Table V. Second-Order Rate Constants k_{NP} (M^{-1} s^{-1}) for Hydrolysis of 4-Nitrophenyl Acetate at 25 °C

nucleophile	k_{NP}	pK_a (H_2O)
11	4.1×10^{-2} [a]	7.3
$(NH_3)_5Co^{III}OH$	1.5×10^{-3} [b]	6.4
bovine carbonic anhydrase	4.0×10^{2} [c]	7.5
OH^-	9.5[d]	15.5

[a] At pH 8.2 (50 mM HEPES buffer) and I = 0.10 ($NaClO_4$). [b] From ref 3. [c] pH 8.9, from ref 46. [d] From ref 48.

cycles due to the more facile liberation of the product anion.

Comparison of the Nucleophilicity with Other Hydroxo Species. The aforementioned acetaldehyde hydration and methyl acetate hydrolysis reactions have established that the Zn^{II}–OH species is acting as a nucleophile toward the substrates. In order to compare the intermolecular nucleophilicity of the Zn^{II}–OH species with that of the well studied Co^{III}-bound hydroxide species ($(NH_3)_5Co^{III}$–OH),[3] where neither has an extra vacant site for the prior ester coordination, we ran a kinetic study of 4-nitrophenyl acetate hydrolysis. Here again, the plots of the second-order rate constant vs pH gave a sigmoidal curve like the previous two reaction cases, and its midpoint pH corresponded almost to the pK_a value of 7.3. The resulting second-order rate constant k_{NA} for **11** is summarized in Table V.

It is concluded that as a nucleophile the Zn^{II}–OH is ~1 order of magnitude more reactive than $(NH_3)_5Co^{III}$–OH toward the same ester substrate. The same direct nucleophilic mechanism was proposed for the Co^{III}–OH reaction.[3] Taking into consideration the charge and ligand field difference of the metal ions, this order of nucleophilic efficiency would be reasonable. Note the pK_a of 6.4 for $(NH_3)_5Co^{III}$–OH_2 vs 7.3 for **3**. Compared with free OH^- ion,[48] the Zn^{II}-bound OH^- ion is ~250 times less reactive in 4-nitrophenyl acetate hydrolysis reaction. However, if the pK_a values of 15.5 and 7.3 for free H_2O and Zn^{II}–OH_2, respectively, are considered, the latter would make a more effective nucleophile at neutral pH.

Conclusion

Zinc(II) complex **3** of a symmetrical 12-membered macrocyclic triamine [12]aneN$_3$ **2** has been shown to be the most suitable model for the active site of carbonic anhydrase (CA), where Zn^{II} is bound by three histidine imidazole residues and by a water or hydroxide as the fourth ligand. The pK_a value of 7.3 (at 25 °C and I = 0.1) and inhibitor (such as anions and acetazolamide) binding mode reported for CA are reproduced for the first time with **3**. Zn^{II}–[12]aneN$_3$(OH) **11** is isolable as a trimer, whose X-ray study has proven that the unit **11** takes a 4-coordinate, tetrahedral structure. The extremely short Zn^{II}–OH bond distance of 1.94 Å suggests a strong affinity of Zn^{II} for OH^- and accounts for the extremely low pK_a of 7.3. Such strong affinity of **3** to OH^- ion surpasses any other anions including CA-catalyzing reaction products, CH_3COO^- (from ester substrates) or possibly HCO_3^- (from hydration of CO_2). This fact, characteristic of the Zn^{II} ion, is very favorable for the catalytic cycles. In the two CA-catalyzing reactions, acetaldehyde hydration and ester hydrolysis, the second-order kinetics and the plots of the rate constant vs pH point to a common reaction mechanism involving the direct nucleophilic attack of Zn^{II}–OH at the carbonyl carbons. Although these rates are much slower than those with CA, the reaction mechanism is the same as the one currently accepted for CA. In comparison of the metal-bound OH nucleophilicity toward 4-nitrophenyl acetate, the Zn^{II}–OH is ca. 10 times more powerful than the previously reported $(NH_3)_5Co^{III}$–OH.[3] It is concluded that the amphoteric Zn^{II}-bound OH retains stronger nucleophilicity than the acidic Co^{III}-bound OH. We have found that the nucleophilic power of the Zn^{II}–OH also effects phosphate ester hydrolysis, which will be reported elsewhere. Finally, further structural modification of the basic structure of **2** (e.g., attachment of intramolecular bases to aid proton transfers or of other substituents for substrate recognition or for polarity change, etc.) is likely to yield even closer CA and other Zn^{II}-containing hydrolytic enzyme models, which is currently under investigation in our laboratory.

Acknowledgment. We are grateful for the Special Project Research for Macromolecular Complexes Grant-in-Aid No. 60119003 from the Ministry of Education.

Supplementary Material Available: ^1H NMR chart of **11** in D_2O solution, plots of $1/K'$ vs concentration of anion (SCN^- and Br^-) and of k_{obs} vs Zn^{II} complex concentration, and tables of anisotropic temperature factors, crystal data and data collection summary, final fractional coordinates and equivalent isotropic temperature factors, bond distances, and bond angles (9 pages); listing of observed and calculated structure factors for the Zn^{II}[12]aneN$_3$–OH complex (9 pages). Ordering information is given on any current masthead page.

(48) Jencks, W. P.; Gilchrist, M. *J. Am. Chem. Soc.* **1968**, *90*, 2622.

Sulfonamidoglycosylation of Glycals. A Route to Oligosaccharides with 2-Aminohexose Subunits†

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Received December 12, 1989

Abstract: Reactions of glycals with the combination iodonium di-*sym*-collidine perchlorate (**5**) and benzenesulfonamide (**6**) afforded, stereoselectivity, 2-β-iodo-1-α-sulfonamidohexoses. This process was demonstrated with D-glucal, D-galactal, and D-allal. Treatment of these products with strong base apparently generated a C_1–C_2 sulfonylaziridine. A 2-α-sulfonamide-1-β-linked disaccharide was produced when this reaction was carried out with excess base in the presence of a glycosyl acceptor.

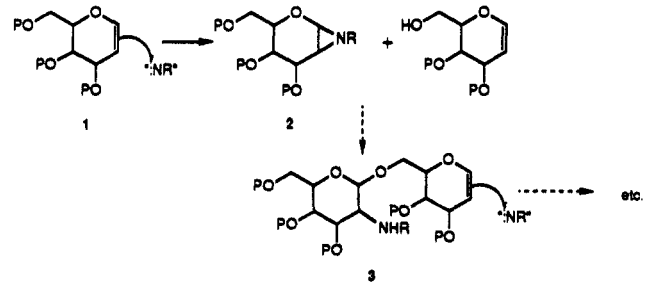
Glycosides of N-acylated 2-amino-2-deoxy saccharides are important subunits of many glyconjugates such as glycoproteins,[1] chitin,[2] and heparin.[3] Several elegant methods have been employed to generate[4] and couple[5] 2-amino-2-deoxy carbohydrates. A particularly interesting method was recently disclosed by Leblanc, Fitzsimmons, and co-workers.[6] Their procedure involved the cycloaddition of an azodicarboxylate to the double bond of

† We dedicate this paper in memory of Dr. Brian Fitzsimmons for his studies on the azaglycosylation of glycals.

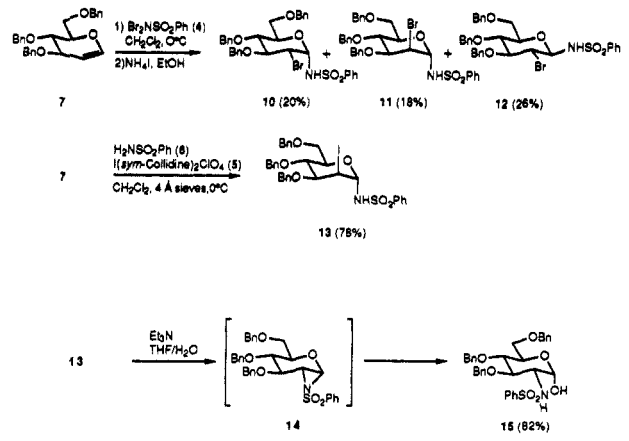
(1) (a) Paulson, J. C. *Trends Biochem. Sci.* **1989**, *14*, 272. (b) Kobota, A. In *Biology of Carbohydrates*; Ginsburg, V., Robbins, P. W., Eds.; J. Wiley & Sons: New York, 1984; Vol. 2, p 87. (c) Montreuil, J. In *Comprehensive Biochemistry*; Neuberger, A., van Deenan, L. L. M., Eds.; Elsevier: Amsterdam, 1982, p 1.

0002-7863/90/1512-5811$02.50/0

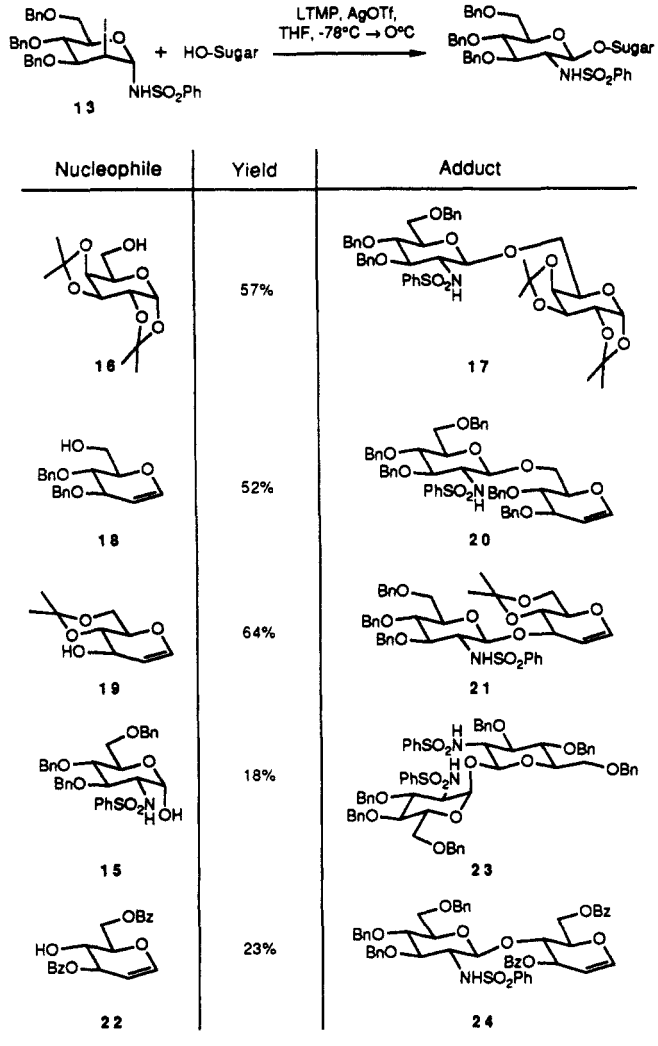
Scheme I



Scheme II



Scheme III



a glycal. The overall stereoselectivity followed from the facial sense of the cycloaddition.

Given our own interests in the synthesis of glycals[7] and in their application in the assembly of oligosaccharides[8,9] we explored another possibility for azaglycosylation of glycals. The plan, shown in Scheme I, involved generation of a 1,2-aziridinohexose (**2**) from a glycal (**1**). Presumably, substitution of the nitrogen with an electron-withdrawing group would enhance the glycosylating powers of the aziridine linkage, thereby leading to **3**.

An inviting scenario was one where system **2** (R = acetyl) would be prepared by the direct insertion of an *N*-acetylnitreneoid species[10] to the double bond of a glycal. Kozlowska-Gramz and Descotes[11] had reported that the analogous *N*-carbomethoxy linkages can be generated in low yield by photolysis of methyl-azidoformate in the presence of glycals. When this photolysis was carried out in the presence of alcohol, mixtures of glycosides bearing a urethane function at C_2 were isolated. Unfortunately, high stereoselectivity was lacking in both the insertion and alcoholysis reactions.

While the possibilities for elaboration of activated 1,2-aziridines by direct insertion have not been exhausted, we have begun to investigate an alternative route, which starts with halosulfonamidation of hexose-derived glycals. Analogous chemistry had previously been investigated with simple olefins such as cyclohexene and dihydropyran.[12] A related strategy, followed by Lafont and Descotes,[13] started with the addition of iodonium azide

(2) Austin, P. R.; Brine, C. J.; Castle, J. E.; Zikakis, J. P. *Science* **1981**, *212*, 749.

(3) (a) Björk, I.; Lindahl, U. *Mol. Cell. Biochem.* **1982**, *48*, 161. (b) Roden, L. In *The Biochemistry of Glycoproteins and Proteoglycans*; Lennarz, W. J., Ed; Plenum: New York, 1980; p 321.

(4) Examples. (a) Opening epoxides with azide: Paulsen, H.; Stenzel, W. *Chem. Ber.* **1978**, *111*, 2334, 2348. Paulsen, H.; Kolář, C.; Stenzel, W. *Chem. Ber.* **1978**, *111*, 2358. (b) Addition of nitrosyl chloride to glycals: Lemieux, R. U.; James, K.; Nagabhushan, T. L. *Can. J. Chem.* **1973**, *51*, 48. Lemieux, R. U.; Ito, Y.; James, K.; Nagabhushan, T. L. *Can. J. Chem.* **1973**, *51*, 7. Lemieux, R. U.; Nagabhushan, T. L.; O'Neil, I. K. *Tetrahedron Lett.* **1964**, 1909. (c) Azidonitration of galactal: Lemieux, R. U.; Ratcliffe, R. M. *Can. J. Chem.* **1979**, *57*, 1244. (d) For fascinating C1 → C2 migrations including that of azide, see: Nicolaou, K. C.; Ladduwahetty, T.; Randall, J. L.; Chucholowski, A. *J. Am. Chem. Soc.* **1986**, *108*, 2466.

(5) For recent reviews, see: (a) Paulsen, H. *Ang. Chem., Int. Ed. Engl.* **1982**, *21*, 155. (b) Schmidt, R. R. *Ang. Chem., Int. Ed. Engl.* **1986**, *25*, 212.

(6) (a) Leblanc, Y.; Fitzsimmons, B. J. *Tetrahedron Lett.* **1989**, *30*, 2889. (b) Leblanc, Y.; Fitzsimmons, B. J.; Springer, J. P.; Rokach, J. *J. Am. Chem. Soc.* **1989**, *111*, 2995. (c) Fitzsimmons, B. J.; Leblanc, Y.; Chan, N.; Rokach, J. *J. Am. Chem. Soc.* **1988**, *110*, 5229. (d) Fitzsimmons, B. J.; Leblanc, Y.; Rokach, J. *J. Am. Chem. Soc.* **1987**, *109*, 285.

(7) (a) Danishefsky, S. J. *Chemtracts: Org. Chem.* **1989**, *2*, 273. (b) Danishefsky, S. J.; DeNinno, M. P. *Angew. Chem., Int. Ed. Engl.* **1987**, *26*, 15. (c) Danishefsky, S. J. *Aldrichimica Acta* **1986**, *19*, 59.

(8) (a) Halcomb, R. L.; Danishefsky, S. J. *J. Am. Chem. Soc.* **1989**, *111*, 6661. (b) Friesen, R. W.; Danishefsky, S. J. *J. Am. Chem. Soc.* **1989**, *111*, 6656. (c) Danishefsky, S. J.; Selnick, H. G.; Armistead, D. M.; Wincott, F. E. *J. Am. Chem. Soc.* **1987**, *109*, 8119.

(9) For the use of glycals in iodoglycosylation, see: (a) Thiem, J. *ACS Symp. Ser.* **1989**, *No. 386*, 131. (b) Thiem, J.; Karl, H.; Schwenter, J. *Synthesis* **1978**, 696.

(10) (a) Meth-Cohn, O. *Acc. Chem. Res.* **1987**, *20*, 18. (b) Scriven, E. F. V., Ed. *Azides and Nitrenes*; Academic: New York, 1984. (c) Lwowski, W. In *Reactive Intermediates*; Jones, M. R., Jr., Moss, R. A., Eds.; J. Wiley & Sons: New York, 1981; Vol. 2, p 315; 1978; Vol. 1, p 197. (d) For the addition of ethyl azidoformate to dihydropyran, see: Brown, I.; Edwards, O. E. *Can. J. Chem.* **1965**, *43*, 1266. (e) For the addition of methyl azidoformate to 2-methylenetetrahydropyran, see: Kozlowska-Gramsz, E.; Descotes, G. *J. Heterocycl. Chem.* **1983**, *20*, 671.

(11) (a) Kozloska-Gramsz, E.; Descotes, G. *Can. J. Chem.* **1982**, *60*, 558. (b) Kozlowska-Gramsz, E.; Descotes, G. *Tetrahedron Lett.* **1981**, *22*, 563.

(12) For the addition of *N,N*-dihalosulfonamides to dihydropyran, see: (a) Barton, D. H. R.; Britten-Kelly, M. R.; Ferreira, D. *J. Chem. Soc., Perkin Trans. I* **1978**, 1682. (b) Otsuki, K.; Hagihao, K.; Takemura, S.; Ueno, Y. *Chem. Pharm. Bull.* **1970**, *18*, 281. (c) Takemura, S.; Otsuki, K.; Okamoto, K.; Ueno, Y. *Chem. Pharm. Bull.* **1968**, *16*, 1881, 2267. (d) Takemura, S.; Otsuki, K.; Okamoto, K.; Ueno, Y. *Chem. Pharm. Bull.* **1968**, *16*, 1885. (e) Ueno, Y.; Takemura, S.; Ando, Y.; Terauchi, H. *Chem. Pharm. Bull.* **1967**, *15*, 1193.

to glycals. A Staudinger reaction converted the resultant products to β-iodophosphoramidates. One such intermediate was converted to a disaccharide, albeit in low yield. It was proposed that the glycosylation had involved a phosphorylated 1,2-aziridine. We hoped that halosulfonamidation would be more easily carried out and might be more stereoselective.

Our early efforts centered around the reactions of glycals with *N,N*-dibromobenzenesulfonamide (**4**).[12e] However, superior results were obtained from the combination of iodonium di-*sym*-collidine perchlorate (**5**)[14] and benzenesulfonamide (**6**). Three glycals, tri-*O*-benzyl-D-glucal (1,5-anhydro-3,4,6-tri-*O*-benzyl-2-deoxy-D-*arabino*-hex-1-enitol, **7**), tri-*O*-benzyl-D-galactal (1,5-anhydro-3,4,6-tri-*O*-benzyl-2-deoxy-D-*lyxo*-hex-1-enitol, **8**), and 3-*O*-benzyl-4,6-*O*-benzylidene-D-allal (1,5-anhydro-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-D-*ribo*-hex-1-enitol, **9**) were investigated.

Reaction of **7** with **4** was conducted in methylene chloride at 0 °C. The product, presumably containing a nitrogen–bromine bond, was reduced with ammonium iodide in methanol. The adducts **10** (20%), **11** (18%) and **12** (26%) were isolated. In the hopes of improving the stereoselectivity of the addition reaction, glycal **7** was treated with **5** and **6** (methylene chloride at 0 °C). The trans-diaxial iodosulfonamide **13** was isolated in 78% yield. Several attempts to isolate the 1,2-*N*-sulfonylaziridine **14** after treatment of **13** with base were unsuccessful. NMR spectral analysis of the products of such reactions pointed to the presence of the 2-sulfonimidohemiacetal **15**, albeit in impure form.[15] Compound **15** was independently synthesized by treatment of **13** with triethylamine/aqueous THF. These experiments suggested the likelihood that **14** was being produced, but was vulnerable to rapid hydrolysis at the anomeric carbon. We then pursued the possibility that the presumed aziridine could be interdicted by a sugar-derived nucleophile generated in situ, comparable to the one case described by Descotes in the phosphorylaziridine[13a] series.

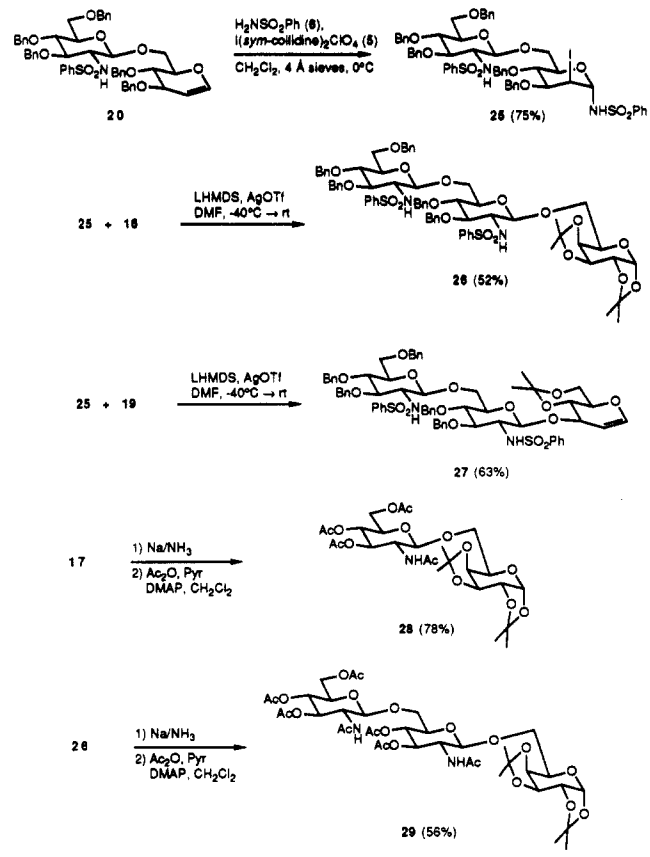
This proposition was reduced to practice. Treatment of **13** and diacetonegalactose (**16**) with 2.2 equiv of lithium tetramethylpiperidide (LTMP) in THF at −78 °C containing 1.4 equiv of silver triflate, followed by warming at 0 °C afforded a 57% yield of **17**. We next surveyed the possibility that the nucleophilic sugar, (i.e., glycosyl acceptor) might itself be a glycal. This too was shown to be viable. When the diprotected glycals **18** and **19** were utilized as coupling partners with **13**, disaccharides **20** and **21** were obtained in 52% and 64% yields, respectively. Two particularly challenging cases were also screened. The first was the coupling of anomeric nucleophile **15** with iodosulfonamide **13**. The second involved the alkoxide derived from the dibenzoate **22**. Even in these unfavorable instances, disaccharides **23** and **24** were obtained, albeit in modest yields (18% and 23%, respectively).

The prospect of a trisaccharide synthesis by this method was evaluated and shown to be workable. Reaction of **20** with **6** under the usual conditions afforded the trans-diaxial sulfonamide **25**. Coupling of this system with **16** (3.3 equiv of LTMP, 1.6 equiv of AgOTf) afforded trisaccharide **26** (52%). Similarly, coupling of **25** with glycal **19** afforded a 63% yield of **27**.

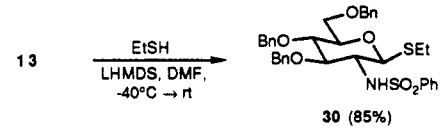
While it will be of interest to examine the biological properties of these sulfonamidoglucosides, it was important to determine that these sulfonamides could be converted to the familiar *N*-acetyl functions. Treatment of disaccharide **17** with excess sodium in ammonia followed by peracetylation of the aminotriol, afforded disaccharide **28** (78%). Similar processing of **26** afforded a 56% of yield **29**.

In the work described thus far, glycosides are produced in a manner such that the C_1-glycoside and the C_2-sulfonamide are trans-diequatorial. The ability to generate α- and β-glycosides

Scheme IV



from anomeric sulfides has been well demonstrated.[16] With a view to promoting access to α-glycosides of glucosamine, the sulfonamide migration reaction was conducted in the presence of lithium ethanethiolate. This reaction produced an 85% yield of **30**.[17]



The applicability of sulfonamidoglycosylation to the galactal series was also investigated. Reaction of **8** with **5** and **6** afforded iodosulfonamide **31** (74%). Coupling of **31** with **16** and **19** provided **32** and **33**, respectively, although in reduced yields.

Finally, we examined this coupling methodology in the allal series. Treatment of **9** with **4** or **6** afforded 3:1 mixtures of **34** and **35**. We have thus far processed forward only the principal diaxial product. Treatment of either **34a** or **34b** with **16** under basic conditions afforded the diequatorial product **36**. Thus the halosulfonamide addition–rearrangement glycosylation strategy on allal provides a C_1–C_2 diequatorial pattern. In this case, the

(13) (a) Lafont, D.; Descotes, G. *Carbohydr. Res.* **1988**, *175*, 35. (b) Lafont, D.; Descotes, G. *Carbohydr. Res.* **1987**, *166*, 195.

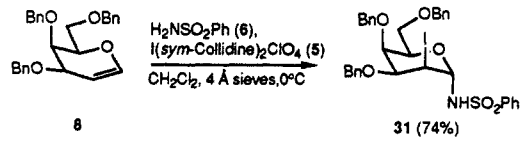
(14) (a) Lemieux, R. U.; Morgan, A. R. *Can. J. Chem.* **1965**, *43*, 2190. (b) Compare: Iley, D. E.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1975**, *97*, 2563.

(15) The 490-MHz ^{1}H NMR suggested that the aziridine was present initiallty (approximately 30% of the crude reaction material). A pair of doublets [δ 5.06, 3.12 (J = 5.4 Hz)], which were tentatively assigned as H-1 and H-2 respectively, disappeared over several hours.

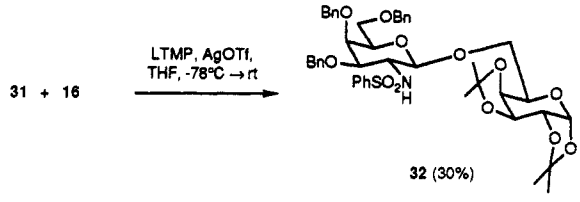
(16) Recent examples were glycosyl donors were generated via the following. (a) NBS activation of phenyl thioglycosides: Nicolaou, K. C.; Seitz, S. P.; Papahatjis, D. P. *J. Am. Chem. Soc.* **1983**, *105*, 2430. (b) Conversion of phenylthio sugars to glycosyl fluorides: Nicolaou, K. C.; Dolle, R. E.; Papahatjis, D. P.; Randall, J. L. *J. Am. Chem. Soc.* **1984**, *106*, 4189. Nicolaou, K. C.; Randal, J. L.; Furst, G. T. *J. Am. Chem. Soc.* **1985**, *107*, 5556. (c) Mercury(II) activation of phenyl thioglycosides: Ferrier, R. J.; Hay, R. W.; Vethaviyasar, N. *Carbohydr. Res.* **1973**, *27*, 55. Garegg, P. J.; Henrichson, C.; Norberg, T. *Carbohydr. Res.* **1983**, *116*, 162. (d) Alkylsulfenylation of anomeric thioalkyl groups: Fügedi, P.; Garegg, P. J. *Carbohydr. Res.* **1986**, *149*, C9. (e) Methyl triflate activation of ethyl thioglycosides: Lönn, H. *Carbohydr. Res.* **1985**, *139*, 105, 115. (f) Triflic anhydride activation of anomeric phenyl sulfoxides: Kahne, D.; Walker, S.; Cheng, Y.; Van Engan, D. *J. Am. Chem. Soc.* **1989**, *111*, 6881.

(17) A similar transformation had been reported by Barton et al.[12a] starting with a bromosulfonamide derived from dihydropyran.

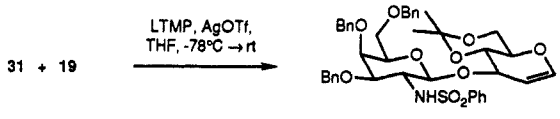
Scheme V



8 31 (74%)

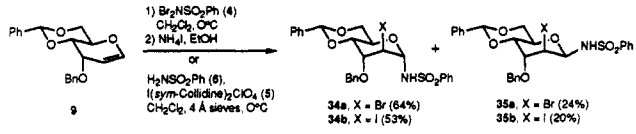


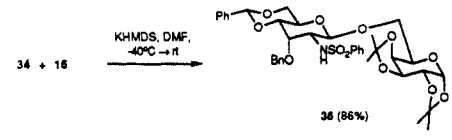
32 (30%)



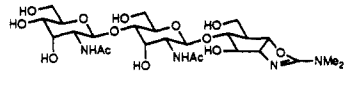
33 (31%)

Scheme VI





36 (86%)



37

Leblanc and Fitzsimmons' [2 + 4] cycloaddition route leads the C_1–C_2 diaxial pattern.[6b] The C_1–C_2 diequatorial pattern would be of particular advantage in a synthesis of the chitnase inhibitor allosamidine (**37**).[18]

In summary, the work described here provides a strategy for the rapid assembly of oligosaccharides with repeating β-linked glucosamine subunits via the sulfonamidoglycosylation of glycals. It will be recalled that hetero-Diels–Alder methodology allows for the synthesis of glycals of virtually unlimited structural diversity.[7] Accordingly, a path has now been developed for the rapid synthesis of oligosaccharides containing significantly modified 2-amino-2-deoxy saccharides. It will be of interest to examine conjugates of such novel oligosaccharides with respect to their impact on biorecognition. Further efforts will be directed toward fine tuning these protocols with a view to yield improvements and with particular emphasis on the synthesis of important conjugates of 2-aminohexoses.

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Experimental Section

3,4,6-Tri-*O*-benzyl-2-bromo-2-deoxy-α-D-glucopyranosyl Benzenesulfonamide (10), 3,4,6-Tri-*O*-benzyl-2-bromo-2-deoxy-α-D-mannopyranosyl Benzenesulfonamide (11), and 3,4,6-Tri-*O*-benzyl-2-bromo-2-deoxy-β-D-glucopyranosyl Benzenesulfonamide (12). A solution of 3,4,6-tri-*O*-benzyl-D-glucal (**7**; 200 mg, 0.480 mmol) in CH_2Cl_2 (0.3 mL) was added dropwise to a stirred suspension of *N*,*N*-dibromobenzenesulfonamide (**4**; 161 mg, 0.512 mmol) in CH_2Cl_2 (0.5 mL) at 0 °C. After 15 min, ethanol (2 mL) and NH_4I (81 mg, 0.56 mmol) were added to the reaction and stirred an additional 1 h at room temperature. The mixture was reduced with saturated $Na_2S_2O_3$ (5 mL) and extracted with ether (50 mL). The combined organic layers were dried (Na_2SO_4) and concentrated. Analysis of the crude mixture by ^1H NMR indicated the product ratio **10**/**11**/**12** was 1.1:1.0:1.3. The residue was flash chromatographed (silica, 0% → 2% → 4% → 6% EtOAc in CH_2Cl_2) to afford *cis*-bromosulfonamide **10** (63.9 mg, 20%) followed by *trans*-bromosulfonamide **11** (55.4 mg, 18%), and then *trans*-bromosulfonamide **12** (82.6 mg, 26%). **10**: oil; $[\alpha]_D$ +110° (*c* 0.950, $CHCl_3$); IR (neat) ν_{max} 3280, 3060, 3030, 2910, 2870, 1455, 1340, 1175–1030 (br) cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.94–7.90 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.54–7.49 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.44–7.39 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.36–7.24 (m, 13 H, Ar*H*), 7.14–7.09 (m, 2 H, Ar*H*), 5.65 (d, 1 H, *J* = 4.3 Hz, N*H*), 5.64 (t, 1 H, *J* = 4.5 Hz, H-1), 4.82 (AB q, 2 H, *J* = 10.4 Hz, ν = 42.3 Hz, CH_2Ph), 4.72 (d, 1 H, *J* = 10.8 Hz, CH*H*Ph), 4.47 (d, 1 H, *J* = 10.8 Hz, CH*H*Ph), 4.43 (AB q, 2 H, *J* = 12.1 Hz, ν = 49.2 Hz, CH_2Ph), 4.14–4.07 (m, 1 H, H-2), 3.74–3.68 (m, 2 H, H-3 and H-4), 3.54 (br d, 1 H, *J* = 9.6 Hz, H-5), 3.49 (dd, 1 H, *J* = 10.9, 2.7 Hz, H-6), 3.00 (dd, 1 H, *J* = 10.9, 2.0 Hz, H-6); ^{13}C NMR (63 MHz, $CDCl_3$) δ 139.9, 137.7, 137.6, 137.5, 132.9, 128.9, 128.3, 128.0, 127.8 (2), 127.7, 127.4, 81.8, 81.6, 78.8, 75.9, 75.0, 73.4, 71.2, 67.1, 49.4; HRMS (FAB) calcd for $C_{33}H_{34}BrNNaO_6S$ (M + Na) 674.1190, found 674.1180. Anal. Calcd for $C_{33}H_{34}BrNO_6S$: C, 60.74; H, 5.25; N, 2.15; S, 4.91. Found: C, 60.59; H, 5.07; N, 2.16; S, 4.77. **11**: oil; $[\alpha]_D$ +6.2° (*c* 0.96, $CHCl_3$); IR (neat) ν_{max} 3270, 3060, 3030, 2870, 1455, 1335, 1165, 1120, 1100, 1050, 1035 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.88–7.84 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.49–7.44 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.39–7.34 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.39–7.22 (m, 13 H, Ar*H*), 7.12–7.08 (m, 2 H, Ar*H*), 6.32 (d, 1 H, *J* = 8.0 Hz, N*H*), 5.56 (dd, 1 H, *J* = 8.0, 3.3 Hz, H-1), 4.68 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.66 (d, 1 H, *J* = 11.5 Hz, CH*H*Ph), 4.50 (d, 1 H, *J* = 12.0 Hz, CH*H*Ph), 4.49 (d, 1 H, *J* = 11.6 Hz, CH*H*Ph), 4.45 (t, 1 H, *J* = 3.4 Hz, H-2), 4.41 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.34 (d, 1 H, *J* = 12.0 Hz, CH*H*Ph), 3.89 (t, 1 H, *J* = 8.0 Hz, H-4), 3.75 (dd, 1 H, *J* = 7.8, 3.6 Hz, H-3), 3.50 (dd, 1 H, *J* = 10.8, 4.2 Hz, H-6), 3.43 (dt, 1 H, *J* = 7.6, 3.8 Hz, H-5), 3.05 (dd, 1 H, *J* = 10.7, 2.8 Hz, H-6); ^{13}C NMR (63 MHz, $CDCl_3$) δ 140.4, 138.0, 137.8, 137.3, 132.8, 128.9, 128.4, 128.3 (2), 128.0 (2), 127.9, 127.7, 127.6, 127.2, 82.2, 74.6, 73.8, 73.3, 73.2, 71.6, 67.6, 50.4; MS (FAB) *m*/*e* (rel. intensity) 676 (35), 674 (M + Na, 32), 329 (20), 307 (29), 289 (17), 245 (77), 182 (17), 181 (100), 176 (69), 165 (14); HRMS (FAB) calcd for $C_{33}H_{34}BrNNaO_6S$ (M + Na) 674.1190, found 674.1191. Anal. Calcd for $C_{33}H_{34}BrNO_6S$: C, 60.74; H, 5.25; N, 2.15; S, 4.91. Found: C, 60.90; H, 5.32; N, 1.93; S, 5.01. **12**: Recrystallization of the resulting colorless solid (EtOAc/hexanes) gave colorless crystals: mp 149–150.5 °C; $[\alpha]_D$ +36.1° (*c* 1.04, $CHCl_3$); IR (KBr) ν_{max} 3250, 3050, 3020, 2870, 1455, 1335, 1170, 1095, 1045 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.94–7.90 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.53–7.47 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.43–7.37 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.37–7.19 (m, 13 H, Ar*H*), 7.16–7.12 (m, 2 H, Ar*H*), 5.44 (d, 1 H, *J* = 9.5 Hz, N*H*), 4.94 (d, 1 H, *J* = 10.3 Hz, CH*H*Ph), 4.88–4.83 (m, 1 H, H-1), 4.81 (d, 1 H, *J* = 10.3 Hz, CH*H*Ph), 4.75 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.51 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.35 (AB q, 2 H, *J* = 12.1 Hz, ν = 33.5 Hz, CH_2Ph), 3.73–3.66 (m, 2 H, H-2 and H-3), 3.62–3.56 (m, 2 H, H-4 and H-6), 3.42 (ddd, 1 H, *J* = 9.8, 3.5, 1.9 Hz, H-5), 3.37 (dd, 1 H, *J* = 10.9, 1.9 Hz); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.1, 137.7, 137.6, 132.7, 128.7, 128.4, 128.1, 128.0, 127.9, 127.8, 127.3, 85.8, 84.9, 78.5, 76.6, 76.1, 75.0, 73.6, 68.0, 51.8; HRMS (FAB) calcd for $C_{33}H_{34}BrNNaO_6S$ (M + Na) 674.1190, found 674.1199. Anal. Calcd for $C_{33}H_{34}BrNO_6S$: C, 60.74; H, 5.25; N, 2.15; S, 4.91. Found: C, 60.86; H, 5.05; N, 1.98; S, 4.99.

3-*O*-Benzyl-4,6-*O*-benzylidene-2-bromo-2-deoxy-α-D-altropyranosyl Benzenesulfonamide (34a) and 3-*O*-Benzyl-4,6-*O*-benzylidene-2-bromo-2-deoxy-β-D-altropyranosyl Benzenesulfonamide (35a). A solution of 3-*O*-benzyl-4,6-*O*-benzylidene-D-allal (**9**; 852 mg, 2.63 mmol) in CH_2Cl_2 (1 mL) was added dropwise to a stirred suspension of *N*,*N*-dibromobenzenesulfonamide (**4**; 869 mg, 2.76 mmol) in CH_2Cl_2 (2.5 mL) at 0 °C. After 30 min, ethanol (6 mL) and NH_4I (336 mg, 2.92 mmol) were added to the reaction and the resultant mixture was stirred an additional 1.5 h at room temperature. The mixture was reduced with saturated $Na_2S_2O_3$ (50 mL) and extracted with ether (3 × 50 mL). The combined organic layers were dried (Na_2SO_4) and concentrated, and the residue

was chromatographed (silica, 15% EtOAc in hexanes) to afford *trans*-sulfonamide **34a** (860 mg, 61%) followed by *cis*-sulfonamide **35a** (236 mg, 17%) as off-white solids. **34a**: The residue was recrystallized (ether/hexanes) to afford colorless needles: mp 170–170.5 °C; $[\alpha]_D$ +15.8° (*c* 1.11, $CHCl_3$); IR (KBr) ν_{max} 3250, 3050, 3020, 2860, 1450, 1325, 1160, 1105, 1045, 1025, 905 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.88–7.85 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.59–7.54 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.53–7.46 (m, 2 H, $SO_2C(CHCH)_2CH$); 7.42–7.32 (m, 10 H, Ar*H*), 6.91 (d, 1 H, *J* = 10.0 Hz, N*H*), 5.46 (s, 1 H, C*H*Ph), 5.45 (d, 1 H, *J* = 10.0 Hz, H-1), 4.87 (d, 1 H, *J* = 11.7 Hz, CH*H*Ph), 4.74 (d, 1 H, *J* = 11.7 Hz, CH*H*Ph), 4.27 (dd, 1 H, *J* = 9.8, 2.5 Hz, H-4), 4.18 (d, 1 H, *J* = 3.2 Hz, H-2), 4.11 (t, 1 H, *J* = 2.7 Hz, H-3), 3.65 (td, 1 H, *J* = 9.9, 5.1 Hz, H-5), 3.50 (t, 1 H, *J* = 10.2 Hz, H-6_a), 3.30 (dd, 1 H, *J* = 10.2, 5.1 Hz, H-6_e); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.6, 136.7, 137.1, 132.8, 129.2, 129.0, 128.8, 128.5, 128.3, 128.0, 127.1, 126.0, 102.3, 82.7, 76.2, 75.1, 74.3, 68.5, 59.8, 45.3; MS (CI) *m/e* (rel. intensity) 562 (4), 560 (M + 1, 4), 405 (20), 403 (21), 149 (62), 107 (52), 91 (100); HRMS (CI) calcd for $C_{26}H_{27}BrNO_6S$ (M + H) 560.0742, found 560.0707. Anal. Calcd for $C_{26}H_{26}BrNO_6S$: C, 55.72; H, 4.68; N, 2.50; S, 5.72. Found: C, 55.99; H, 4.65; N, 2.37; S, 5.77. **35a**: Recrystallization (ether/hexanes) of the residue produced flaky, colorless crystals: mp 84–91 °C; $[\alpha]_D$ −6.2° (*c* 1.25, $CHCl_3$); IR (KBr) ν_{max} 3270, 3070, 3030, 2970, 2880, 1455, 1365, 1170, 1095 (br), 1010 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.90–7.86 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.58–7.54 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.51–7.47 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.47–7.42 (m, 2 H, Ar*H*), 7.39–7.29 (m, 8 H, Ar*H*), 5.49 (d, 1 H, *J* = 11.0 Hz, N*H*), 5.44 (s, 1 H, C*H*Ph), 5.28 (dd, 1 H, *J* = 11.0, 1.8 Hz, H-1), 4.74 (AB q, *J* = 11.9 Hz, ν = 62.0 Hz, CH_2Ph), 4.20 (dd, 1 H, *J* = 3.0, 1.9 Hz, H-2), 4.15–4.11 (m, 2 H, H3 and H4), 4.00 (td, 1 H, *J* = 9.7, 5.1 Hz, H-5), 3.88 (dd, 1 H, *J* = 10.4, 5.1 Hz, H-6_e), 3.46 (t, 1 H, *J* = 10.3 Hz, H-6_a); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.0, 137.3, 137.1, 132.8, 129.1, 128.8, 128.4, 128.2, 128.0, 127.8, 127.2, 126.1, 102.1, 78.3, 76.6, 75.0, 73.7, 68.3, 65.8, 52.9; MS (CI) *m/e* (rel. intensity) 405 (18), 403 (17), 374 (9), 372 (7), 246 (10), 149 (70), 143 (15), 141 (8), 108 (12), 107 (25), 105 (14), 92 (9), 91 (100), 79 (13), 77 (18); HRMS (CI) calcd for $C_{26}H_{27}BrNO_6S$ (M + H) 560.0742, found 560.0709. Anal. Calcd for $C_{26}H_{26}BrNO_6S$: C, 55.72; H, 4.68; N, 2.50; S, 5.72. Found: C, 56.01; H, 4.95; N, 2.21; S, 5.48.

General Method for I(*sym*-collidine)$_2$ClO$_4$-Mediated Addition of Benzenesulfonamide to Glycals 7–9 and 20. To a 0 °C suspension of glycal, benzenesulfonamide (**6**; 1.2 equiv), and powdered 4-Å molecular sieves (approximately equal to the weight of the glycal) in CH_2Cl_2 (0.1 M in glycal) was added solid I(*sym*-collidine)$_2$ClO$_4$ (**5**; 1.5 equiv). Once TLC indicated that reaction was complete (10–30 min for glucal and galactal, overnight for allal), the mixture was filtered and diluted with ether. The combined organic layers were washed with saturated $Na_2S_2O_3$, saturated $CuSO_4$, and saturated NaCl, dried (Na_2SO_4), and concentrated. Flash chromatography of the resulting residue provided the desired iodosulfonamide.

3,4,6-Tri-*O*-benzyl-2-deoxy-2-iodo-α-D-mannopyranosyl Benzenesulfonamide (13). 3,4,6-Tri-*O*-benzyl-D-glucal (**7**; 654 mg, 1.57 mmol), benzenesulfonamide (**6**; 314 mg, 2.00 mmol), and I(*sym*-collidine)$_2$ClO$_4$ (**5**; 1.21 g, 2.58 mmol) provided **13** (858 mg, 78%) upon workup and flash chromatography (silica, 30% EtOAc in hexanes) as an off-white solid. Recrystallization of the residue (EtOAc/hexanes) provided colorless crystals: mp 123–125 °C; $[\alpha]_D$ −57.2° (*c* 0.990, $CHCl_3$); IR (KBr) ν_{max} 3240, 3060, 3030, 2860, 1450, 1325, 1160, 1100, 1040, 1030 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 7.91–7.84 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.54–7.45 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.54–7.20 (m, 15 H, Ar*H*), 7.17–7.07 (m, 2 H, Ar*H*), 5.83 (d, 1 H, *J* = 8.0 Hz, N*H*), 5.62 (dd, 1 H, *J* = 8.1, 3.5 Hz, H-1), 4.67 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.55 (t, 1 H, *J* = 3.7 Hz, H-2), 4.55 (AB q, 2 H, *J* = 11.5 Hz, ν = 49.3 Hz, CH_2Ph), 4.44 (AB q, 2 H, *J* = 12.1 Hz, ν = 44.8 Hz, CH_2Ph), 4.40 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 3.84 (t, 1 H, *J* = 7.7 Hz, H-4), 3.50 (dd, 1 H, *J* = 10.5, 8.3 Hz, H-6), 3.46–3.39 (m, 1 H, H-5), 3.13 (dd, 1 H, *J* = 7.4, 3.9 Hz, H-3), 3.04 (dd, 1 H, *J* = 10.5, 2.9 Hz, H-6); ^{13}C NMR (63 MHz, $CDCl_3$) δ 140.5, 138.1, 137.8, 137.2, 132.8, 128.9, 128.4, 128.3, 128.2, 128.1, 127.9, 127.8, 127.7, 127.5, 127.3, 83.2, 77.4, 74.7, 74.4, 73.4, 73.3, 71.6, 67.7, 30.9; MS (FAB) *m/e* (rel. intensity) 700 (M + 1, 12), 543 (39), 449 (52), 445 (70), 443 (100), 346 (70), 325 (42), 302 (66), 281 (52), 267 (60), 237 (46); HRMS (FAB) calcd for $C_{33}H_{35}INO_6S$ (M + H) 700.1230, found 700.1190. Anal. Calcd for $C_{33}H_{34}INO_6S$: C, 56.66; H, 4.90; N, 2.00; S, 4.58. Found: C, 56.90; H, 4.81; N, 1.84; S, 4.66.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→6)-3,4-di-*O*-benzyl-2-deoxy-2-iodo-α-D-mannopyranosyl Benzenesulfonamide (25).** Glycal **20** (128 mg, 0.143 mmol), benzenesulfonamide (30.9 mg, 0.196 mmol), and I(*sym*-collidine)$_2$ClO$_4$ (102.0 g, 0.218 mmol) provided **25** (124 mg, 73%) upon workup and flash chromatography (silica, 30% EtOAc in hexanes) as a glass: $[\alpha]_D$ +14.0° (*c* 1.13, $CHCl_3$); IR (KBr) ν_{max} 3270, 3250, 3220, 2870, 1480, 1330, 1160, 1070 (br) cm^{-1}, ^1H NMR (490 MHz, $CDCl_3$) δ 7.95–7.91 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.91–7.86 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.59–7.54 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.51–7.45 (m, 2 H, $SO_2C(CHCH)_2CH$, 7.37–7.13 (m, 26 H, Ar*H*), 7.10–7.05 (m, 2 H, Ar*H*), 6.25 (d, 1 H, *J* = 9.1 Hz, N*H'*), 5.78 (d, 1 H, *J* = 8.4 Hz, N*H*), 5.33 (t, 1 H, *J* = 8.4 Hz, H-1'), 4.70 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.66 (s, 2 H, CH_2Ph), 4.59 (d, 1 H, *J* = 7.0 Hz, H-1), 4.55 (AB q, 2 H, *J* = 12.3 Hz, ν = 35.2 Hz, CH_2Ph), 4.53 (AB q, 2 H, *J* = 11.7 Hz, ν = 49.5 Hz, CH_2Ph), 4.48 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.37 (dd, 1 H, *J* = 7.8, 2.9 Hz, H-2'), 4.34 (AB q, 2 H, *J* = 11.6 Hz, ν = 57.0 Hz, CH_2Ph), 3.90–3.85 (m, 1 H), 3.72–3.49 (m, 8 H), 3.47 (dt, 1 H, *J* = 9.3, 3.5 Hz), 3.20 (dd, 1 H, *J* = 7.0, 3.5 Hz); ^{13}C NMR (63 MHz, $CDCl_3$) δ 142.5, 139.9, 138.2, 138.1, 137.3, 137.1, 133.1, 131.8, 129.0, 128.5, 128.4, 128.3, 128.1, 128.0, 127.9, 127.7, 127.6, 127.5, 127.3, 127.2, 127.0, 102.4, 82.5, 82.2, 78.7, 78.5, 75.3, 74.9, 74.8, 74.6, 73.4, 72.8, 72.4, 69.1, 68.2, 59.6, 29.0; MS (FAB) *m/e* (rel. intensity) 1181 (M + H, 6), 464 (52), 402 (40), 356 (55), 323 (37), 314 (30), 307 (58), 302 (34), 289 (40), 271 (66), 266 (100), 260 (35), 236 (69); HRMS (FAB) calcd for $C_{59}H_{61}IN_2NaO_{12}S_2$ (M + Na) 1203.2611, found 1203.2631. Anal. Calcd for $C_{59}H_{61}IN_2O_{12}S_2$: C, 60.00; H, 5.20; N, 2.37; S, 5.43. Found: C, 59.99; H, 5.17; N, 2.19; S, 5.14.

3,4,6-Tri-*O*-benzyl-2-deoxy-2-iodo-α-D-talopyranosyl Benzenesulfonamide (31). 3,4,6-Tri-*O*-benzyl-D-galactal (**8**; 1.01 g, 2.42 mmol), benzenesulfonamide (**6**; 0.57 g, 2.93 mmol), and I(*sym*-collidine)$_2$ClO$_4$ (**5**; 1.8 g, 3.9 mmol) provided **31** (1.25 g, 74%) upon workup and flash chromatography (silica, 13% EtOAc in toluene). The material was obtained as a yellow solid, which should be stored in a freezer. Recrystallization of the residue (EtOAc/hexanes) provided colorless needles: mp 135.5–136.5 °C (dec); $[\alpha]_D$ −33.1° (*c* 1.13, $CHCl_3$); IR (KBr) ν_{max} 3130, 3060, 3030, 1455, 1340, 1320, 1155, 1140, 1085, 1020 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.93–7.88 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.44–7.20 (m, 18 H, Ar*H*), 5.37 (d, 1 H, *J* = 9.2 Hz, N*H*), 5.44 (t, 1 H, *J* = 8.6 Hz, H-1), 4.72 (AB q, 2 H, *J* = 10.7 Hz, ν = 13.5 Hz, CH_2Ph), 4.56 (AB q, 2 H, *J* = 10.9 Hz, ν = 59.0 Hz, CH_2Ph), 4.41 (AB q, 2 H, *J* = 11.6 Hz, ν = 41.1 Hz, CH_2Ph), 4.18–4.13 (m, 1 H, H-5), 4.10 (dd, 1 H, *J* = 8.1, 3.1 Hz, H-2), 3.88 (br s, 1 H, H-3), 3.81 (br d, 1 H, *J* = 11.1 Hz, H-6), 3.77 (dd, 1 H, *J* = 5.3, 2.5 Hz, H-4), 3.72 (dd, 1 H, *J* = 11.3, 3.4 Hz, H-6); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.1, 138.3, 137.6, 132.6, 128.7, 128.5, 128.3, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 127.5, 127.3, 79.4, 77.7, 75.4, 75.3, 74.8, 73.5, 72.1, 66.9, 28.9; MS (FAB) *m/e* (rel. intensity) 700 (M + 1, 11), 449 (24), 444 (16), 443 (48), 433 (27), 346 (16), 325 (18), 309 (20), 302 (30), 279 (18), 248 (18), 247 (17), 246 (24), 245 (100), 241 (28); HRMS (FAB) calcd for $C_{33}H_{35}INO_6S$ (M + H) 700.1230, found 700.1206. Anal. Calcd for $C_{33}H_{34}INO_6S$: C, 56.66; H, 4.90; N, 2.00; S, 4.58. Found: C, 56.60; H, 4.97; N, 1.95; S, 4.90.

3-*O*-Benzyl-4,6-*O*-benzylidene-2-deoxy-2-iodo-α-D-altropyranosyl Benzenesulfonamide (34b) and 3-*O*-Benzyl-4,6-*O*-benzylidene-2-deoxy-2-iodo-β-D-altropyranosyl Benzenesulfonamide (35b). Following reaction overnight, workup, and flash chromatography (silica, 20 → 25% EtOAc in hexanes), 3-*O*-benzyl-4,6-*O*-benzylidene-D-allal (**9**; 227 mg, 0.700 mmol), benzenesulfonamide (**6**; 135 mg, 0.859 mmol), and I(*sym*-collidine)$_2$ClO$_4$ (**5**; 0.60 g, 1.3 mmol) provided **34b** (212 mg, 50%), than 1:1 mixture of **34b** and **35b** (23.4 mg, 6%), followed by **35b** (73.4 mg, 17%). **34b**: The solid residue was recrystallized from EtOAc/hexanes to give colorless crystals: mp 184–185 °C; $[\alpha]_D$ −32.3° (*c* 1.20, $CHCl_3$); IR (KBr) ν_{max} 3350, 3060, 3030, 2920, 2870, 1455, 1420, 1355, 1280, 1220, 1170, 1120, 1060, 1025 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 7.98–7.86 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.64–7.56 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.56–7.48 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.46–7.33 (m, 10 H, Ar*H*), 6.99 (d, 1 H, *J* = 9.9 Hz, N*H*), 5.50 (s, 1 H, C*H*Ph), 5.49 (d, 1 H, *J* = 9.8 Hz, H-1), 4.80 (AB q, 2 H, *J* = 11.8 Hz, ν 39.0 Hz, CH_2Ph), 4.46 (dd, 1 H, *J* = 9.6, 2.5 Hz, H-4), 4.34 (d, 1 H, *J* = 2.9 Hz, H-2), 4.13 (t, 1 H, *J* = 2.6 Hz, H-3), 3.66 (td, 1 H, *J* = 9.8, 4.9 Hz, H-5), 3.53 (t, 1 H, *J* = 10.0 Hz, H-6_a), 3.29 (dd, 1 H, *J* = 9.9, 4.9 Hz, H-6_e); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.5, 137.0, 136.7, 132.8, 129.2, 129.0, 128.8, 128.5, 128.2, 128.0, 127.1, 126.0, 102.1, 84.1, 77.4, 75.2, 74.0, 68.4, 60.0, 21.5; MS (CI) *m/e* (rel. intensity) 451 (14), 374 (11), 373 (11), 372 (42), 325 (29), 253 (11), 246 (11), 217 (11), 158 (18), 149 (86), 143 (34), 108 (17), 107 (34), 105 (12), 91 (100), 79 (12); HRMS (CI) calcd for $C_{26}H_{27}INO_6S$ (M + H) 608.0604, found 608.0593. Anal. Calcd for $C_{26}H_{26}INO_6S$: C, 51.41; H, 4.31; N, 2.30; S, 5.28. Found: C, 51.55; H, 4.29; N, 2.17; S, 5.58. **35b**: Recrystallization of the residue provided flaky, colorless crystals: mp 121 (dec); $[\alpha]_D$ −35.7° (*c* 1.12 ($CHCl_3$); IR (KBr) ν_{max} 3240, 3060, 3030, 2870, 1455, 1345, 1170, 1140, 1100 (br), 1010 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 7.95–7.87 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.65–7.57 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.55–7.30 (m, 12 H, Ar*H*), 5.48 (s, 1 H, C*H*Ph), 5.29 (d, 1 H, *J* = 11.1 Hz, N*H*), 4.77 (AB q, 2 H, *J* = 11.9 Hz, ν = 23.5 Hz, CH_2Ph), 4.61 (dd, 1 H, *J* = 11.1,

3.7 Hz, H-1), 4.39–4.30 (m, 2 H, H-2 and H-4), 4.19 (t, 1 H, J = 2.6 Hz, H-3), 4.02 (td, 1 H, J = 9.9, 5.0 Hz, H-5), 3.88 (dd, 1 H, J = 10.3, 5.1 Hz, H-6_e), 3.48 (t, 1 H, J = 10.3 Hz, H-6_a); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.1, 137.5, 137.2, 132.9, 129.2, 128.9, 128.5, 128.3, 128.0, 127.8, 127.2, 126.1, 102.2, 78.3, 78.0, 75.2, 73.5, 68.4, 66.4, 34.3; MS (CI) m/e (rel. intensity) 479 (10), 373 (14), 372 (54), 325 (39), 266 (10), 246 (10), 217 (13), 158 (19), 149 (88), 143 (38), 108 (14), 107 (34), 105 (12), 91 (100), 79 (12); HRMS (CI) calcd for $C_{26}H_{27}INO_6S$ (M + H) 608.0604, found 608.0584.

2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-α-D-glucopyranose (15). To a stirred solution of iodosulfonamide **13** (53.3 mg, 0.0761 mmol) in THF/water (10 mL/4 mL) at room temperature was added triethylamine (21 μL, 0.152 mmol). After 4 h, the solution was added to saturated NaCl (20 mL) and the resultant mixture was extracted with ether (2 × 30 mL). The combined organic layers were dried (Na_2SO_4) and concentrated to give an off-white solid, which was highly insoluble in all common solvent except THF. Recrystallization (hexanes/THF) provided **15** as flaky, colorless crystals (36.9 mg, 82%): mp 223–226 °C (dec); $[\alpha]_D$ +24.1 (c 1.08, THF); IR (KBr) ν_{max} 3320, 3250, 3060, 3030, 2910, 2860, 1455, 1325, 1170, 1140, 1100, 1060, 1055, 1030 cm^{-1}; ^{1}H NMR (490 MHz, THF-d_8) δ 7.89–7.84 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.44–7.38 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.35–7.14 (m, 17 H, ArH), 6.94 (d, 1 H, J = 9.7 Hz, NH), 5.93 (dd, 1 H, J = 4.2, 1.3 Hz, OH), 4.92 (t, 1 H, J = 3.8 Hz, H-1), 4.74 (d, 1 H, J = 11.1 Hz, CHHPh), 4.71 (AB q, 2 H, J = 11.0 Hz, ν = 36.5 Hz, CH_2Ph), 4.56 (d, 1 H, J = 11.1 Hz, CHHPh), 4.49 (AB q, 2 H, J = 12.0 Hz, ν = 30.7 Hz, CH_2Ph), 3.95 (ddd, 1 H, J = 10.0, 4.4, 1.6 Hz, H-5), 3.71 (t, 1 H, J = 9.6 Hz, H-3), 3.70 (dd, 1 H, J = 10.8, 4.3 Hz, H-6), 3.60 (dd, 1 H, J = 10.8, 1.8 Hz, H-6), 3.52 (dd, 1 H, J = 9.8, 9.0 Hz, H-4), 3.42 (tdd, 1 H, J = 9.6, 3.4, 1.2 Hz, H-2); ^{13}C NMR (63 MHz, THF-d_8) δ 144.3, 140.1, 140.0, 139.9, 132.3, 129.4, 128.8, 128.7, 128.6, 128.3 (2), 127.9 (2), 127.8, 127.7, 127.5, 93.3, 81.2, 80.0, 75.7, 75.4, 74.0, 71.2, 70.5, 59.5; MS (FAB) m/e (rel. intensity) 464 (3), 314 (3), 308 (4), 307 (18), 290 (3), 289 (10), 266 (4), 245 (7), 220 (4), 219 (8), 186 (4), 181 (14), 167 (4), 166 (5), 165 (6), 163 (3), 156 (4), 155 (23), 154 (100), 153 (7), 152 (10), 150 (4); HRMS (FAB) calcd for $C_{33}H_{36}NO_7S$ (M + H) 590.2212, found 590.2192. Anal. Calcd for $C_{33}H_{35}NO_7S$: C, 67.21; H, 5.98; N, 2.38; S, 5.44. Found: C, 66.90; H, 5.77; N, 2.22; S, 5.19.

General Procedure for Couplings of Iodosulfonamide 13 to Produce Disaccharides 17, 20, 21, 23, and 24. Dropwise addition of lithium tetramethylpiperidine (LTMP; 1 M in THF, 2.2 equiv) to a −78 °C solution of iodosulfonamide **13** and alcohol (1.3 equiv) in THF (0.15 M in iodosulfonamide) was followed after 10 min by dropwise addition of silver trifluoromethanesulfonate (1.4 equiv) in THF (1 M). The reaction was covered with foil, warmed to 0 °C, and allowed to warm to room temperature as the ice bath melted. After several hours (5–15 h), the reaction was stirred with solid NH_4Cl (several equivalent), filtered, and concentrated. Flash chromatography of the resulting residue provided the coupled product.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→6)-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (17).** Reaction of iodosulfonamide **13** (49.9 mg, 0.0713 mmol) and 1,2:3,4-di-*O*-isopropylidene-D-galactopyranose (**16**; 25.1 mg, 0.0964 mmol) gave, following flash chromatography (25% EtOAc in toluene), disaccharide **17** (34.0 mg, 57%) as a foam: $[\alpha]_D$ −36.8° (c 0.54, $CHCl_3$); IR (KBr) ν_{max} 3260, 3040, 3010, 2970, 2890, 1445, 1375, 1325, 1250, 1205, 1145, 1060 (br) cm^{-1}; ^{1}H NMR (490 MHz, $CDCl_3$) δ 7.91–7.86 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.51–7.46 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.43–7.37 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.35–7.24 (m, 13 H, ArH), 7.18–7.14 (m, 2 H, ArH), 5.52 (d, 1 H, J = 5.1 Hz, H-1′), 4.75 (d, 1 H, J = 7.3 Hz, NH), 4.75 (AB q, 2 H, J = 11.0 Hz, ν = 59.9 Hz, CH_2Ph), 4.72 (d, 1 H, J = 11.0 Hz, CHHPh), 4.53 (dd, 1 H, J = 7.9, 2.3 Hz, H-3′), 4.53 (AB q, 2 H, J = 12.1 Hz, ν = 42.5 Hz, CH_2Ph), 4.53 (d, 1 H, J = 11.0 Hz, CHHPh), 4.50 (d, 1 H, J = 6.8 Hz, H-1), 4.29 (dd, 1 H, J = 5.1, 2.3 Hz, H-2′), 4.06 (dd, 1 H, J = 7.9, 1.6 Hz, H-4′), 3.84–3.80 (m, 1 H, H-5′), 3.75–3.66 (m, 4 H), 3.61–3.45 (m, 4 H), 1.55 (s, 3 H, CH_3), 1.40 (s, 3 H, CH_3), 1.34 (s, 3 H, CH_3), 1.28 (s, 3 H, CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.4, 138.0, 137.9, 137.8, 132.1, 128.6, 128.3 (2), 128.0, 127.7, 127.6, 127.3, 109.1, 108.5, 101.2, 96.2, 81.6, 77.7, 74.9, 74.3, 73.4, 70.9, 70.6, 70.3, 68.9, 67.6, 58.4, 26.1, 25.9, 24.8, 24.3; MS (FAB) m/e (rel. intensity) 832 (M + 1, 7), 464 (65), 402 (52), 356 (58), 323 (31), 314 (36), 307 (57), 289 (40), 271 (44), 266 (100), 260 (33), 236 (58); HRMS (FAB) calcd for $C_{45}H_{54}NO_{12}S$ (M + H) 832.3366, found 832.3437. Anal. Calcd for $C_{45}H_{53}NO_{12}S$: C, 64.96; H, 6.21; N, 1.68; S, 3.85. Found: C, 65.03; H, 6.60; N, 1.82; S, 4.06.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→6)-1,5-anhydro-3,4-di-*O*-benzyl-2-deoxy-D-*arabino*-hex-1-enopyranose (20).** Reaction of iodosulfonamide **13** (185 mg, 0.264 mmol) and 3,4-di-*O*-benzyl-D-glucal (**18**; 122 mg, 0.372 mmol) gave, following flash chromatography (25% EtOAc in toluene), disaccharide **20** (133 mg, 56%) as a colorless solid. Recrystallization (ether/hexanes) of a portion provided flaky, colorless crystals: mp 120.5–122.0 °C; $[\alpha]_D$ −16.6° (c 1.00, $CHCl_3$); IR (KBr) ν_{max} 3250, 3050, 3020, 2840, 1640, 1450, 1320, 1155, 1095 cm^{-1}; ^{1}H NMR (490 MHz, $CDCl_3$) δ 7.88–7.84 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.42–7.37 (m, 1 H, $SO_2(CHCH)_2CH$), 7.37–7.20 (m, 25 H, ArH), 7.17–7.13 (m, 2 H, ArH), 6.33 (dd, 1 H, J = 6.2, 1.1 Hz, H-1′), 4.87 (d, 1 H, J = 10.8 Hz, CHHPh), 4.86 (dd, 1 H, J = 6.2, 3.0 Hz, H-2′), 4.79 (d, 1 H, J = 7.5 Hz, NH), 4.73 (d, 1 H, J = 11.0 Hz, CHHPh), 4.72 (d, 1 H, J = 11.7 Hz, CHHPh), 4.67 (d, 1 H, J = 10.8 Hz, CHHPh), 4.56 (d, 1 H, J = 11.7 Hz, CHHPh), 4.53 (AB q, 2 H, J = 11.7 Hz, ν = 42.0 Hz, CH_2Ph), 4.50 (d, 1 H, J = 11.0 Hz, CHHPh), 4.48 (AB q, 2 H, J = 12.1 Hz, CH_2Ph), 4.26 (d, 1 H, J = 7.2 Hz, H-1), 4.06–4.02 (m, 1 H, H-3′), 3.84 (dd, 1 H, J = 11.8, 2.3 Hz, H-6 or H-6′), 3.67–3.62 (m, 4 H), 3.56–3.43 (m, 5 H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 144.2, 141.7, 138.5, 138.4, 138.3, 138.0, 132.2, 128.7, 128.4 (2), 128.2, 127.8, 127.7, 127.6, 127.4, 102.2, 100.0, 81.6, 76.5, 75.2, 74.7, 74.3, 74.2, 73.5, 73.1, 70.3, 69.3, 68.4, 58.4; MS (FAB) m/e (rel. intensity) 790 (38), 464 (59), 356 (45), 314 (34), 307 (100), 289 (59), 271 (52), 266 (96), 260 (32), 236 (49); HRMS (FAB) calcd for $C_{53}H_{55}NNaO_{10}S$ (M + Na) 920.3446, found 920.3382. Anal. Calcd for $C_{53}H_{55}NO_{10}S$: C, 70.88; H, 6.17; N, 1.56; S, 3.57. Found: C, 70.71; H, 6.14; N, 1.48; S, 3.64.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→3)-1,5-anhydro-2-deoxy-4,6-*O*-isopropylidene-D-*arabino*-hex-1-enopyranose (21).** Reaction of iodosulfonamide **13** (52.4 mg, 0.0749 mmol) and 3,4-*O*-isopropylidene-D-glucal (**19**; 16.6 mg, 0.0891 mmol) gave, following flash chromatography (50% EtOAc in hexanes), disaccharide **21** (36.4 mg, 64%) as a foam: $[\alpha]_D$ −32.4° (c 1.00, $CHCl_3$); IR (KBr) ν_{max} 3280, 3060, 3030, 2990, 2890, 1645, 1455, 1365, 1330, 1240, 1205, 1165, 1090 (br) cm^{-1}; ^{1}H NMR (490 MHz, $CDCl_3$) δ 7.90–7.85 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.51–7.45 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.41–7.34 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.32–7.23 (m, 13 H, ArH), 7.19–7.14 (m, 2 H, ArH), 6.18 (dd, 1 H, J = 6.2, 1.3 Hz, H-1′), 4.88 (d, 1 H, J = 8.0 Hz, NH), 4.70 (d, 1 H, J = 11.0 Hz, CHHPh), 4.70 (AB q, 2 H, J = 11.1 Hz, ν = 34.5 Hz, CH_2Ph), 4.55 (d, 1 H, J = 11.0 Hz, CHHPh), 4.53 (AB q, 1 H, J = 12.2 Hz, ν = 20.2 Hz, CH_2Ph), 4.48 (d, 1 H, J = 7.1 Hz, H-1), 4.40 (dd, 1 H, J = 6.2, 1.9 Hz, H-2′), 4.20 (dt, 1 H, J = 7.3, 1.8 Hz, H-3′), 3.89 (dd, 1 H, J = 10.9, 5.6 Hz, H-6_e′), 3.75 (t, 1 H, J = 10.6 Hz, H-6_a′), 3.72–3.67 (m, 4 H), 3.58 (td, 1 H, J = 10.4, 5.6 Hz, H-5′), 3.55–3.49 (m, 2 H), 3.46 (q, 1 H, J = 7.9 Hz, H-2), 1.41 (s, 3 H, CH_3), 1.34 (s, 3 H, CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 144.3, 141.5, 138.1, 137.8, 137.7, 132.2, 128.8, 128.4, 128.3, 128.1, 127.9, 127.8, 127.7, 127.6, 127.3, 101.1, 99.7, 99.2, 81.1, 75.1, 74.3, 74.1, 73.5, 73.1, 70.8, 69.6, 69.0, 61.5, 58.4, 29.0, 19.0; MS (FAB) m/e (rel. intensity) 572 (19), 554 (23), 464 (58), 402 (41), 374 (22), 356 (45), 326 (24), 323 (25), 314 (46), 308 (29), 307 (99), 289 (73), 272 (22), 271 (45), 266 (100), 260 (22), 236 (57); HRMS (FAB) calcd for $C_{42}H_{48}NO_{10}S$ (M + H) 758.2999, found 758.3023. Anal. Calcd for $C_{42}H_{47}NO_{10}S$: C, 66.56; H, 6.25; N, 1.85; S, 4.23. Found: C, 66.66; H, 6.33; N, 1.97; S, 4.47.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-glucopyranosyl]-α-(1→1′)-2-(benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-β-D-glucopyranoside (23).** Reaction of iodosulfonamide **13** (31.5 mg, 0.0450 mmol) and **15** (25.7 mg, 0.0436 mmol) gave, following flash chromatography (20% EtOAc in toluene), trehalose **23** (9.1 mg, 18%) as a glass. Flash chromatography (33% EtOAc in hexanes) of the residue provided an analytically pure glass: $[\alpha]_D$ +43.5° (c 1.36, $CHCl_3$); IR (neat) ν_{max} 3260, 3060, 3030, 2910, 2870, 1455, 1360, 1325, 1160, 1040 (br) cm^{-1}; ^{1}H NMR (490 MHz, $CDCl_3$) δ 7.95–7.92 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.85–7.81 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.47–7.42 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.41–7.36 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.35–7.30 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.30–7.17 (m, 25 H, ArH), 7.12–7.06 (m, 5 H, ArH), 7.02–6.99 (m, 2 H, ArH), 6.82 (d, 1 H, J = 9.7 Hz, NH), 5.14 (d, 1 H, J = 3.5 Hz, H-1), 4.93 (d, 1 H, J = 8.4 Hz, NH′), 4.75 (d, 1 H, J = 11.0 Hz, CHHPh), 4.70 (AB q, 2 H, J = 10.9 Hz, ν = 9.9 Hz, CH_2Ph), 4.64 (d, 1 H, J = 11.7 Hz, CHHPh), 4.59 (AB q, 2 H, J = 11.0 Hz, ν = 46.0 Hz, CH_2Ph), 4.52 (d, 1 H, J = 12.1 Hz, CHHPh), 4.51 (AB q, 2 H, J = 12.1 Hz, ν = 14.5 Hz, CH_2Ph), 4.47 (d, 1 H, J = 11.0 Hz, CHHPh), 4.46 (d, 1 H, J = 8.0 Hz, H-1′), 4.40 (d, 1 H, J = 11.7 Hz, CHHPh), 4.37 (d, 1 H, J = 12.1 Hz, CHHPh), 4.07 (dt, 1 H, J = 10.2, 2.3 Hz, H-5 or H-5′), 3.91 (dd, 1 H, J = 10.3 Hz, H-3 or H-3′), 3.75–3.63 (m, 7 H), 3.45 (dd, 1 H, J = 10.7, 3.7 Hz, H-6 or H-6′), 3.44 (dt, 1 H, J = 9.5, 2.8 Hz, H-5 or H-5′), 3.34 (dd, 1 H, J = 10.0, 8.7 Hz, H-3 or H-3′); MS (FAB) m/e (rel. intensity) 1183 (M + Na, 14), 464 (16), 448 (20), 447 (68), 356 (16), 307 (25), 289 (20), 266 (28), 236 (17), 182 (19), 181 (100), 167 (30), 166 (14), 165 (18); HRMS (FAB) calcd for $C_{66}H_{68}N_2NaO_{13}S_2$ (M + Na) 1183.4063, found 1183.4122. Anal. Calcd for $C_{66}H_{68}N_2O_{13}S_2$: C, 68.26; H, 5.90; N, 2.41; S, 5.52. Found: C, 67.99; H, 5.89; N, 2.35; S, 5.37.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-gluco-**

pyranosyl]-β-(1→4)-1,5-anhydro-3,6-di-*O*-benzoyl-2-deoxy-D-*arabino*-hex-1-enopyranose (24). Reaction of iodosulfonamide **13** (101.2 mg, 0.145 mmol) and 3,6-di-*O*-benzoyl-D-glucal (**22**; 74.8 mg, 0.211 mmol) gave, following flash chromatography (50% ether in hexanes and then 33% EtOAc in hexanes), disaccharide **24** (30.7 mg, 23%) as a colorless glass: $[\alpha]_D$ −44.6° (*c* 1.04, $CHCl_3$); IR (KBr) ν_{max} 3290, 3060, 3030, 2870, 1740, 1645, 1455, 1315, 1275, 1160, 1100, 1070 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 8.04–7.98 (m, 4 H, $CO_2C(CHCH)_2CH$), 7.85–7.81 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.59–7.50 (m, 2 H, $CO_2C(CHCH)_2CH$), 7.45–7.33 (m, 7 H, $CO_2C(CHCH)_2CH$) and $SO_2C(CHCH)_2CH$), 7.31–7.18 (M, 13 H, Ar*H*), 7.09–7.04 (m, 2 H, Ar*H*), 6.43 (dd, 1 H, *J* = 6.1, 1.2 Hz, H-1′), 5.58 (ddd, 1 H, *J* = 5.6, 3.2, 1.0 Hz, H-3′), 5.02 (d, 1 H, *J* = 8.4 Hz, N*H*), 4.84 (dd, 1 H, *J* = 6.1, 3.2 Hz, H-2′), 4.72 (AB q, 2 H, *J* = 10.9 Hz, ν = 53.5 Hz, CH_2Ph), 4.64 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.56 (dd, 1 H, *J* = 12.1, 5.0 Hz, H-6′), 4.48 (d, 1 H, *J* = 7.7 Hz, H-1), 4.43 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.36 (dd, 1 H, *J* = 12.1 Hz, H-6′), 4.29 (AB q, 2 H, *J* = 12.0 Hz, ν = 37.3 Hz, CH_2Ph), 4.04 (dd, 1 H, *J* = 8.1, 5.7 Hz, H-4′), 3.74 (ddd, 1 H, *J* = 8.2, 4.8, 3.0 Hz, H-5′), 3.55 (t, 1 H, *J* = 8.3 Hz, H-4), 3.55 (q, 1 H, *J* = 8.4 Hz, H-2), 3.45 (dd, 1 H, *J* = 10.7, 2.8 Hz, H-6), 3.44 (t, 1 H, *J* = 8.5 Hz, H-3), 3.39 (dd, 1 H, *J* = 10.6, 4.9 Hz, H-6), 3.33 (ddd, 1 H, *J* = 8.7, 4.8, 3.0 Hz, H-5); ^{13}C NMR (63 MHz, $CDCl_3$) δ 166.4, 165.9, 145.7, 141.8, 138.1, 137.7, 133.4, 133.1, 130.1, 129.8, 129.5, 128.7, 128.5, 128.4, 128.3, 128.2, 127.9, 127.8, 127.7, 127.5, 127.3, 100.6, 99.2, 81.9, 77.6, 75.1, 74.7, 74.6, 74.4, 73.2, 73.1, 68.8, 68.5, 62.2, 59.1; MS (FAB) *m/e* (rel. intensity) 554 (17), 464 (49), 404 (19), 402 (46), 374 (25), 356 (49), 326 (19), 323 (30), 314 (37), 307 (59), 289 (31), 284 (18), 271 (35), 266 (100), 260 (41), 236 (62), 233 (44); HRMS (FAB) calcd for $C_{53}H_{51}NNaO_{12}S$ (M + Na) 948.3031, found 948.3040. Anal. Calcd for $C_{53}H_{51}NO_{12}S$: C, 68.74; H, 5.55; N, 1.51; S, 3.46. Found: C, 68.58; H, 5.51; N, 1.46; S, 3.59.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→6)-*O*-[2-(benzenesulfonamido)-3,4-di-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→6)-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (26).** Dropwise addition of LTMP (0.44 mmol, 3.2 equiv) in THF (0.2 mL) to a −78 °C solution of iodosulfonamide **25** (164 mg, 0.139 mmol) and 1,2:3,4-di-*O*-isopropylidene-D-galactopyranose (**16**; 54.6 mg, 0.210 mmol) in THF (0.8 mL) was followed after 10 min by dropwise addition of silver trifluoromethanesulfonate (55.6 mg, 0.216 mmol) in THF (0.3 mL). The reaction was covered with foil, warmed to 0 °C, and allowed to warm to room temperature as the ice bath melted. After being stirred overnight, the reaction was quenched with solid NH_4Cl (several equivalents), filtered, and concentrated. Flash chromatography (35% EtOAc in toluene) of the residue provided trisaccharide **26** (94.7 mg, 52%) as a colorless glass: $[\alpha]_D$ −37.2° (*c* 1.30, $CHCl_3$); IR (neat) ν_{max} 3280, 3060, 3030, 2900 (br), 1455, 1330, 1165, 1095, 1075 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.90–7.83 (m, 4 H, $SO_2C(CHCH)_2CH$), 7.49–7.44 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.42–7.19 (m, 28 H, Ar*H*), 7.15–7.10 (m, 2 H, Ar*H*), 5.57 (d, 1 H, *J* = 5.1 Hz, H-1″), 4.76 (d, 1 H, *J* = 7.1 Hz, N*H* or N*H*′), 4.71 (d, 1 H, *J* = 10.8 Hz, CH*H*Ph), 4.71 (AB q, 2 H, *J* = 10.8 Hz, ν = 30.8 Hz, CH_2Ph), 4.71 (d, 1 H, *J* = 7.4 Hz, N*H* or N*H*′), 4.64 (AB q, 2 H, *J* = 11.2 Hz, ν = 35.1 Hz, CH_2Ph), 4.63 (d, 1 H, *J* = 11.2 Hz, CH*H*Ph), 4.52 (dd, 1 H, *J* = 7.9, 2.3 Hz, H-3″), 4.51 (d, 1 H, *J* = 10.8 Hz, CH*H*Ph), 4.50 (AB q, 2 H, *J* = 12.1 Hz, CH_2Ph), 4.42 (d, 1 H, *J* = 11.2 Hz, CH*H*Ph), 4.41 (d, 1 H, *J* = 6.6 Hz, H-1 or H-1′), 4.34 (d, 1 H, *J* = 7.7 Hz, H-1 or H-1′), 4.28 (dd, 1 H, *J* = 5.1, 2.3 Hz, H-2″), 4.03 (dd, 1 H, *J* = 7.9, 1.9 Hz, H-4″), 3.81 (ddd, 1 H, *J* = 6.8, 4.3, 1.4 Hz, H-5″), 3.73 (dd, 1 H, *J* = 11.9, 2.9 Hz, H-6 or H-6′), 3.70 (dd, 1 H, *J* = 11.4, 4.3 Hz, H-6″), 3.68–3.63 (m, 3 H), 3.54 (dt, 1 H, *J* = 9.3, 7.8 Hz, H-2 or H-2′), 3.50 (dd, 1 H, *J* = 11.2, 6.8 Hz, H-6″), 3.48–3.38 (m, 5 H), 3.35 (t, 1 H, *J* =7.8 Hz, H-4 or H-4′), 3.12 (ddd, 1 H, *J* = 8.3, 7.1, 3.0 Hz, H-5 or H-5′), 1.53 (s, 3 H, CH_3), 1.40 (s, 3 H, CH_3), 1.33 (s, 3 H, CH_3), 1.26 (s, 3 H, CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.9, 141.5, 138.1, 137.8, 137.7, 132.2, 128.6, 128.4, 128.3, 128.0, 127.8, 127.7, 127.6, 127.2, 109.3, 108.6, 102.0, 100.2, 96.2, 82.0, 80.8, 77.7, 77.6, 75.2, 74.8, 74.5, 74.3, 74.0, 73.7, 73.4, 71.1, 70.6, 70.4, 68.8, 67.5, 67.2, 58.9, 57.6, 26.1, 26.0, 24.8, 24.2; HRMS (FAB) calcd for $C_{71}H_{80}N_2NaO_{18}S_2$ (M + Na) 1335.4748, found 1335.4775. Anal. Calcd for $C_{71}H_{80}N_2O_{18}S_2$: C, 64.92; H, 6.14; N, 2.13; S, 4.88. Found: C, 65.04; H, 5.96; N, 1.95; S, 5.11.

***O*-[2-(Benzenesulfonamido)-3,4,6-tri-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→6)-*O*-[2-(benzenesulfonamido)-3,4-di-*O*-benzyl-2-deoxy-D-glucopyranosyl]-β-(1→3)-1,5-anhydro-2-deoxy-4,6-*O*-[isopropylidene-D-*arabino*-hex-1-enopyranose (27).** Dropwise addition of LTMP (0.28 mmol, 3.2 equiv) in THF (0.15 mL) to a −78 °C solution of iodosulfonamide **25** (103 mg, 0.0872 mmol) and 3,4-*O*-isopropylidene-D-glucal (**19**; 27 mg, 0.14 mmol) in THF (0.65 mL) was followed after 10 min by dropwise addition of silver trifluoromethanesulfonate (61 mg, 0.28 mmol) in THF (0.2 mL). The reaction was covered with foil, warmed to 0 °C, and allowed to slowly warm to room temperature. After being stirred overnight, the reaction was treated with solid NH_4Cl (several equivalents), filtered, and concentrated. Flash chromatography (50% EtOAc in hexanes and then 50% ether in hexanes → 40% ether in CH_2Cl_2) of the residue gave trisaccharide **27** (68.4 mg, 63%) as a colorless glass: mp 82–85 °C; $[\alpha]_D$ −35.2 (*c* 1.22, $CHCl_3$); IR (KBr) ν_{max} 3280, 3250, 3220, 2870, 1640, 1450, 1330, 1160, 1095, 1070 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.87–7.84 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.84–7.80 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.51–7.46 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.40–7.17 (m, 28 H, Ar*H*), 7.10–7.06 (m, 2 H, Ar*H*), 6.08 (dd, 1 H, *J* = 6.1, 0.9 Hz, H-1″), 5.24 (d, 1 H, *J* = 8.0 Hz, N*H* or N*H*′), 4.90 (d, 1 H, *J* = 7.8 Hz, N*H* or N*H*′), 4.76 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.68 (d, 1 H, *J* = 11.0 Hz, CH*H*Ph), 4.66 (AB q, 2 H, *J* = 11.0 Hz, ν = 19.7 Hz, CH_2Ph), 4.64 (d, 1 H, *J* = 11.3 Hz, CH*H*Ph), 4.53 (d, 1 H, *J* = 10.9 Hz, CH*H*Ph), 4.50 (AB q, 2 H, *J* = 12.1 Hz, ν = 47.0 Hz, CH_2Ph), 4.50 (dd, 1 H, *J* = 6.5, 1.9 Hz, H-2″), 4.48 (d, 1 H, *J* = 11.0 Hz, CH*H*Ph), 4.42 (d, 1 H, *J* = 11.3 Hz, CH*H*Ph), 4.27 (d, 1 H, *J* = 7.8 Hz, H-1 or H-1′), 4.24 (d, 1 H, *J* = 7.0 Hz, H-1 or H-1′), 4.17 (dt, 1 H, *J* = 7.5, 1.5 Hz, H-3′), 3.87 (dd, 1 H, *J* = 10.8, 5.4 Hz, $H\text{-}6_e''$), 3.81 (dd, 1 H, *J* = 12.1, 2.5 Hz, H-6 or H-6′), 3.70 (t, 1 H, *J* = 10.5 Hz, $H\text{-}6_a''$), 3.64–3.57 (m, 5 H), 3.53 (dt, 1 H, *J* = 9.3, 7.8 Hz, H-2 or H-2′), 3.46–3.33 (m, 6 H), 3.31 (dd, 1 H, *J* = 10.4, 7.5 Hz, H-4″), 3.14 (td, 1 H, *J* = 7.7, 2.0 Hz, H-5 or H-5′), 1.38 (s, 3 H, CH_3), 1.36 (s, 3 H, CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 144.5, 141.7, 141.6, 138.0, 137.8, 137.8, 132.2, 132.0, 128.7, 128.6, 128.3, 128.2, 127.9, 127.8, 127.7, 127.6, 127.4, 127.2, 102.4, 100.4, 99.8, 98.0, 82.1, 81.6, 77.8, 77.5, 74.8, 74.7, 74.4, 74.2, 74.1, 73.4, 71.7, 70.4, 69.5, 68.9, 68.7, 61.5, 59.1, 58.2, 29.3, 19.2; HRMS (FAB) calcd for $C_{68}H_{74}N_2NaO_{16}S_2$ (M + Na) 1261.4380, found 1261.4351. Anal. Calcd for $C_{68}H_{74}N_2O_{16}S_2$: C, 65.90; H, 6.02; N, 2.26; S, 5.17. Found: C, 65.78; H, 6.13; N, 2.23; S, 5.17.

***O*-(2-Acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-D-glucopyranosyl)-β-(1→6)-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (28).** To a −78 °C solution of **17** (127 mg, 0.153 mmol) in THF (2 mL) was added ammonia (20 mL). Small pieces of sodium were added until a deep blue color was maintained for 25 min, after which solid NH_4Cl was added. After evaporation of the ammonia, the residue was treated with methanol, filtered, and concentrated. A solution of the crude product in DMF (7 mL) was treated with triethylamine (1 mL, 7.2 mmol), acetic anhydride (0.5 mL, 5.4 mmol), and DMAP (10 mg, 0.082 mmol). After being stirred for 10 h, the mixture was diluted with water (70 mL) and extracted with ethyl acetate (4 × 25 mL), and the combined organic layers were dried (Na_2SO_4), concentrated, and chromatographed (ethyl acetate) to afford **28** (70.1 mg, 78%) as a glass: $[\alpha]_D$ −55.8° (*c* 0.955, $CHCl_3$); IR (neat) ν_{max} 3280, 2980, 2940, 1745, 1665, 1550, 1435, 1375, 1225 (br), 1170, 1070, 1045 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 5.54 (d, 1 H, *J* = 8.9 Hz, N*H*), 5.53 (d, 1 H, *J* = 5.1 Hz, H-1′), 5.15 (t, 1 H, *J* = 9.7 Hz, H-3), 5.10 (t, 1 H, *J* = 9.5 Hz, H-4), 4.69 (d, 1 H, *J* = 8.5 Hz, H-1), 4.58 (dd, 1 H, *J* = 7.9, 2.4 Hz, H-3′), 4.31 (dd, 1 H, *J* = 5.1, 2.4 Hz, H-2′), 4.26 (dd, 1 H, *J* = 12.3, 4.6 Hz, H-6), 4.15 (dd, 1 H, *J* = 7.9, 1.7 Hz, H-4′), 4.13 (dd, 1 H, *J* = 12.3, 2.4 Hz, H-6), 4.02 (dt, 1 H, *J* = 10.0, 8.7 Hz, H-2), 4.01–3.93 (m, 2 H, H-6′ and H-5′), 3.74 (dd, 1 H, *J* = 13.0, 9.2 Hz, H-6′), 3.68 (ddd, 1 H, *J* = 9.6, 4.6, 2.5 Hz, H-5), 2.08 (s, 3 H, $COCH_3$), 2.02 (s, 3 H, $COCH_3$), 2.01 (s, 3 H, $COCH_3$), 1.96 (s, 3 H, $COCH_3$), 1.51 (s, 3 H, O_2CMeCH_3), 1.44 (s, 3 H, O_2CMeCH_3), 1.32 (s, 3 H, O_2CMeCH_3), 1.32 (s, 3 H, O_2CMeCH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 170.9, 170.6, 170.3, 169.2, 109.3, 108.6, 101.8, 96.2, 73.1, 71.8, 71.0, 70.6, 70.2, 68.9, 68.5, 68.3, 62.0, 54.1, 26.0, 25.9, 24.9, 24.2, 23.2, 20.6, 20.5; MS (CI) *m/e* (rel. intensity) 590 (M + 1, 19), 530, (8), 470 (10), 331 (15), 330 (100), 270 (10), 210 (12), 150 (12), 143 (12), 139 (10), 101 (17), 85 (10), 81 (9); HRMS (CI) calcd for $C_{26}H_{40}NO_{14}$ (M + H) 590.2448; found 590.2455. Anal. Calcd for $C_{26}H_{39}NO_{14}$: C, 52.96; H, 6.67; N, 2.38. Found: C, 52.93; H, 6.82; N, 2.38.

***O*-(2-Acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-D-glucopyranosyl)-β-(1→6)-*O*-(2-acetamido-3,4-di-*O*-acetyl-2-deoxy-D-glucopyranosyl)-β-(1→6)-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (29).** To a −78 °C solution of **25** (127 mg, 0.153 mmol) in THF (0.5 mL) was added ammonia (4 mL). Small pieces of sodium were added until a deep blue color was maintained for 20 min, after which solid NH_4Cl was added. The residue, following evaporation of the ammonia, was treated with methanol at 0 °C, filtered, and concentrated. A solution of the crude product in DMF (1 mL) was treated with triethylamine (0.6 mL, 4.3 mmol), acetic anhydride (0.2 mL, 2.1 mmol), and DMAP (13 mg, 0.11 mmol). After being stirred for 10 h, the mixture was diluted with water (10 mL), and extracted with ethyl acetate (9 × 10 mL), and the combined organic layers were dried (Na_2SO_4), concentrated, and chromatographed (EtOAc) to afford **29** (34.6 mg, 56%) as a white solid. Recrystallization (EtOAc/MeOH/hexanes) afforded colorless crystals: mp 246–248 °C (dec); $[\alpha]_D$ −48.2° (*c* 1.03, $CHCl_3$); IR (KBr) ν_{max} 3290, 3100, 3010, 2960, 1760, 1665, 1570, 1385, 1255, 1235, 1080, 1055 cm^{-1}; ^1H NMR

(490 MHz, $CDCl_3$) δ 6.15 (d, 1 H, J = 8.9 Hz, NH or NH'), 5.77 (d, 1 H, J = 8.9 Hz, NH or NH'), 5.55 (d, 1 H, J = 5.0 Hz, H-1''), 5.16 (dd, 1 H, J = 10.4, 9.3 Hz, H-3), 5.15 (dd, 1 H, J = 10.4, 9.3 Hz, H-3'), 5.05 (t, 1 H, J = 9.6 Hz, H-4), 4.99 (t, 1 H, J = 9.6 Hz, H-4'), 4.64 (d, 1 H, J = 8.5 Hz, H-1 or H-1'), 4.58 (dd, 1 H, J = 7.9, 2.3 Hz, H-3''), 4.55 (d, 1 H, J = 8.4 Hz, H-1 or H-1'), 4.31 (dd, 1 H, J = 5.0, 2.3 Hz, H-2''), 4.26 (dd, 1 H, J = 12.3, 4.8 Hz, H-6), 4.17 (dd, 1 H, J = 8.0, 1.7 Hz, H-4''), 4.12 (dd, 1 H, J = 12.3, 2.4 Hz, H-6), 4.06–3.92 (m, 5 H, H-2, H-2', H-5'', H-6', and H-6''), 3.74 (dd, 1 H, J = 12.1, 9.0 Hz, H-6''), 3.69–3.62 (m, 2 H, H-5 and H-5'), 3.50 (dd, 1 H, J = 11.6, 6.0 Hz, H-6'), 2.09 (s, 3 H, $COCH_3$), 2.03 (s, 3 H, $COCH_3$), 2.02 (s, 3 H, $COCH_3$), 2.01 (s, 3 H, $COCH_3$), 2.01 (s, 3 H, $COCH_3$), 1.98 (s, 3 H, $COCH_3$), 1.96 (s, 3 H, $COCH_3$), 1.50 (s, 3 H, $CMeCH_3$), 1.46 (s, 3 H, $CMeCH_3$), 1.32 (s, 3 H, $CMeCH_3$), 1.32 (s, 3 H, $CMeCH_3$); ^{13}C NMR (63 MHz, $CDCl_3$) δ 170.8, 170.7, 170.6, 170.3, 169.8, 169.3, 109.3, 108.6, 101.7, 101.1, 96.2, 73.2, 73.0, 71.8, 71.0, 70.6, 70.3, 68.9, 68.6, 68.0, 67.8, 62.0, 53.9, 53.6, 26.1, 26.0, 24.9, 24.2, 23.2, 23.0, 20.6; MS (FAB) m/e (rel. intensity) 877 (M + H, 4), 619 (7), 618 (30), 617 (100), 497 (9), 331 (10), 330 (63), 307 (8), 289 (8), 288 (14), 228 (10), 210 (33); HRMS (FAB) calcd for $C_{38}H_{56}N_2NaO_{21}$ (M + Na) 899.3275, found 899.3284. Anal. Calcd for $C_{38}H_{56}N_2O_{21}$: C, 52.05; H, 6.44; N, 3.19. Found: C, 51.90; H, 6.20; N, 2.91.

S-Ethyl 2-(Benzenesulfonamido)-3,4,6-tri-O-benzyl-2-deoxy-1-thio-β-D-glucopyranoside (30). Lithium hexamethyldisilazide (LHMDS; 1.0 M in THF, 0.462 mmol) was added dropwise to a stirred solution of ethanethiol (57 μL, 0.770 mmol) in dry DMF (1.5 mL) at −40 °C, followed by dropwise addition of iodosulfonamide **13** (107.6 mg, 0.154 mmol) in DMF (1 mL). After 1 h, the cooling bath was removed and the reaction was stirred an additional 4 h. The reaction was diluted with ether (100 mL), washed with saturated NH_4Cl (30 mL) and water (3 × 30 mL), dried (Na_2SO_4), concentrated, and flash chromatographed (33% EtOAc in hexanes) to afforded **30** (82.1 mg, 85%) as a solid. Recrystallization (hexanes/EtOAc) of a sample provided colorless needles: mp 137–138.5 °C; $[\alpha]_D$ −35.4° (c 1.12, $CHCl_3$); IR (KBr) ν_{max} 3320, 3290, 3060, 3030, 2920, 2860, 1330, 1160, 1070 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.90–7.85 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.41–7.36 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.35–7.18 (m, 15 H, ArH), 7.12–7.06 (m, 2 H, ArH), 5.13 (d, 1 H, J = 8.0 Hz, NH), 4.66 (d, 1 H, J = 10.9 Hz, CHPh), 4.65 (AB q, 2 H, J = 11.0 Hz, ν = 30.4 Hz, CH_2Ph), 4.52 (AB q, 1 H, J = 12.1 Hz, ν = 18.3 Hz, CH_2Ph), 4.50 (d, 1 H, J = 10.9 Hz, CHPh), 4.37 (d, 1 H, J = 9.1 Hz, H-1), 3.68 (dd, 1 H, J = 10.8, 2.8 Hz, H-6), 3.64 (dd, 1 H, J = 10.9, 4.7 Hz, H-6), 3.63 (t, 1 H, J = 8.3 Hz, H-4), 3.60–3.52 (m, 2 H, H-2 and H-3), 3.49 (ddd, 1 H, J = 8.7, 4.6, 2.9 Hz, H-5), 2.6–2.4 (m, 2 H, SCH_2CH_3), 1.13 (t, 3 H, J = 7.4 Hz, SCH_2CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.5, 138.1, 137.9, 137.8, 132.2, 128.6, 128.3, 128.2, 127.7, 127.6, 127.5, 127.4, 127.2, 84.3, 83.4, 79.1, 77.9, 74.6, 74.3, 73.3, 69.2, 58.5, 24.4, 14.6; MS (EI) m/e (rel. intensity) 480 (18), 430 (16), 356 (19), 326 (14), 324 (11), 323 (17), 271 (19), 266 (32), 260 (20), 254 (20), 253 (96), 236 (22), 207 (13), 182 (15), 181 (100); HRMS (FAB) calcd for $C_{35}H_{39}NNaO_6S_2$ (M + Na) 656.2118, found 656.2073. Anal. Calcd for $C_{35}H_{39}NO_6S_2$: C, 66.33; H, 6.20; N, 2.21; S, 10.12. Found: C, 66.29; H, 6.20; N, 2.16; S, 10.19.

O-[2-(Benzenesulfonamido)-3,4,5-tri-O-benzyl-2-deoxy-D-galactopyranosyl]-β-(1→6)-1,2:3,4-di-O-isopropylidene-α-D-galactopyranose (32). Dropwise addition of LTMP (0.30 mmol, 2.2 equiv) in THF (0.3 mL) to a −78 °C solution of iodosulfonamide **31** (94.6 mg, 0.135 mmol) and 1,2:3,4-di-O-isopropylidene-D-galactopyranose (**16**; 52 mg, 0.20 mmol) in THF (1 mL) was followed after 10 min by dropwise addition of silver trifluoromethanesulfonate (52 g, 0.20 mmol) in THF (0.2 mL). The reaction was covered with foil and allowed to warm to room temperature. After being stirred overnight, the reaction was stirred with solid NH_4Cl (several equivalents), filtered, and concentrated. Flash chromatography (25% EtOAc in toluene) of the resulting oil provided disaccharide **32** (33.9 mg, 30%) as a glass: $[\alpha]_D$ −32.8° (c 0.85, $CHCl_3$); IR (neat) ν_{max} 3280, 3060, 3030, 2990, 2910 (br), 1455, 1380, 1330, 1260, 1215, 1165, 1200, 1175 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.90–7.85 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.46–7.40 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.36–7.21 (m, 17 H, ArH), 5.51 (d, 1 H, J = 5.1 Hz, H-1'), 4.78 (d, 1 H, J = 11.5 Hz, CHPh), 4.61 (d, 1 H, J = 6.0 Hz, NH), 4.56 (d, 1 H, J = 11.7 Hz, CHPh), 4.53 (dd, 1 H, J = 8.0, 2.3 Hz, H-3'), 4.50 (d, 1 H, J = 11.5 Hz, CHPh), 4.42 (AB q, 2 H, J = 11.7 Hz, ν = 15.8 Hz, CH_2Ph), 4.41 (d, 1 H, J = 8.2 Hz, H-1), 4.40 (d, 1 H, J = 11.7 Hz, CHPh), 4.27 (dd, 1 H, J = 5.1, 2.3 Hz, H-2'), 4.14 (dd, 1 H, J = 7.9, 1.8 Hz, H-4'), 3.93–3.87 (m, 2 H), 3.76 (dd, 1 H, J = 11.4, 4.5 Hz), 3.74 (ddd, 1 H, J = 10.7, 8.2 6.0 Hz, H-2), 3.62–3.48 (m, 4 H), 3.46 (dd, 1 H, J = 10.7, 5.3 Hz, H-3), 1.55 (s, 3 H, CH_3), 1.40 (s, 3 H, CH_3), 1.32 (s, 3 H, CH_3), 1.28 (s, 3 H, CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 141.7, 138.6, 138.0, 137.8, 132.0, 128.8, 128.5, 128.4, 128.2, 128.0, 127.9, 127.8, 127.7, 127.6, 127.5, 127.3, 109.2, 108.7, 102.0, 96.3, 80.1, 74.5, 73.6 (2), 72.2, 71.8, 71.2, 70.8, 70.6, 68.6, 67.9, 67.8, 56.6, 26.2, 26.0, 25.0, 24.4; HRMS (FAB) calcd for $C_{45}H_{53}NNaO_{12}S$ (M + Na) 854.3188, found 854.3179. Anal. Calcd for $C_{45}H_{53}NO_{12}S$: C, 64.96; H, 6.21; N, 1.68; S, 3.85. Found: C, 64.81; H, 6.27; N, 1.59; S, 3.87.

O-[2-(Benzenesulfonamido)-3,4,6-tri-O-benzyl-2-deoxy-D-galactopyranosyl]-β-(1→3)-1,5-anhydro-2-deoxy-4,6-isopropylidene-D-*arabino*-hex-1-enopyranose (33). Dropwise addition of LTMP (0.34 mmol, 2.2 equiv) in THF (0.3 mL) to a −78 °C solution of iodosulfonamide **31** (109.6 mg, 0.157 mmol) and 3,4-O-isopropylidene-D-glucal (**19**; 43.5 mg, 0.234 mmol) in THF (1 mL) was followed after 10 min by dropwise addition of silver trifluoromethanesulfonate (53 mg, 0.21 mmol) in THF (0.2 mL). The reaction was covered with foil and allowed to warm to room temperature. After being stirred overnight, the reaction was stirred with solid NH_4Cl (several equivalents), filtered, and concentrated. Flash chromatography (25% EtOAc in toluene) of the resulting oil provided disaccharide **33** (37.3 mg, 31%) as a solid. Recrystallization (hexanes/EtOAc) afforded colorless crystals: mp 140–141.5 °C; $[\alpha]_D$ −12.5 (c 0.95, $CHCl_3$); IR (KBr) ν_{max} 3300, 3060, 3030, 2990, 2910, 2880, 1650, 1455, 1330, 1165, 1100 cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.85–7.81 (m, 2 H, $SO_2C(CHCH)_2CH$), 7.44–7.39 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.38–7.16 (m, 17 H, ArH), 6.20 (dd, 1 H, J = 6.0, 1.5 Hz, H-1'), 4.89 (d, 1 H, J = 6.4 Hz, NH), 4.75 (d, 1 H, J = 11.4 Hz, CHPh), 4.64 (dd, 1 H, J = 6.2, 2.0 Hz, H-2'), 4.55 (d, 1 H, J = 11.6 Hz, CHPh), 4.49 (d, 1 H, J = 8.3 Hz, H-1), 4.48 (d, 1 H, J = 11.4 Hz, CHPh), 4.42 (AB q, 2 H, J = 11.9 Hz, ν = 13.1 Hz, CH_2Ph), 4.30 (d, 1 H, J = 11.6 Hz, CHPh), 4.25 (dt, 1 H, J = 7.3, 1.8 Hz, H-3'), 4.93 (br d, 1 H, J = 2.0 Hz, H-4), 3.88 (dd, 1 H, J = 10.9, 5.6 Hz, $H\text{-}6_e'$), 3.80 (dd, 1 H, J = 10.5, 7.3 Hz, H-4'), 3.76 (t, 1 H, J = 10.7 Hz, $H\text{-}6_a'$), 3.69 (ddd, 1 H, J = 10.8, 8.3, 6.4 Hz, H-2), 3.62 (dd, 1 H, J = 8.7, 8.0 Hz, H-6) 3.61 (td, 1 H, J = 10.4, 5-7 Hz, H-5'), 3.52 (dd, 1 H, J = 8.9, 5.2 Hz, H-6), 3.48 (ddd, 1 H, J = 7.7, 5.3, 0.8 Hz, H-5), 3.44 (dd, 1 H, J = 10.7, 2.6 Hz, H-3), 1.41 (s, 3 H, CH_3), 1.34 (s, 3 H, CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 144.2, 141.5, 138.6, 137.9, 137.5, 132.0, 128.6, 128.4, 128.2, 127.9, 127.8, 127.5, 127.4, 102.1, 100.8, 99.7, 79.6, 74.5, 73.8, 73.6, 73.5, 71.8, 71.4 (2), 69.6, 68.4, 61.7, 56.5, 29.0, 19.0; MS (FAB) m/e (rel. intensity) 781 (41), 780 (M + Na, 87), 329 (22), 314 (22), 307 (61), 289 (33), 220 (34), 181 (100), 176 (76), 169 (81), 165 (23); HRMS (FAB) calcd for $C_{42}H_{47}NNaO_{10}S$ (M + Na) 780.2820, found 780.2863. Anal. Calcd for $C_{42}H_{47}NO_{10}S$: C, 66.56; H, 6.25; N, 1.85; S, 4.23. Found: C, 66.37; H, 6.12; N, 1.83; S, 4.26.

O-[2-(Benzenesulfonamido)-3-O-benzyl-4,6-O-benzylidene-2-deoxy-D-allopyranosyl]-β-(1→6)-1,2:3,4-di-O-isopropylidene-α-D-galactopyranose (36). Potassium hexamethyldisilazide (KHMDS; 0.5 M in toluene, 0.190 mmol) was added dropwise to a −40 °C stirred solution of *trans*-bromosulfonamide **34a** (50.3 mg, 0.0897 mmol) and 1,2:3,4-di-O-isopropylidene-D-galactopyranose (**16**; 35.9 mg, 0.138 mmol) in DMF (0.8 mL). The reaction mixture was stirred for 30 min at −40 °C and then allowed to warm to room temperature over several hours. After 5 h, the reaction was poured into saturated NH_4Cl (4 mL) and was extracted with ether (4 × 4 mL). The combined ether layers were dried (Na_2SO_4) and concentrated, and the resulting oil was chromatographed (33% EtOAc in hexanes) to provide **36** (56.8 mg, 86%) as a colorless glass: $[\alpha]_D$ −73.2° (c 1.23, $CHCl_3$); IR (neat) ν_{max} 3430, 3070, 2990, 2940, 2910, 1455, 1385, 1340, 1260, 1215, 1175, 1090 (br) cm^{-1}; ^1H NMR (490 MHz, $CDCl_3$) δ 7.91–7.88 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.57–7.52 (m, 1 H, $SO_2C(CHCH)_2CH$), 7.51–7.44 (m, 4 H, ArH), 7.42–7.30 (m, 8 H, ArH), 5.54 (d, 1 H, J = 5.1 Hz, H-1'), 5.48 (s, 1 H, CHPh), 5.24 (d, 1 H, J = 7.3 Hz, NH), 4.97 (d, 1 H, J = 11.1 Hz, CHPh), 4.85 (d, 1 H, J = 8.3 Hz, H-1), 4.56 (dd, 1 H, J = 7.8, 2.4 Hz, H-3'), 4.55 (d, 1 H, J = 11.2 Hz, CHPh), 4.34 (dd, 1 H, J = 10.4, 5.1 Hz, $H\text{-}6_e$), 4.32 (dd, 1 H, J = 5.1, 2.4 Hz, H-2'), 4.23 (t, 1 H, J = 2.5 Hz, H-3), 4.06 (td, 1 H, J = 9.7, 5.2 Hz, H-5), 4.06 (dd, 1 H, J = 7.9, 1.9 Hz, H-4'), 3.89 (ddd, J = 6.5, 4.3, 1.9 Hz, H-5'), 3.85 (dd, 1 H, J = 11.4, 4.3 Hz, H-6'), 3.71 (t, 1 H, J = 10.4 Hz, $H\text{-}6_a$), 3.63 (dd, 1 H, J = 9.5, 2.2 Hz, H-4), 3.61 (dd, 1 H, J = 11.4, 7.4 Hz, H-6'), 3.33 (ddd, 1 H, J = 8.2, 7.5, 2.9 Hz, H-2), 1.55 (s, 3 H, CH_3), 1.44 (s, 3 H, CH_3), 1.36 (s, 3 H, CH_3), 1.32 (s, 3 H, CH_3); ^{13}C NMR (63 MHz, $CDCl_3$) δ 140.6, 138.3, 137.3, 132.4, 129.1, 128.9, 128.3 (2), 128.0, 127.7, 127.2, 126.1, 109.2, 108.6, 102.1, 100.3, 96.2, 79.9, 76.3, 74.8, 70.8, 70.6, 70.3, 69.0, 68.9, 67.5, 63.8, 57.0, 26.1, 25.9, 24.8, 24.3; MS (FAB) m/e (rel. intensity) 740 (M + H, 11), 480 (54), 447 (33), 373 (22), 372 (100), 349 (45), 310 (21); HRMS (FAB) calcd for $C_{38}H_{46}NO_{12}S$ (M + H) 740.2741, found 740.2759. Anal. Calcd for $C_{38}H_{45}NO_{12}S$: C, 61.69; H, 6.13; N, 1.89; S, 4.33. Found: C, 61.41; H, 6.19; N, 1.69; S, 4.34.

Alternatively, KHMDS (0.5 M in toluene, 0.174 mmol) was added dropwise to a −40 °C stirred solution of *trans*-iodosulfonamide **34b** (50.2 mg, 0.0826 mmol) and 1,2:3,4-di-O-isopropylidene-D-galactopyranose (**16**; 33 mg, 0.13 mmol) in DMF (0.8 μL). The reaction mixture was stirred for 30 min at −40 °C and then allowed to warm to room tem-

perature over several hours. After 5 h, the reaction was poured into saturated NH_4Cl (4 mL) and was extracted with ether (5 × 4 mL). The combined ether layers were dried (Na_2SO_4) and concentrated, and the resulting oil was chromatographed (33% EtOAc in hexanes) to provide **36** (52.5 mg, 86%) as a colorless glass.

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Synthesis and Photochemistry of Some Anthraquinone-Substituted β-Cyclodextrins

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Abstract: Anthraquinone-substituted β-cyclodextrins (β-CD) **1-3** have been synthesized by reaction of the corresponding sulfonyl chlorides with β-CD. The anthraquinone-capped β-CD **3** is produced as a mixture of A,C and A,D isomers. Irradiation of **1-3** results in the formation of the corresponding hydroquinones and oxidation of the CD moiety. The main photoproduct from **2** after regeneration of the anthraquinone contains a C6 aldehyde in a hemiacetal or hydrate form. Molecular mechanics suggests that the position of the aldehyde is on the E-glucose ring and that the intramolecular H-abstraction reaction shows some selectivity.

Introduction

Cyclodextrins (CDs) have received much attention as host molecules in complexation and catalysis studies.[1] They are composed of α-D-glucose residues and possess well-defined cavities. Their relatively small size and ease of functionalization make them ideal substrates for enzyme modeling experiments.[2] Many derivatized cyclodextrins have been synthesized to date, and some show remarkable catalytic activity.[3] More recently, cyclodextrins have been used to modify photochemical reactions.[4] Few photochemically active, derivatized cyclodextrins have been synthesized; for example, benzophenone, rose bengal, and porphyrin moieties have been attached to β-CD resulting in host sensitizer systems for triplet energy transfer,[5] singlet oxygen generation[6] and photoreduction,[7] respectively. This paper describes the synthesis and photochemical properties of β-CD derivatized with anthraquinones and examines their viability as photooxidation sensitizers.

The photochemistry of anthraquinones has been well established.[8] The chemistry of the water-soluble anthraquinonesulfonates and -disulfonates is most relevant to this study since the anthraquinones are bonded to β-CD via a sulfonate ester bond. Anthraquinonesulfonate (AQS) photochemistry is dominated by triplet state reactions due to rapid and efficient intersystem crossing from the singlet state.[9-11] The excited triplet AQS then usually reacts via one of two mechanisms depending on the available substrates: electron transfer or hydrogen abstraction. For example, photolysis of 2-AQS in aqueous NaBr produces Br_2 by photooxidation of the bromide anion to atomic bromine.[12,13] This simple and clean reaction can "store" solar energy; indeed, much of the interest in water-soluble anthraquinones stems from their potential use in solar energy conversion schemes. The triplet state can also react through hydrogen abstraction in the presence of certain substrates; for example, 2-propanol is readily oxidized to acetone by reaction with photoexcited anthraquinone-2-sulfonate.[14] Wells and co-workers have demonstrated that the photooxidation mechanism is initiated by a hydrogen abstraction rather than an electron transfer.[14] In the absence of substrates with either low oxidation potentials or abstractable hydrogens, the excited anthraquinonesulfonates will react with water to generate hydroxyanthraquinonesulfonates.[15] This side reaction destroys their utility in most solar energy storage schemes.

Experimental Section

Commercially available β-cyclodextrin (Amaizo) was used after vacuum drying (0.05 mm) at 100 °C for 12 h with a liquid N_2 trap. Pyridine was fractionally distilled, and the fraction between 114 and 115 °C was collected and stored over activated 4-Å molecular sieves until used. ^1H and ^{13}C NMR spectra were obtained with a GE QE-300 spectrometer. UV/vis spectra were measured on a Beckman DU-70 instrument. TLC was carried out with Baker 0.25-mm precoated silica plates (60F-254); spot detection was done with UV and staining with vanillin. Reverse-phase column chromatography was done with Baker RP-18 silica gel. High-pressure liquid chromatography was performed on a Waters 660 system, equipped with a variable wavelength absorption detector, using a Whatman ODS-3 analytical or a Waters carbohydrate column.

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