}$ = 10.5 Hz, $J_{5',6'a}$ = 3.0 Hz, $J_{5',6'b}$ = 4.5 Hz, H-5′), 3.44 (3H, s, OCH_3), 3.55 (1H, t, $J_{3,4+4,5}$ = 22.7 Hz, H-4), 3.77 (1H, dd, $J_{5',6'a}$ = 3.0 Hz, $J_{6'a,6'b}$ = 12.0 Hz, H-6′a), 4.08 (1H, dd, $J_{5',6'b}$ = 4.5 Hz, $J_{6'a,6'b}$ = 12.0 Hz, H-6′b), 4.11 (1H, d, $J_{1',2'}$ = 10.8 Hz, H-1′), 4.40 (1H, ddd, $J_{4,5}$ = 11.5 Hz, $J_{5,6a}$ = 3.3 Hz, $J_{5,6b}$ = 1.9 Hz, H-5), 4.75−4.83 (2H, m, H-3′, H-6′), 4.86 (1H, dd, $J_{5,6b}$ = 1.9 Hz, $J_{6a,6b}$ = 12.5 Hz, H-6b), 4.97 (1H, dd, $J_{1',2'}$ = 10.8, $J_{2',3'}$ = 9.5 Hz, H-2′), 5.13 (1H, dd, $J_{3',4'}$ = 9.5 Hz, $J_{4',5'}$ = 10.5 Hz, H-4′), 5.20 (1H, d, $J_{1,2}$ = 3.4 Hz, H-1), 5.25 (1H, dd, $J_{1,2}$ = 3.4 Hz, $J_{2,3}$ = 9.9 Hz, H-2), 5.92 (1H, dd, $J_{2,3}$ = 9.9 Hz, $J_{3,4}$ = 11.2 Hz, H-3), 7.3−8.2 (15H, Ar). Anal. Calcd for $C_{42}H_{44}O_{16}SSe$: C, 55.08; H, 4.84. Found: C, 54.84; H, 4.79.

Methyl 4-Seleno-(5′-thio-α-D-glucopyranosyl)-α-D-glucopyranoside (3). A freshly prepared solution of sodium methoxide in methanol (0.2 N, 2.5 mL) was added to disaccharide (**23**) (95 mg, 0.1 mmol), and the mixture was stirred under nitrogen for 3 h. The solution was acidified to pH 3 with Rexyn (H^+) resin and filtered. The filtrate was neutralized with Amberlite basic ion exchange resin, filtered, and concentrated. The residue was purified by column chromatography with hexane-dichloromethane−methanol (1.2:1:1) as eluant [R_f 0.32]. The *title compound* (**3**) was obtained as a foam (35 mg, 81%): $[\alpha]_D^{20}$ +51° (*c* 0.75 in CH_3OH); ^{13}C NMR (D_2O) δ 47.6 (C-1′), 48.7 (C-4), 49.9 (C-5′), 57.9 (OCH_3), 62.8 (C-6), 65.3 (C-6′), 74.1 (C-5), 75.3 (C-2), 75.6 (C-3), 76.3 (C-4′), 78.0 (C-2′), 78.4 (C-3′), 102.3 (C-1); ^1H NMR (D_2O) δ 3.02 (1H, t, $J_{3,4+4,5}$ = 22.0 Hz, H-4), 3.20 (1H, dt, $J_{4',5'}$ = 10.4 Hz, $J_{5',6'a+5',6'b}$ = 9.2 Hz, H-5′), 3.44 (3H, s, OCH_3), 3.47 (1H, t, $J_{2',3'+3',4'}$ = 18.4 Hz, H-3′), 3.53 (1H, dd, $J_{1,2}$ = 3.6 Hz, $J_{2,3}$ = 9.5 Hz, H-2), 3.58 (1H, dd, $J_{3',4'}$ = 9.1 Hz, $J_{4',5'}$ = 10.4 Hz, H-4′), 3.84−3.96 (5H, m, H-5, 6′a, 6′b, 2, 6a), 3.93 (1H, t, $J_{2,3+3,4}$ = 19.0 Hz, H-3), 4.04 (1H, dd, $J_{5,6b}$ = 1.9 Hz, $J_{6a,6b}$ = 11.9 Hz, H-6b), 4.68 (1H, d, $J_{1',2'}$ = 4.3 Hz, H-1′), 4.84 (1H, d, $J_{1,2}$ = 3.6 Hz, H-1); ES-MS calcd for $C_{13}H_{24}O_9SSe$ M^+ 436, found 459 $(M + Na)^+$.

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