Generalizing Glycosylation: Synthesis of the Blood Group Antigens Le^a, Le^b, and Le^x Using a Standard Set of Reaction Conditions

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Abstract: Because there are no general reaction conditions for any glycosylation method, biologically interesting oligosaccharides can only be made in a small number of laboratories in the world. To make carbohydrate synthesis accessible to nonspecialists, it is critical to have glycosylation methods that will work in a wide range of cases under a single set of conditions. The Lewis blood group antigens have attracted the attention of numerous synthetic carbohydrate groups because of their structural complexity. Although they have been synthesized many times, they have never been made using a single glycosylation method under one set of reaction conditions. In this paper, we show that the sulfoxide glycosylation method can be used to form all of the glycosidic linkages in the Lewis blood group antigens Le^a (**1**), Le^b (**2**), and Le^x (**3**) stereoselectively under a uniform set of reaction conditions. This work highlights the flexibility of the sulfoxide method and demonstrates its utility for constructing families of related oligosaccharides.

Introduction

Synthetic methods to produce oligosaccharides are decades behind synthetic methods to make other biopolymers. There are several excellent methods available to form amide and phosphodiester linkages, and the synthesis of peptides and oligonucleotides has been automated so that researchers with little synthetic expertise can make quantities of any natural peptide or oligonucleotide. In contrast, biologically interesting oligosaccharides can only be made in a small number of laboratories in the world. The main reason for this is that there are no general reaction conditions for any glycosylation method.[1] The outcome of a glycosylation reaction is heavily dependent on the structures of the glycosyl donor and acceptor; changes in even one protecting group can have unpredictable and often dramatic effects on the stereochemical outcome and yield of glycosylation.[2] Several different reaction conditions or even several different glycosylation methods may be necessary to form the glycosidic bonds in a complicated oligosaccharide, and the appropriate reactions are typically identified only after considerable experimentation. Making carbohydrate synthesis accessible to chemists who do not have special expertise in the field requires glycosylation methods which will work in a wide range of cases under a single set of reaction conditions.

The Lewis blood group antigens are a biologically important family of oligosaccharides (Figure 1) that have attracted the attention of numerous synthetic carbohydrate groups because of their structural complexity.[3−5] They are branched oligosaccharides containing both α and β linkages to hindered secondary alcohols. Each blood group antigen has been synthesized several times previously. However, the blood group antigens have never been synthesized using a single glycosylation method under a single set of reaction conditions. In fact, even for the most reliable glycosylation methods the conditions used to synthesize different glycosidic linkages in the family are

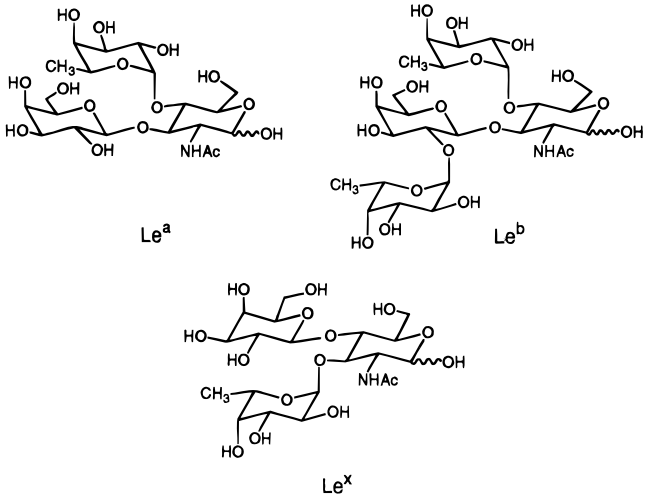

Figure 1. Lewis blood antigens.

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(1) (a) Halcomb, R. L.; Wong, C.-H. *Curr. Opin. Struct. Biol.* **1993**, *3*, 694. (b) Toshima, K.; Tatsuta, K. *Chem. Rev.* **1993**, *93*, 1503.

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(3) For syntheses of Le^a, see: (a) Lemieux, R. U.; Driguez, H. *J. Am. Chem. Soc.* **1975**, *97*, 4063−4068. (b) Jacquinet, J.-C.; Sinay, P. *J. Chem. Soc., Perkin Trans. 1* **1979**, 319−322. (c) Bovin, N. V.; Zurabyan, S. E.; Khorlin, A. Ya. *Bioorg. Khim.* **1980**; *6*, 121−126. (d) Matta, K. L.; Rana, S. S. *Carbohydr. Res.* **1983**, *117*, 101−111. (e) Bovin, N. V.; Ivanova, I. A.; Khorlin, A. Ya. *Bioorg. Khim.* **1986**, *11*, 362−370. (d) Marz, J.; Kunz, H. *Synlett* **1992**, 589−590.

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(5) For syntheses of Le^x, see: (a) Jacquinet, J.-C.; Sinay, P. *J. Chem. Soc., Perkin Trans. 1* **1979**, 314−318. (b) Hindsgaul, O.; Norberg, T.; Pendu, J. L.; Lemieux, R. U. *Carbohydr. Res.* **1982**, *109*, 109−142. (c) Lonn, H. *Carbohydr. Res.* **1985**, *139*, 115−121. (d) Sato, S.; Ito, Y.; Nukada, T.; Nakahara, Y.; Ogawa, T. *Carbohydr. Res.* **1987**, *167*, 197−210. (e) Nilsson, M.; Norberg, T. *Carbohydr. Res.* **1988**, *183*, 71−82. (f) Sato, S.; Ito, Y.; Ogawa, T. *Tetrahedron Lett.* **1988**, *29*, 5267−5270. (g) Classon, B.; Garegg, P. J.; Helland, A.-C. *J. Carbohydr. Chem.* **1989**, *8*, 543−551. (h) Nilsson, M.; Norberg, T. *J. Carbohydr. Chem.* **1989**, *8*, 613−627. (i) Nicolaou, K. C.; Caulfield, T. J.; Kataoka, H.; Stylianides, N. A. *J. Am. Chem. Soc.* **1990**, *112*, 3693−3695. (j) von dem Bruch, K.; Kunz, H. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 101−103. (k) Toepfer, A.; Kinzy, W.; Schmidt, R. R. *Liebigs Ann. Chem.* **1994**, 449−464.

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sufficiently different to suggest that they were arrived at only after extensive experimentation with different parameters (*e.g.*, promoters, temperature, time, and solvent).

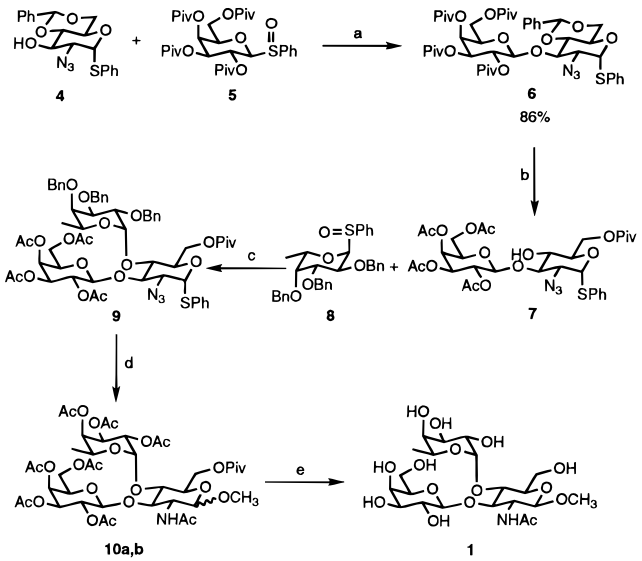
In 1989 we discovered the sulfoxide glycosylation reaction and have been exploring its potential for the synthesis of oligosaccharides both in solution and on the solid phase.[6,7] We wanted to compare the sulfoxide method to the best available glycosylation methods, which have all been applied to the synthesis of the blood group antigens. Because we believe that it is important to have glycosylation methods which can be applied to new glycosidic linkages without having to experiment with the reaction conditions, we imposed the constraint that all the glycosidic linkages be synthesized using a single set of conditions. Despite this constraint, the solution syntheses of the Lewis antigens presented below compare favorably with the best individual syntheses reported to date. Since we have obviated decisions about how to carry out the individual glycosylation reactions by defining a "universal" set of conditions that work for all the glycosidic linkages in the Lewis blood group family, it should be possible to make analogues of the blood group antigens using the routes outlined. It should be noted that the availability of methods that permit the synthesis of a wide range of glycosidic linkages under one set of reaction conditions may also make possible automated oligosaccharide synthesis and the construction of carbohydrate libraries.

Results

Schemes 1, 2, and 3 outline our syntheses of the three blood group antigens using the sulfoxide glycosylation method.

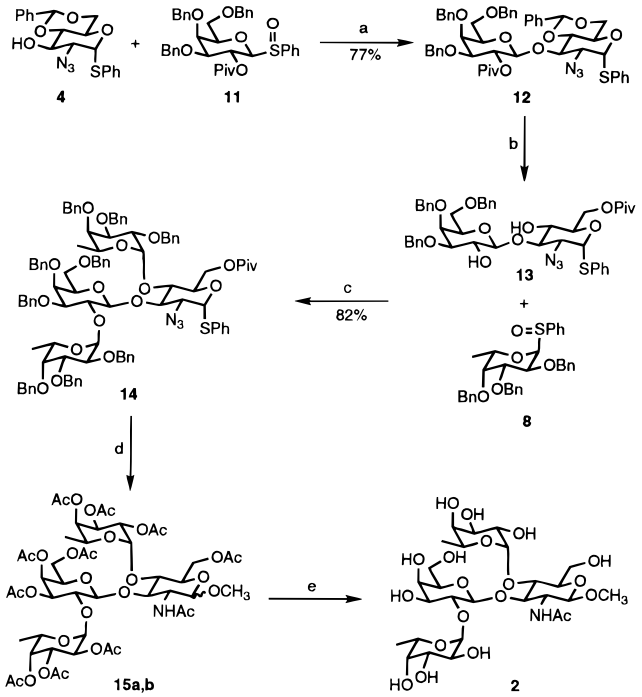
Synthesis of Le^a. The synthesis of Le^a (Scheme 1) began with the coupling of phenyl 2-azido-4,6-*O*-benzylidene-2-deoxy-1-thio-α-D-glucopyranoside (**4**)[8] with the perpivaloyl galactosyl sulfoxide **5**.[9] Compound **4** was treated with sulfoxide **5** (2 equiv) and triflic anhydride (1 equiv) in dichloromethane at −78 °C to produce stereoselectively the *β*-1,3-linked disaccharide **6** in 83% yield. The stereochemical control was a result of neighboring group participation from the C-2 pivaloyl ester.[10]

Scheme 1[a] Synthesis of Le^a



[a] (a)Tf_2O, DTBMP, CH_2Cl_2, −78 to −30 °C, 1 h; (b) (1) LiOH, CH_3OH, rt, overnight; (2) Ac_2O, DMAP, pyridine, rt, 2 h (78%, two steps); (3) TFA, CH_2Cl_2 (v/v = 1:2), rt, 1 h; (4) PivCl, DMAP, Et_3N, CH_2Cl_2, rt, 2 h, 93%; (c) Tf_2O, DTBMP, CH_2Cl_2, −78 to 0 °C, 1.5 h; (d) (1) $Hg(OCOCF_3)_2$, wet CH_2Cl_2, 20 min, 77%; (2) CH_3I, NaH, DMF, rt, 20 min, 84%; (3) Lindlar catalyst, H_2, EtOAc, rt, overnight; (4) Pd/C, H_2, EtOAc, rt, 8 h; (5) Ac_2O, DMAP, pyridine, rt, 10 min, 66% (α-anomer 29%, *β*-anomer 37%) over three steps; (e) $NaOCH_3$, CH_3OH, rt, overnight, 97%.

Scheme 2[a] Synthesis of Le^b



[a] (a)Tf_2O, DTBMP, CH_2Cl_2, −78 to −30 °C, 1 h; (b) (1) TFA, CH_2Cl_2 (v/v = 1:2), rt, 1 h, 78%; (2) LiOH, THF, CH_3OH, rt, 1 week, 99%; (3) PivCl, DMAP, Et_3N, CH_2Cl_2, rt, 2 h, 74%; (c) Tf_2O, DTBMP, CH_2Cl_2, −78 to 0 °C, 1.5 h; (d) (1) $Hg(OCOCF_3)_2$, wet CH_2Cl_2, 20 min, 77%; (2) CH_3I, NaH, DMF, rt, 30 min, 88%; (3) Na, NH_3, −78 °C, 2 h; (4) Ac_2O, pyridine, rt, 20 min, 31% (α-anomer 10%, *β*-anomer 21%) over two steps; (e) $NaOCH_3$, CH_3OH, rt, 30 min, 100%.

The pivaloyl groups were removed under basic conditions, and the free alcohols were acetylated. The benzylidene acetal was then removed using trifluoroacetic acid, and the primary alcohol was selectively protected to afford the glycosyl acceptor **7** (62% yield over the four steps). To produce the desired α-fucoside

(6) (a) Kahne, D.; Walker, S.; Cheng, Y.; van Engen, D. *J. Am. Chem. Soc.* **1989**, *111*, 6881. (b) Yang, D.; Kim, S.-H.; Kahne, D. *J. Am. Chem. Soc.* **1991**, *113*, 4715. (c) Cheng, Y.; Ho, D. M.; Gottlieb, C. R.; Kahne, D.; Bruck, M. A. *J. Am. Chem. Soc.* **1992**, *114*, 7319. (d) Raghavan, S.; Kahne, D. *J. Am. Chem. Soc.* **1993**, *115*, 1580. (e) Andreotti, A. H.; Kahne, D. *J. Am. Chem. Soc.* **1993**, *115*, 3352. (f) Kim, S.-H.; Augeri, D.; Yang, D.; Kahne, D. *J. Am. Chem. Soc.* **1994**, *116*, 1766. (g) Silva, D. J.; Kahne, D.; Kraml, C. K. *J. Am. Chem. Soc.* **1994**, *116*, 2641. (h) Walker, S.; Gange, D.; Gupta, V.; Kahne, D. *J. Am. Chem. Soc.* **1994**, *116*, 3197. (i) Yan, L.; Taylor, C. M.; Goodnow, R.; Kahne, D. *J. Am. Chem. Soc.* **1994**, *116*, 6953. (j) Yan, L.; Kahne, D. *Synlett* **1995**, 526.

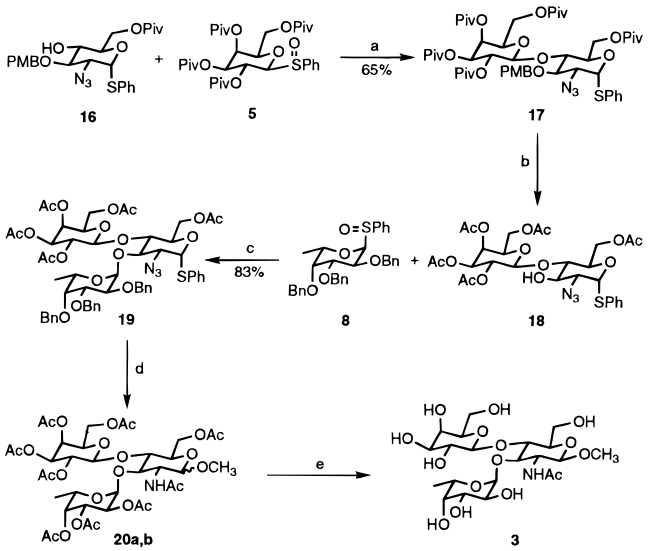
(7) Others have also investigated the sulfoxide method, see: (a) Ikemoto, N.; Schreiber, S. L. *J. Am. Chem. Soc.* **1990**, *112*, 9657. (b) Stork, G.; Kim, G. *J. Am. Chem. Soc.* **1992**, *114*, 1087. (c) Chanteloup, L.; Beau, J.-M. *Tetrahedron Lett.* **1992**, *33*, 5347. (d) Sarkar, A. K.; Matta, K. L. *Carbohydr. Res.* **1992**, *233*, 245. (e) Ikemoto, N.; Schreiber, S. L. *J. Am. Chem. Soc.* **1992**, *114*, 2524. (f) Berkowitz, D. B.; Danishefsky, S. J.; Schulte, G. K. *J. Am. Chem. Soc.* **1992**, *114*, 4518. (g) Wang, Y.; Zhang, H.; Voelter, W. *Z. Naturforscher* **1993**, *48b*, 1143. (h) Sliedregt, L. A. J. M.; van der Marel, G. A.; van Boom, J. H. *Tetrahedron Lett.* **1994**, *35*, 4015. (i) Wang, Y.; Zhang, H.; Voelter, W. *Chem. Lett.* **1995**, 273. (j) Wang, Y.; Zhang, H.; Voelter, W. *Z. Naturforscher* **1995**, *50b*, 661. (k) Zhang, H.; Wang, Y.; Voelter, W. *Tetrahedron Lett.* **1995**, *36*, 1243. (l) Crioh, D.; Sun, S. *J. Org. Chem.* **1996**, *61*, 4506.

(8) Compound **4** is synthesized from the readily available 1,3,4,6-tetra-*O*-acetyl-2-azido-2-deoxy-D-glucopyranoside (Lemieux, R. U.; Ratcliffe, R. M. *Can. J. Chem.* **1979**, *57*, 1244. Pavliak, V.; Kovác, P. *Carbohydr. Res.* **1991**, *210*, 333): (1) PhSH, $BF_3{\cdot}Et_2O$, CH_2Cl_2, 3 days, room temperature (rt); (2) $NaOCH_3$, CH_3OH, 1 h, rt; (3) $PhCH(OCH_3)_2$, $TsOH{\cdot}H_2O$, DMF, 24 h, rt (54% over three steps).

(9) Compound **5** is synthesized from the readily available phenyl 1-thio-*β*-D-galactopyranoside (Ferrier, R. J.; Furneaux, R. H. In *Methods in Carbohydrate Chemistry*; BeMiller, J. N., Whilstler, R. L., Eds.; Academic Press: New York, 1980; Vol. VIII, pp 251): (1) PivCl, DMAP, pyridine, 24 h, reflux; (2) *m*CPBA, CH_2Cl_2, 15 min, −78 °C (86% over two steps).

(10) Kunz, H.; Harreus, A. *Liebigs Ann. Chem.* **1982**, 41.

Scheme 3[a] Synthesis of Le^x



[a] (a) Tf_2O, DTBMP, CH_2Cl_2, −78 to −30 °C, 1 h; (b) (1) LiOH, CH_3OH, rt, overnight; (2) Ac_2O, DMAP, pyridine, rt, 2 h (78%, two steps); (3) 10%TFA in CH_2Cl_2, rt, 30 min, 97%; (c) Tf_2O, DTBMP, CH_2Cl_2, −78 to 0 °C, 1.5 h; (d) (1) $Hg(OCOCF_3)_2$, wet CH_2Cl_2, 20 min, 77%; (2) CH_3I, NaH, DMF, rt, 1 h, 90%; (3) Lindlar catalyst, H_2, EtOAc, rt, overnight; (4) Pd/C, H_2, EtOAc, rt, 8 h; (5) Ac_2O, DMAP, pyridine, rt, 10 min, 55% (α-anomer 22%, β-anomer 33%) over three steps; (e) $NaOCH_3$, CH_3OH, rt, overnight, 100%.

the perbenzylated fucose sulfoxide **8**[11] (2 equiv) was activated with triflic anhydride (1 equiv) and added to **7** in dichloromethane at −78 °C. The desired α-linked product **9** was isolated in 95% yield. No β-glycoside was isolated. For glycosyl donors with C2 ether protecting groups, the sulfoxide glycosylation method gives good to excellent α selectivity for glycosylations to secondary alcohols. The α stereoselectivity is better than those obtained with many other glycosylation methods (see Discussion section).[12]

To complete the synthesis of Le^a, the anomeric thiophenyl group of trisaccharide **9** was hydrolyzed with mercury(II) trifluoroacetate and the resulting lactols were alkylated with iodomethane in DMF to give a mixture of α and β methyl ethers. The azido group was then reduced with the Lindlars catalyst, and the benzyl ethers were hydrogenolyzed using palladium on charcoal. Treatment with acetic anhydride and DMAP produced trisaccharide **10** as a mixture of α and β methyl ethers. Following separation by flash chromatography on silica gel, treatment of the β methyl glycoside of **10** with sodium methoxide gave 94% of Le^a (**1**) which was correlated with the reported data.[3a]

Synthesis of Le^b. Le^b (Scheme 2) was constructed following a route similar to that used to construct Le^a except that the galactosyl sulfoxide used in the first glycosylation reaction was synthesized with a protecting group pattern which would permit us to selectively unmask the C2 alcohol of the galactose at a later stage in the synthesis. The requisite galactosyl sulfoxide **11** was synthesized in three steps from the known 1,2-acetyl-3,4,6-tri-*O*-benzyl-D-galactopyranoside.[13] Activation of **11** with triflic anhydride at −78 °C and reaction with glycosyl acceptor **4** produced the desired β-linked disaccharide **12** stereoselectively in 77% yield. This yield is similar to that obtained for the formation of the β linkage in the synthesis of Le^a (Scheme 1, **6**). Thus, the differences in the protecting group patterns do not significantly affect the yield of glycosylation here. In contrast, the yields obtained with other methods for glycosylation in the presence of a participating C2 ester are very sensitive to the protecting groups on the remaining hydroxyls.[2] Electron-withdrawing protecting groups such as esters decrease the reactivity of glycosyl donors and higher temperatures are required for the activation with most methods. Yields are often dramatically reduced.

The protected disaccharide **12** was converted to the diol **13** by hydrolysis of the benzylidene group with trifluoroacetic acid, saponification of the C2 pivaloyl group with lithium hydroxide, and selective protection of the C6 alcohol of the glucosamine. Bisfucosylation to produce **14** was accomplished stereoselectively using 4 equiv of the perbenzylated fucosyl sulfoxide **8**. The desired product was isolated in 82% yield, indicating that the two fucosylations proceeded in better than 90% yield. Again, these yields are almost identical to the yield obtained for fucosylation of Le^a. Compound **14** was converted to **15** in a manner analogous to that used for Le^a (Scheme 1, **9** to **10**) and then saponified to produce Le^b (**2**) which correlated with the reported data.[4c]

Synthesis of Le^x. Le^x (Scheme 3) contains the same three sugars as Le^a, but they are linked in a different manner. In Le^a, a β-linked galactose is attached to the C3 position of the glucosamine and an α-linked fucose is attached to the C4 position. In Le^x, the positions of the galactose and fucose sugars are reversed. Therefore, synthesizing Le^a and Le^x requires that one be able to make both an α and a β linkage to both secondary alcohols at C3 and C4 of glucosamine. Le^x was synthesized from phenyl 2-azido-2-deoxy-3-*O*-(4′-methoxybenzyl)-6-*O*-pivaloyl-1-thio-α-D-glucopyranoside (**16**),[14] using the same perpivaloylated galactosyl sulfoxide **5** used in the synthesis of Le^a. Formation of the β-linkage to the C4 position to produce protected disaccharide **17** proceeds in slightly lower yield (65%) than the corresponding glycosylation in the Le^a synthesis (Scheme 1, **6**), perhaps because the C4 hydroxyl in **16** is more hindered than the C3 hydroxyl in **4**. After replacing the five pivaloyl groups in **17** with acetyl groups, the *p*-methoxybenzyl ether group was removed with 10% trifluoroacetic acid in dichloromethane at room temperature to give **18**. These acidic conditions are so mild that they can be used to remove the *p*-methoxybenzyl protecting groups even in the presence of extremely labile glycosidic linkages to tertiary alcohols.[6j] The disaccharide nucleophile **18** was fucosylated with the perbenzylated fucosyl sulfoxide **8** to introduce the α 1,3-linkage in **19** stereoselectively in 83% yield. Compound **19** was converted to **20** in a manner analogous to that used for Le^a (Scheme 1, **9** to **10**) and then saponified to produce Le^x (**3**) which correlated with reported data.[5b]

Discussion

The syntheses of the three blood group antigens highlight the generality of the sulfoxide method for constructing this family of oligosaccharides. Both the α and β glycosidic linkages were formed stereoselectively using the same set of reaction conditions. In general, the sulfoxide reaction is quite

(11) Fucose sulfoxide **8** is synthesized from the readily available phenyl 1-thio-L-fucopyranoside (ref 9): (1) BnCl, NaH, Bn_4NI, DMF, 24 h, 60 °C; (2) *m*CPBA, CH_2Cl_2, 15 min, −78 °C (96% over two steps).

(12) Thompson, C.; Kahne, D. Unpublished results.

(13) Galactose sulfoxide **11** is synthesized from the readily available 1,2-di-*O*-acetyl-3,4,6-tri-*O*-benzyl-D-galactopyranoside (Kong, F.; Du, J.; Shang, H. *Carbohydr. Res.* **1987**, *162*, 217): (1) PhSH, $BF_3{\cdot}Et_2O$, CH_2Cl_2, 5 h, rt; (2) $NaOCH_3$, CH_3OH, 24 h, rt; (3) PivCl, DMAP, Et_3N, CH_2Cl_2, 24 h, reflux (48% over three steps).

(14) Compound **16** is synthesized from the readily available 1,3,4,6-tetra-*O*-acetyl-2-azido-2-deoxy-D-glucopyranoside (see ref 8): (1) PhSH, $BF_3{\cdot}Et_2O$, CH_2Cl_2, 3 days, rt; (2) $NaOCH_3$, CH_3OH, 1 h, rt; (3) $(CH_3)_2C(OCH_3)_2$, $TsOH{\cdot}H_2O$, DMF, 24 h, rt; (4) *p*-$CH_3OC_6H_4CH_2Cl$, NaH, DMF, 1 h, rt; (5) $TsOH{\cdot}H_2O$, CH_3OH, 1 h, rt; (6) PivCl, DMAP, Et_3N, CH_2Cl_2, 2 h, rt (36% over six steps).

reliable for forming α linkages to secondary alcohols and for forming β linkages (1,2-trans linkages) whenever neighboring group participation is used. The high reactivity of anomeric sulfoxides is the key to the reliable formation of both types of linkages under the same set of reactions conditions. Like many other glycosylation reactions, the sulfoxide reaction goes through an oxonium ion intermediate. We believe that the α selectivity reflects a kinetic preference for axial attack on a chairlike transition state. Because glycosyl sulfoxides can be activated at very low temperatures, the kinetic selectivity for the α isomer is typically higher than that for other methods. In the formation of β (1,2-trans) linkages, stereochemical control is typically achieved using neighboring group participation from an ester at C2 of the glycosyl donor. While this strategy predictably produces the desired β configuration, ester groups inductively disfavor activation and/or ejection of the leaving group at the anomeric center. Many glycosylation methods are not compatible with neighboring group participation because the glycosyl donors cannot be activated when there are electron-withdrawing protecting groups on the ring. (The sensitivity of many glycosylation reactions to protecting group patterns has been used to great advantage in "armed/disarmed" strategies for iterative oligosaccharide synthesis.) However, glycosyl sulfoxides with ester protecting groups can be activated under the same conditions used for electron-donating protecting groups, permitting the use of a standard set of conditions to form very different glycosidic linkages. The ability to form different glycosidic linkages with similar efficiency using the same set of reaction conditions should make the sulfoxide method simpler to use for newcomers than methods which require different conditions for different glycosidic linkages. We note that others[7] who have used the sulfoxide glycosylation reaction in a wide range of substrates have used conditions very similar to those reported here and in our earlier work.[6]

Having a uniform set of reaction conditions should ultimately make solid phase synthesis of oligosaccharides and carbohydrate libraries possible as well. In fact, some of the choices we made in the above syntheses were dictated by our interest in developing solid phase methods for the construction of oligosaccharides. For example, although there are good methods for the one-step conversion of a 4,6-benzylidene acetal into a C6 benzyl ether, the conditions are not suitable for resin synthesis; hence, we used a two-step process to produce a C6 pivaloyl ester. Similarly, hydrogenolytic removal of benzyl ethers is not reliable in a resin matrix.[15] We have developed mild acidic conditions to remove *p*-methoxybenzyl groups which should translate readily to the heterogeneous environment of a resin. Simply by changing the benzyl groups to *p*-methoxybenzyl groups, the blood group antigens can be synthesized and deprotected on a solid support using the routes outlined.[6j]

Conclusions

We have used the sulfoxide glycosylation method to make all the glycosidic linkages in the Lewis blood group antigens Le^a, Le^b, and Le^x. Our syntheses are comparable to the best syntheses of these molecules.[3−5] Given the demonstrated predictability of the sulfoxide glycosylation reaction for this family of oligosaccharides, it should be possible to make other members of the Lewis blood group family as well as analogues without having each synthesis turn into a new problem that must be solved by experimenting with different reaction conditions or glycosylation methods.

Experimental Section

General Methods. NMR spectra were recorded on a JEOL GSX 270 FT or a JEOL GSX 500 FT NMR spectrometer. Proton chemical shifts are reported in parts per million (ppm) downfield from tetramethylsilane (TMS) unless noted otherwise. Coupling constants (*J*) are reported in hertz (Hz). Carbon chemical shifts are reported in parts per million (ppm) with reference to internal solvent $CDCl_3$ (77.00 ppm) unless noted otherwise. Multiplicities are abbreviated as follows: singlet (s), doublet (d), triplet (t), quartet (q), multiplet (m), and broadened (br). High-resolution mass spectra (HRMS) were obtained on a Kratos MS50 spectrometer (Princeton University Mass facility), and high-resolution fast atom bombardment mass spectra (HRFABMS) were obtained on a VG ZAB or a VG 7070 (University of California, Riverside, Mass facility).

Analytical thin-layer chromatography (TLC) was performed using silica gel 60 F254 precoated plates (0.25 mm thick) with a fluorescent indicator. Flash chromatography was performed using silica gel 60 (200−400 mesh) from EM Science.[16]

All reactions were carried out under argon atmosphere with dry, freshly distilled solvents under anhydrous conditions unless otherwise noted. All reagents were purchased from commercial suppliers and used without further purification unless otherwise noted.

Phenyl 2,3,4,6-Tetra-*O*-pivaloyl-1-thio-β-D-galactopyranoside and Sulfoxide Derivatives (5). To a solution of phenyl 2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-galactopyranoside[9] (1.28 g, 2.91 mmol) in MeOH (25 mL) at 25 °C was added NaOMe (83 mg, 1.54 mmol). The reaction mixture was stirred at 25 °C overnight and neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to give the crude tetraol as a white residue which was dried azeotropically by toluene (3 × 5 mL) and taken to the next step without further purification.

To the crude tetraol (2.91 mmol) and 4-dimethylaminopyridine (178 mg, 1.46 mmol) in pyridine (25 mL) at 25 °C was added pivaloyl chloride (3.6 mL, 29.1 mmol) dropwise via syringe. The mixture was refluxed for 24 h and then cooled to room temperature, and the reaction was quenched with MeOH (5 mL). Solvent was removed *in vacuo*, and the residue was dissolved in CH_2Cl_2 and washed with 1 N aqueous HCl (150 mL) and saturated aqueous $NaHCO_3$ (3 × 150 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (5% EtOAc in petroleum ether) to afford the sulfide (1.60 g, 90% 2 steps) as a white solid: $R_f = 0.20$ (5% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.8, 177.2, 176.7, 176.4, 133.5, 131.4, 128.8, 128.3, 85.8, 74.7, 72.1, 66.9, 66.6, 61.5, 38.9, 38.7, 27.1, 27.0; ^1H NMR ($CDCl_3$, 270 MHz) δ 7.5−7.2 (5H, m), 5.50 (1H, d, $J = 3.0$ Hz), 5.30 (1H, dd, $J = 9.6$, 9.9 Hz), 5.21 (1H, dd, $J = 3.0$, 9.9Hz), 4.81 (1H, d, $J = 9.6$Hz), 4.32−4.06 (3H, m), 1.30, 1.27, 1.25, 1.17 (4 × 9H, 4s); HRFABMS calcd for $C_{32}H_{47}O_9S$ ($M - H^-$) 607.2941, found 607.2942.

To a solution of the above sulfide (7.50 g, 12.3 mmol) in CH_2Cl_2 (100 mL) at −78 °C was added 3-chloroperoxybenzoic acid (3.33 g, 12.3 mmol) in CH_2Cl_2 (10 mL). After 15 min of stirring at −78 °C, the mixture was poured into saturated aqueous $NaHCO_3$ (500 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 500 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (20% EtOAc in petroleum ether) to afford sulfoxide **5** (7.4 g, 96%, diastereomeric ratio is 2.1:1 which favors the more polar product) as a white solid: $R_f = 0.41$ (20% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.7, 177.3, 176.7, 176.0, 138.7, 131.5, 128.8, 125.8, 89.4, 75.5, 72.1, 66.4, 64.3, 61.0, 38.9, 38.8, 38.7, 38.6, 27.0, 26.9; ^1H NMR ($CDCl_3$, 270 MHz) δ 7.7−7.5 (5H, m), 5.56 (1H, t, $J = 9.9$Hz), 5.38 (1H, d, $J = 3.3$Hz), 5.18 (1H, dd, $J = 3.1$, 10.1Hz), 4.46 (1H, d, $J = 9.9$Hz), 4.44−3.91 (3H, m), 1.24, 1.15, 1.10 (4 × 9H, 4s); $R_f = 0.25$ (20% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.6, 177.0, 176.9, 176.2, 137.0, 132.0, 128.6, 127.1, 92.2, 75.0, 71.7, 66.0, 64.8, 60.2, 38.9, 38.7, 38.6, 27.0, 26.8; ^1H NMR ($CDCl_3$, 270 MHz) δ 7.8−7.5 (5H, m), 5.31 (1H, d, $J = 2.6$Hz), 5.16 (1H, dd, $J = 3.0$, 9.6Hz), 5.09 (1H, dd, $J = 9.6$, 9.9Hz), 4.68 (1H, d, $J = 9.6$Hz), 4.13−4.03 (2H, m), 3.78−3.68 (1H, m), 1.25, 1.16, 1.09, 0.94 (4 × 9H, 4s); HRFABMS calcd for $C_{32}H_{48}O_{10}S$ (M^+) 624.2968, found 624.2968.

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Phenyl 2-Azido-4,6-*O*-benzylidene-2-deoxy-1-thio-α-D-glucopyranoside (4). To a solution of 1,3,4,6-tetra-*O*-acetyl-2-azido-2-deoxy-D-glucopyranoside[8] (1.33 g, 3.57 mmol) and thiophenol (570 μL, 5.35 mmol) in CH_2Cl_2 (20 mL) was added $BF_3{\cdot}Et_2O$ (2.2 mL, 17.8 mmol). The mixture was stirred for 3 days at 25 °C, diluted with CH_2Cl_2 (20 mL), and poured into 200 mL water. The organic layer was washed with saturated aqueous $NaHCO_3$ (3 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (15% EtOAc in petroleum ether) to afford the sulfide (1.34 g, 89%, α/β = 2.1:1) as a white solid: R_f = 0.28 (25% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 170.4, 169.8, 169.7, 169.6, 134.1, 132.4, 132.2, 130.2, 129.2, 129.1, 128.9, 128.0, 86.5, 85.8, 75.7, 74.4, 72.0, 68.7, 68.5, 68.0, 62.6, 62.0, 61.9, 61.6, 20.6; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.6−7.3 (10H, m), 5.65 (1H, d, J = 5.6Hz), 5.34 (1H, dd, J = 9.3, 9.9Hz), 5.12−5.01 (2H, m), 4.93 (1H, t, J = 9.6Hz), 4.59 (1H, m), 4.50 (1H, d, J = 10.2Hz), 4.30 (1H, dd, J = 4.8, 12.4Hz), 4.2−4.0 (4H, m), 3.71−3.68 (1H, m), 3.41 (1H, dd, J = 9.6, 10.2Hz), 2.1−2.0 (18H, m); HRMS calcd for $C_{18}H_{21}O_7N_3S$ (M^+) 423.1100, found 423.1107.

To a solution of the above sulfide (3.5 g, 8.36 mmol) in MeOH/THF (v/v = 5:1, 50 mL) was added catalytic amount of NaOMe. After 1 h of stirring at 25 °C, the reaction mixture was neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to give the crude triol as a white residue which was dried azeotropically by toluene (3 × 20 mL) and taken to next step without further purification.

To a solution of the above crude triol (8.36 mmol) and benzaldehyde dimethyl acetal (3.8 mL, 25.08 mmol) in DMF (50 mL) was added $TsOH{\cdot}H_2O$ (795 mg, 4.18 mmol). After 24 h of stirring at 25 °C, the reaction mixture was neutralized with Amberlite IRA-400(OH). The resin was filtered off, and the filtrate was concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2 (50 mL) and washed with saturated aqueous $NaHCO_3$ (2 × 200 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (15% EtOAc in petroleum ether) to afford α anomer **4** (1.34 g, 89%) as a white solid: R_f = 0.27 (15% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 136.8, 133.0, 132.5, 129.5, 129.2, 128.4, 128.0, 126.3, 102.2, 87.8, 81.6, 70.7, 68.5, 63.9, 63.4; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (10H, m), 5.57 (1H, d, J = 5.9Hz), 5.56 (1H, s), 4.39 (1H, td, J = 5.1, 9.9Hz), 4.23 (1H, dd, J = 5.0, 10.5Hz), 4.07 (1H, t, J = 9.5Hz), 3.92 (1H, dd, J = 5.5, 9.9Hz), 3.76 (1H, t, J = 10.3Hz), 3.58 (1H, dd, J = 9.2, 9.5Hz), 2.81 (1H, s); HRMS calcd for $C_{19}H_{19}O_4N_3S$ (M^+) 385.1096, found 385.1106.

Phenyl (2,3,4,6-Tetra-*O*-pivaloyl-β-D-galactopyranosyl)-(1→3)-2-azido-4,6-*O*-benzylidene-2-deoxy-1-thio-α-D-glucopyranoside (6). To a solution of sulfoxide **5** (109 mg, 0.175 mmol) in CH_2Cl_2 (5 mL) at −78 °C was added Tf_2O (15 μL, 0.089 mmol), and then the mixture was warmed up to −60 °C. After 15 min of stirring at −60 °C, to the mixture were added nucleophile **4** (37 mg, 0.096 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (110 mg, 0.526 mmol) in CH_2Cl_2 (5 mL) dropwise via syringe. After 10 min of stirring at −60 °C, the mixture was slowly warmed up to −30 °C over 30 min, quenched by saturated aqueous $NaHCO_3$ (5 mL), and washed with saturated aqueous $NaHCO_3$ (2 × 100 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (13% EtOAc in petroleum ether) to afford disaccharide **6** (70 mg, 83%) as a white solid: R_f = 0.32 (15% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.6, 177.3, 176.8, 176.6, 136.8, 132.7, 132.5, 129.3, 129.2, 128.4, 128.1, 126.0, 101.7, 100.5, 87.3, 80.2, 77.1, 71.1, 70.9, 69.3, 68.5, 66.3, 63.6, 63.5, 60.6, 39.0, 38.9, 38.7, 38.6, 27.2, 27.1; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (10H, m), 5.60 (1H, d, J = 4.4Hz), 5.55 (1H, s), 5.34 (1H, d, J = 2.6Hz), 5.27 (1H, dd, J = 8.1, 10.3Hz), 5.08 (1H, dd, J = 3.5, 10.5Hz), 4.87 (1H, d, J = 8.1Hz), 4.40 (1H, td, J = 4.8, 9.9Hz), 4.19 (1H, dd, J = 5.0, 10.5Hz), 4.05−4.04 (2H, m), 4.00 (1H, dd, J = 8.4, 10.6Hz), 3.94 (1H, dd, J = 6.2, 11.0Hz), 3.79−3.75 (2H, m), 3.72 (1H, dd, J = 7.0, 8.1Hz), 1.23, 1.22, 1.14, 1.11 (4 × 9H, 4s); HRFABMS calcd for $C_{45}H_{60}O_{13}N_3S$ ($M - H^-$) 882.3847, found 882.3861.

Phenyl (2,3,4,6-Tetra-*O*-acetyl-β-D-galactopyranosyl)-(1→3)-2-azido-2-deoxy-6-*O*-pivaloyl-1-thio-α-D-glucopyranoside (7). To a solution of disaccharide **6** (267 mg, 0.302 mmol) in MeOH (5 mL) was added $LiOH{\cdot}H_2O$ (30 mg, 0.715 mmol). After the solution was stirred overnight at 25 °C, the reaction mixture was neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to produce the crude tetraol as a white residue which was dried azeotropically by toluene (3 × 5 mL) and taken to next step without further purification.

To the above crude tetraol (0.303 mmol) and 4-dimethylaminopyridine (19 mg, 0.155 mmol) in pyridine (10 mL) at 25 °C was added acetic anhydride (230 μL, 2.42 mmol) dropwise via syringe. After 2 h of stirring at 25 °C, the reaction was quenched with MeOH (1 mL) and concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2 and washed with 1 N aqueous HCl (50 mL) and saturated aqueous $NaHCO_3$ (3 × 100 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (14% Et_2O in $CHCl_3$) to afford the tetraacetate (170 mg, 79% two steps) as a white solid: R_f = 0.27 (35% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 170.2, 170.1, 170.0, 169.4, 136.8, 132.6, 132.3, 129.2, 128.3, 128.1, 125.8, 101.3, 87.6, 80.6, 78.1, 71.0, 70.8, 69.5, 68.4, 66.7, 63.6, 63.4, 60.8, 20.7, 20.6, 20.5, 20.4; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.3 (10H, m), 5.61 (1H, d, J = 5.5Hz), 5.58 (1H, s), 5.33 (1H, brd, J = 3.3Hz), 5.27 (1H, dd, J = 8.1, 10.3Hz), 4.98 (1H, dd, J = 3.3, 10.3Hz), 4.83 (1H, d, J = 8.1Hz), 4.42−4.37 (1H, m), 4.20 (1H, dd, J = 4.8, 10.3Hz), 4.11−4.02 (2H, m), 3.96 (1H, dd, J = 5.7, 10.1Hz), 3.90 (1H, dd, J = 5.9, 11.4Hz), 3.79−3.74 (2H, m), 3.71 (1H, brdd, J = 6.6, 7.0Hz), 2.14, 2.12, 1.98, 1.94 (4 × 3H, 4s); HRFABMS calcd for $C_{33}H_{37}O_{13}N_3S$ (M^+) 715.2047, found 715.2062.

The above tetraacetate (132 mg, 0.185 mmol) was added to a mixture of trifluoroacetic acid and CH_2Cl_2 (v/v = 1:2, 5 mL) at 25 °C. After 1 h of stirring at 25 °C, the mixture was diluted with CH_2Cl_2 (10 mL) and poured into saturated aqueous $NaHCO_3$ (100 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (55% EtOAc in petroleum ether) to afford the diol (98 mg, 85%) as a white solid: R_f = 0.22 (50% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 170.3, 169.9, 169.5, 132.6, 132.4, 129.1, 128.1, 101.9, 87.1, 84.5, 72.3, 71.2, 70.7, 69.3, 68.4, 66.8, 62.5, 62.0, 61.6, 20.5, 20.4; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.3 (5H, m), 5.64 (1H, d, J = 5.5Hz), 5.41 (1H, brd, J = 3.3Hz), 5.28 (1H, dd, J = 8.1, 10.3Hz), 5.06 (1H, dd, J = 3.3, 10.6Hz), 4.67 (1H, d, J = 8.1Hz), 4.20−4.07 (5H, m), 3.87−3.81 (3H, m), 3.64−3.62 (2H, m), 2.14, 2.13, 2.08, 2.00 (4 × 3H, 4s); HRFABMS calcd for $C_{26}H_{37}O_{13}N_4S$ ($M + NH_4^+$) 645.2078, found 645.2068.

To the above diol (98 mg, 0.157 mmol) in pyridine (10 mL) at 25 °C was added pivaloyl chloride (194 μL, 1.56 mmol) dropwise via syringe. After 2 h of stirring at 25 °C, the reaction was quenched with MeOH (1 mL) and concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2 and washed with 1 N aqueous HCl (50 mL) and saturated aqueous $NaHCO_3$ (3 × 100 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (35% EtOAc in petroleum ether) to afford **7** (103 mg, 92%) as a white solid: R_f = 0.32 (35% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 178.2, 170.4, 170.0, 169.9, 169.6, 132.9, 132.0, 129.2, 127.9, 102.1, 87.3, 84.5, 71.4, 70.7, 69.4, 68.4, 66.8, 63.2, 62.5, 61.7, 38.8, 27.1, 20.6, 20.5, 20.4; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.6−7.2 (5H, m), 5.63 (1H, d, J = 5.5Hz), 5.43 (1H, brd, J = 2.6Hz), 5.31 (1H, dd, J = 8.1, 10.6Hz), 5.06 (1H, dd, J = 3.5, 10.4Hz), 4.67 (1H, d, J = 8.1Hz), 4.41−4.22 (3H, m), 4.19 (1H, dd, J = 4.8, 11.4Hz), 4.14 (1H, dd, J = 7.7, 11.4Hz), 4.11 (1H, d, J = 1.5Hz), 4.07 (1H, dd, J = 5.5, 7.7Hz), 3.83 (1H, dd, J = 5.5, 10.3Hz), 3.61 (1H, dd, J = 8.1, 10.3Hz), 3.56 (1H, dd, J = 8.4, 9.5Hz), 2.18, 2.13, 2.09, 2.01 (4 × 3H, 4s), 1.18 (9H, s); HRFABMS calcd for $C_{31}H_{42}O_{14}N_3S$ ($M + H^+$) 712.2388, found 712.2383.

Phenyl 2,3,4-Tri-*O*-benzyl-1-thio-β-L-fucopyranoside and Sulfoxide Derivatives (8). To a solution of phenyl 2,3,4-tri-*O*-acetyl-1-thio-β-L-fucopyranoside[11] (928 mg, 2.43 mmol) in MeOH (25 mL) at 25 °C was added catalytic amount of K_2CO_3. The mixture was stirred overnight at 25 °C and neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to afford the crude triol as a white residue which was dried azeotropically by toluene (3 × 5 mL) and taken to the next step without further purification.

To a solution of the above crude triol (2.43 mmol), benzyl chloride (1.7 mL, 14.6 mmol), and catalytic amount of tetrabutylammonium

iodide in DMF (25 mL) at 25 °C was added NaH (60%, 583 mg, 14.6 mmol). The mixture was heated to 60 °C for 24 h and then cooled down to 25 °C, and the reaction was quenched with MeOH (2 mL) and concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2 and washed with saturated aqueous $NaHCO_3$ (3 × 100 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (5% EtOAc in petroleum ether) to afford the sulfide (1.3 g, 100%, 2 steps) as a white solid: R_f = 0.34 (10% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 138.7, 138.3, 134.3, 131.5, 128.7, 128.4, 128.3, 128.1, 127.9, 127.6, 127.5, 127.4, 126.9, 87.5, 84.5, 77.0, 75.5, 74.6, 72.8, 17.3; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.6−7.2 (20H, m), 5.03−4.58 (7H, m), 3.93 (1H, t, J = 9.2Hz), 3.64−3.48 (3H, m), 1.26 (3H, d, J = 6.3Hz); HRMS calcd for $C_{33}H_{34}O_4S$ (M^+) 526.2178, found 526.2168.

To a solution of the above sulfide (7.50 g, 12.3 mmol) in CH_2Cl_2 (100 mL) at −78 °C was added 3-chloroperoxybenzoic acid (3.33 g, 12.3 mmol) in CH_2Cl_2 (10 mL). After 15 min of stirring at −78 °C, the mixture was poured into saturated aqueous $NaHCO_3$ (500 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 500 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (20% EtOAc in petroleum ether) to afford sulfoxide **8** (7.4 g, 96%, diastereomeric ratio is 2.1:1 which favors the more polar product) as a white solid: R_f = 0.29 (30% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 140.2, 138.3, 138.0, 137.9, 130.6, 128.4, 128.1, 127.8, 127.7, 127.5, 125.4, 94.0, 84.5, 75.8, 75.7, 75.4, 74.3, 73.7, 72.6, 16.5; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.6−7.2 (20H, m), 5.04−4.68 (6H, m), 4.44 (1H, t, J = 9.6Hz), 3.87 (1H, d, J = 9.6Hz), 3.64 (1H, dd, J = 2.8, 9.4Hz), 3.58 (1H, d, J = 2.0Hz), 3.32 (1H, q, J = 6.3Hz), 1.02 (3H, d, J = 6.3Hz); R_f = 0.15 (30% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 140.2, 138.4, 138.0, 137.8, 130.9, 128.4, 128.2, 128.0, 127.9, 127.6, 127.2, 126.1, 95.3, 84.4, 75.7, 75.2, 74.4, 74.2, 73.7, 72.4, 16.7; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.6−7.1 (20H, m), 4.90−4.51 (6H, m), 4.46 (1H, d, J = 9.2Hz), 3.98 (1H, dd, J = 8.9, 9.2Hz), 3.68 (1H, dd, J = 2.5, 9.1Hz), 3.60−3.57 (2H, m), 1.19 (3H, d, J = 6.3Hz); HRFABMS calcd for $C_{33}H_{35}O_5S$ ($M + H^+$) 543.2205, found 543.2206.

Phenyl (2,3,4,6-Tetra-*O*-acetyl-*β*-D-galactopyranosyl)-(1→3)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→4)]-2-azido-2-deoxy-6-*O*-pivaloyl-1-thio-α-D-glucopyranoside (9). To a solution of sulfoxide **8** (142 mg, 0.262 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (165 mg, 0.788 mmol) in CH_2Cl_2 (10 mL) at −78 °C was added Tf_2O (22 μL, 0.131 mmol), and then the reaction mixture was warmed to −60 °C. After 15 min of stirring at −60 °C, to the mixture was added nucleophile **7** (95 mg, 0.134 mmol) in CH_2Cl_2 (5 mL) dropwise via syringe. After 10 min of stirring at −60 °C, the reaction was slowly warmed to −5 °C over 1 h, quenched by saturated aqueous $NaHCO_3$ (5 mL), and washed with saturated aqueous $NaHCO_3$ (2 × 100 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (27% EtOAc in petroleum ether) to afford trisaccharide **9** (143 mg, 95%) as a white solid: R_f = 0.42 (30% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.8, 170.1, 170.0, 169.7, 169.5, 138.7, 138.6, 137.8, 132.9, 132.1, 129.2, 128.9, 128.5, 128.4, 128.3, 128.2, 127.9, 127.8, 127.7, 127.4, 127.0, 100.8, 98.4, 87.0, 80.6, 77.2, 76.3, 74.9, 74.8, 74.0, 72.9, 72.4, 71.0, 70.8, 70.4, 68.5, 66.8, 66.6, 65.7, 61.7, 60.2, 38.8, 27.3, 20.9, 20.6, 20.5, 16.8; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (20H, m), 5.60 (1H, d, J = 4.4Hz), 5.37 (1H, d, J = 3.3Hz), 5.16 (1H, dd, J = 8.3, 10.5Hz), 5.04 (1H, d, J = 8.1Hz), 5.00 (1H, dd, J = 3.3, 10.3Hz), 4.98 (1H, d, J = 12.5Hz), 4.87−4.84 (3H, m), 4.81 (1H, d, J = 3.3Hz), 4.78 (2H, d, J = 11.7Hz), 4.75 (1H, q, J = 7.0Hz), 4.45−4.40 (2H, m), 4.34−4.31 (1H, m), 4.19−4.13 (2H, m), 4.02−3.94 (3H, m), 3.87−3.80 (2H, m), 3.75 (1H, brs), 3.70 (1H, dd, J = 8.8, 9.5Hz), 2.11, 2.04, 1.96, 1.78 (4 × 3H, 4s), 1.30 (3H, d, J = 6.2Hz), 1.16 (9H, s); HRFABMS calcd for $C_{58}H_{69}O_{20}N_4S$ ($M + NO_2^+$) 1173.4228, found 1173.4225.

Methyl (2,3,4,6-Tetra-*O*-acetyl-*β*-D-galactopyranosyl)-(1→3)-[2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl-(1→4)]-2-acetamido-2-deoxy-6-*O*-pivaloyl-α,*β*-D-glucopyranoside (10a,b). To a solution of trisaccharide **9** (105 mg, 0.093 mmol) in wet CH_2Cl_2 (10 mL) was added mercury(II) trifluoroacetate (199 mg, 0.465 mmol). After 20 min of stirring at 25 °C, the mixture was poured into 1 N aqueous HCl (50 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (40% EtOAc in petroleum ether) to afford the lactol (74 mg, 77%) as a white solid: R_f = 0.34 (40% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 178.2, 178.1, 170.1, 170.0, 169.8, 169.6, 169.4, 138.7, 138.6, 138.5, 138.4, 137.7, 128.8, 128.5, 128.4, 128.3, 127.9, 127.7, 127.4, 127.0, 100.8, 98.3, 96.4, 91.4, 80.6, 77.7, 76.4, 75.3, 75.1, 74.9, 74.0, 73.9, 73.8, 72.7, 72.3, 72.1, 71.0, 70.3, 69.7, 68.5, 66.7, 66.5, 65.8, 61.1, 60.9, 60.2, 38.9, 27.3, 20.8, 20.6, 20.5, 16.8; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (25.5H, m), 5.35 (1.7H, d, J = 3.3Hz), 5.26 (0.7H, dd, J = 3.3, 3.7Hz), 5.16−5.11 (1.7H, m), 5.07 (1H, d, J = 8.1Hz), 5.03−4.93 (4.1H, m), 4.88−4.73 (11.9H, m), 4.61−4.58 (2.0H, m), 4.55−4.52 (0.7H, m), 4.31−4.28 (0.7H, m), 4.25 (1H, dd, J = 2.8, 12.3Hz), 4.16−3.87 (10.9H, m), 3.75 (0.7H, brs), 3.73 (1H, brs), 3.69−3.60 (2.4H, m), 3.55 (1H, dd, J = 9.5, 9.9Hz), 3.5−3.4 (1H, m), 3.29 (0.7H, dd, J = 2.9, 10.3Hz), 3.18 (1H, dd, J = 8.1, 9.9Hz), 2.11, 2.10, 2.03, 1.97, 1.96, 1.79, 1.77, 1.75 (20.4H, m), 1.30 (2.1H, d, J = 6.6Hz), 1.27 (3H, d, J = 6.6Hz), 1.20 (15.3H, s); HRFABMS calcd for $C_{52}H_{64}O_{19}N_3$ ($M - H^-$) 1034.4134, found 1034.4172.

To a solution of the above lactol (82 mg, 0.079 mmol) and iodomethane (50 μL, 0.803 mmol) in DMF (5 mL) was added NaH (60%,16 mg, 0.40 mmol). After 20 min of stirring at 25 °C, the mixture was diluted with CH_2Cl_2 and poured into saturated aqueous $NaHCO_3$ (50 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (30% EtOAc in petroleum ether) to afford the methyl ether (70 mg, 84%) as a white solid: R_f = 0.41 (30% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 125.8 MHz) δ 177.8, 170.0, 169.7, 169.5, 169.4, 138.6, 138.5, 137.8, 128.9, 128.8, 128.4, 128.3, 128.2, 127.9, 127.7, 127.4, 127.0, 102.8, 100.8, 98.5, 98.3, 97.8, 80.7, 80.6, 77.8, 76.4, 75.5, 75.1, 75.0, 73.9, 73.7, 72.9, 72.5, 72.4, 72.3, 71.0, 70.9, 70.3, 69.5, 68.5, 67.5, 66.8, 66.5, 65.4, 61.5, 61.2, 60.3, 57.0, 55.0, 38.9, 27.3, 27.2, 20.8, 20.7, 20.6, 20.5, 16.8, 16.7; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (25.5H, m), 5.35 (1.7H, m), 5.16−5.10 (1.7H), 5.11 (1H, d, J = 8.1Hz), 5.07−4.93 (4.7H, m), 4.87−4.73 (12.6H, m), 4.61−4.53 (1.7H, m), 4.30 (1H, dd, J = 3.9, 12.3Hz), 4.25 (0.7H, dd, J = 4.4, 12.1Hz), 4.16−4.12 (2.7H, m), 4.08 (1.7H, dd, J = 8.4, 10.6Hz), 4.02 (0.7H, dd, J = 9.5, 9.9Hz), 3.98−3.86 (5.8H, m), 3.74 (0.7H, brs), 3.72 (1H, brs), 3.66−3.61 (m), 3.55 (1H, t, J = 9.5Hz), 3.52 (3H, s), 3.50−3.44 (1H, m), 3.39 (2.1H, s), 3.34 (0.7H, dd, J = 3.5, 10.1Hz), 3.19 (1H, dd, J = 8.1, 9.9Hz), 2.10, 2.09, 2.03, 1.96, 1.95, 1.79, 1.77 (20.4H, m), 1.30 (2.1H, d, J = 6.6Hz), 1.26 (3H, d, J = 6.6Hz), 1.20 (6.3H, s), 1.19 (9H, s); HRFABMS calcd for $C_{53}H_{67}O_{19}N_3Na$ ($M + Na^+$) 1072.4266, found 1072.4242.

The above methyl ether (17 mg, 0.016 mmol) was dissolved in EtOAc (5 mL) and stirred vigorously under hydrogen (1 atm) with the Lindlar catalyst (100 mg). After the reaction was run overnight, the catalyst was filtered off and the filtrate was concentrated. The residue was dissolved in EtOAc (5 mL) and stirred vigorously under hydrogen (1 atm) with Pd/C (100 mg). After 8 h of stirring at 25 °C, the catalyst was filtered off and the filtrate was concentrated. To the solution of the residue in CH_2Cl_2 (5 mL) were added Ac_2O, DMAP, and Et_3N. After 10 min of stirring at 25 °C, the reaction was quenched with MeOH (1 mL) and concentrated *in vacuo*. The residue was purified by flash chromatography (100% EtOAc) to afford 5 mg (34%) of α anomer **10a** and 6 mg (41%) of β anomer **10b** as white solids. For β-OCH_3: R_f = 0.15 (100% EtOAc); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.8, 170.7, 170.5, 170.3, 170.2, 170.1, 170.0, 169.9, 169.4, 100.5, 100.2, 95.1, 78.0, 76.2, 72.5, 72.2, 71.3, 71.0, 70.8, 68.5, 67.9, 66.8, 65.0, 62.3, 60.7, 56.1, 54.0, 38.8, 27.2, 23.5, 20.7, 15.8; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.79 (1H, d, J = 8.8Hz), 5.41 (1H, d, J = 2.9Hz), 5.32 (1H, d, J = 2.2Hz), 5.26 (1H, dd, J = 3.3, 11.0Hz), 5.21 (1H, dd, J = 3.3, 11.0Hz), 5.13 (1H, dd, J = 8.1, 10.3Hz), 5.04 (1H, d, J = 3.7Hz), 4.99 (1H, dd, J = 3.5, 10.4Hz), 4.82 (1H, d, J = 8.1Hz), 4.74 (1H, q, J = 6.5Hz), 4.53 (1H, d, J = 5.9Hz), 4.46 (1H, dd, J = 3.5, 11.9Hz), 4.36 (1H, dd, J = 5.9, 11.4Hz), 4.22 (1H, dd, J = 8.1, 11.4Hz), 4.06 (1H, dd, J = 7.0, 7.3Hz), 4.01 (1H, dd, J = 5.5, 11.7Hz), 3.90 (1H, dd, J = 7.0, 7.3Hz), 3.87−3.81 (2H, m), 3.71−3.66 (1H, m), 3.42 (3H, s), 2.18, 2.17, 2.09, 2.08, 2.07, 2.04, 1.98, 1.97 (8 × 3H, 8s), 1.24 (3H, d, J = 6.9Hz), 1.22 (9H, s); HRFABMS calcd for $C_{40}H_{60}NO_{23}$ ($M + H^+$) 922.3556, found 922.3543.

Methyl *β*-D-Galactopyranosyl-(1→3)-[α-L-fucopyranosyl-(1→4)]-2-acetamido-2-deoxy-*β*-D-glucopyranoside (1). To a solution of

trisaccharide **10b** (9 mg, 0.0098 mmol) in MeOH (5 mL) was added excess LiOH·H_2O. After the solution was stirred overnight at 25 °C, the reaction mixture was neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to give **1** (5 mg, 94%) as a white solid: ^{13}C NMR (D_2O, 125.8 MHz, CH_3OH as internal reference) δ 174.8, 103.2, 102.1, 98.4, 76.5, 75.8, 75.1, 72.8, 72.6, 72.2, 70.8, 69.4, 68.6, 68.1, 67.2, 61.9, 60.0, 57.4, 55.8, 22.6, 15.7; ^{1}H NMR (D_2O, 500 MHz) δ 4.98 (1H, d, J = 4.0Hz), 4.8−4.7 (1H, m), 4.44 (1H, d, J = 7.7Hz), 4.41 (1H, d, J = 8.4Hz), 4.02 (1H, t, J = 9.9Hz), 3.95 (1H, brd, J = 10.3Hz), 3.87−3.67 (4H, m), 3.58 (1H, dd, J = 3.3, 9.9Hz), 3.53−3.52 (2H, m), 3.46 (3H, s), 3.44 (1H, t, J = 9.9Hz), 1.99 (3H, s), 1.14 (3H, d, J = 6.6Hz); HRFABMS calcd for $C_{21}H_{37}NO_{15}Na$ (M + Na^+) 566.2061, found 566.2082.

Phenyl 3,4,6-Tri-*O*-benzyl-2-*O*-pivaloyl-1-thio-*β*-D-galactopyranoside and Sulfoxide Derivatives (11). To a solution of phenyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl-1-thio-*β*-D-galactopyranoside[13] (2.79 g, 4.78 mmol) in a mixture of MeOH and THF (v/v = 2:1, 50 mL) at 25 °C was added NaOMe (136 mg, 2.52 mmol). The mixture was stirred overnight at 25 °C and neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated and purified by flash chromatrography to afford the alcohol (2.32 g, 90%) as a white solid: R_f = 0.37 (20% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 138.5, 137.9, 137.7, 132.5, 132.0, 128.7, 128.4, 128.3, 128.0, 127.8, 127.7, 127.6, 127.5, 127.4, 127.3, 88.3, 83.1, 77.4, 74.2, 73.4, 73.1, 72.3, 68.9, 68.6; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−7.2 (20H, m), 4.9−4.4 (7H, m), 4.1−3.9 (2H, m), 3.64 (3H, s), 3.45 (1H, dd, J = 2.6. 9.4Hz), 2.57 (1H, brs); HRMS calcd for $C_{33}H_{34}O_5S$ (M^+) 542.2128, found 542.2130.

To a solution of the above alcohol (1.58 g, 2.92 mmol), 4-dimethylaminopyridine (178 mg, 1.43 mmol), and triethylamine (1.2 mL, 8.75 mmol) in CH_2Cl_2 (50 mL) at 25 °C was added pivaloyl chloride (725 μL, 5.83 mmol). The mixture was refluxed for 24 h and then cooled to 25 °C, and the reaction was quenched with MeOH (5 mL) and extracted with saturated aqueous $NaHCO_3$ (3 × 150 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (15% EtOAc in petroleum ether) to afford the pivaloate (1.32 g, 72%) as a white solid: R_f = 0.29 (10% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 176.7, 138.4, 137.8, 137.7, 133.9, 131.7, 128.7, 128.4, 128.3, 128.1, 128.0, 127.8, 127.7, 127.6, 127.4, 127.3, 127.2, 87.1, 81.9, 77.5, 74.2, 73.5, 72.9, 72.3, 69.2, 68.8, 38.7, 27.1; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−7.2 (20H, m), 5.48 (1H, t, J = 9.9Hz), 4.92 (1H, d, J = 11.6Hz), 4.66 (1H, d, J = 9.9Hz), 4.64−4.38 (5H, m), 3.97 (1H, d, J = 2.6Hz), 3.68−3.59 (4H, m), 1.22 (9H, s); HRFABMS calcd for $C_{38}H_{43}O_6S$ (M + H^+) 627.2780, found 627.2805.

To a solution of the above pivaloate (319 mg, 0.51 mmol) in CH_2Cl_2 (20 mL) at −78 °C was added 3-chloroperoxybenzoic acid (137 mg, 0.51 mmol) in CH_2Cl_2 (5 mL). After 15 min of stirring at −78 °C, the mixture was poured into saturated aqueous $NaHCO_3$ (100 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (30% EtOAc in petroleum ether) to afford sulfoxide **11** (290 mg, 89%, diastereomeric ratio is 2.1:1 which favors the more polar product) as a white solid: R_f = 0.44 (30% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 176.3, 139.6, 138.1, 137.7, 137.5, 131.0, 128.6, 128.4, 128.1, 128.0, 127.8, 127.7, 127.5, 127.2, 125.5, 91.0, 81.8, 78.7, 74.1, 73.4, 72.3, 68.6, 66.8, 38.8, 27.1; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.6−7.1 (20H, m), 5.69 (1H, dd, J = 9.9, 9.6Hz), 4.85−4.30 (6H, m), 4.22 (1H, d, J = 9.6Hz), 3.89 (1H, d, J = 2.6Hz), 3.68 (1H, dd, J = 2.5, 9.7Hz), 3.58−3.52 (3H, m), 1.23 (9H, s); R_f = 0.33 (30%EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.1, 138.3, 137.9, 137.6, 137.4, 131.4, 128.4, 128.2, 128.0, 127.8, 127.7, 127.3, 127.1, 126.8, 92.9, 81.0, 77.3, 73.8, 73.4, 72.4, 72.2, 67.5, 67.2, 38.8, 27.1; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.8−6.9 (20H, m), 5.36 (1H, t, J = 9.6Hz), 4.77−4.30 (7H, m), 3.88 (1H, brs), 3.66−3.36 (4H, m), 1.24 (9H, s); HRFABMS calcd for $C_{38}H_{42}O_7SNa$ (M + Na^+) 665.2549, found 665.2586.

Phenyl (3,4,6-Tri-*O*-benzyl-2-*O*-pivaloyl-*β*-D-galactopyranosyl)-(1→3)-2-azido-4,6-O-benzylidene-2-deoxy-1-thio-α-D-glucopyranoside (12). To a solution of sulfoxide **11** (290 mg, 0.452 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (284 mg, 1.36 mmol) in CH_2Cl_2 (10 mL) at −78 °C was added Tf_2O (38 μL, 0.226 mmol), and then the reaction mixture was warmed to −60 °C. After 15 min of stirring at −60 °C, nucleophile **4** (98 mg, 0.255 mmol) in CH_2Cl_2 (7.5 mL) was added to the mixture dropwise via syringe. After another 10 min of stirring at −60 °C, the mixture was slowly warmed to 0 °C over 1 h, and the reaction was quenched by saturated aqueous $NaHCO_3$ (5 mL) and washed with saturated aqueous $NaHCO_3$ (2 × 100 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (15% EtOAc in petroleum ether) to afford disaccharide **12** (177 mg, 77%) as a white solid: R_f = 0.33 (20% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 176.7, 138.4, 137.8, 137.7, 137.2, 132.7, 132.6, 129.1, 129.0, 128.4, 128.3, 128.2, 128.1, 128.0, 127.8, 127.5, 127.4, 127.0, 126.0, 101.3, 101.0, 87.3, 81.2, 81.0, 77.2, 74.3, 73.5, 73.3, 72.1, 71.7, 68.5, 68.4, 63.5, 38.9, 27.2; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (25H, m), 5.57 (1H, d, J = 4.8Hz), 5.51 (1H, s), 5.47 (1H, dd, J = 8.1, 10.3Hz), 4.89 (1H, d, J = 11.4Hz), 4.76 (1H, d, J = 8.1Hz), 4.63−4.48 (3H, m), 4.35 (1H, dt, J = 4.8, 9.9Hz), 4.30−4.23 (2H, m), 4.14 (1H, dd, J = 4.8, 10.3Hz), 3.98−3.97 (2H, m), 3.90 (1H, d, J = 2.6Hz), 3.81−3.77 (1H, m), 3.69 (1H, t, J = 10.3Hz), 3.62 (1H, dd, J = 9.5, 10.3Hz), 3.50 (1H, dd, J = 2.6, 10.3Hz), 3.43−3.40 (2H, m), 1.23 (9H, s); HRFABMS calcd for $C_{51}H_{55}O_{10}N_3SNa$ (M + Na^+) 924.3506, found 924.3483.

Phenyl (3,4,6-Tri-*O*-benzyl-*β*-D-galactopyranosyl)-(1→3)-2-azido-2-deoxy-6-*O*-pivaloyl-1-thio-α-D-glucopyranoside (13). Disaccharide **12** (177 mg, 0.196 mmol) was added into a mixture of trifluoroacetic acid and CH_2Cl_2 (v/v = 1:2, 20 mL) at 25 °C. After 1 h of stirring at 25 °C, the mixture was diluted with CH_2Cl_2 (10 mL) and poured into saturated aqueous $NaHCO_3$ (150 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 150 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (35% EtOAc in petroleum ether) to afford the diol (125 mg, 78%) as a white solid: R_f = 0.31 (35% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 176.9, 137.8, 137.4, 132.8, 132.7, 129.1, 128.4, 128.3, 128.2, 128.0, 127.9, 127.8, 127.7, 127.2, 101.6, 87.1, 82.6, 81.1, 74.3, 73.8, 73.7, 72.5, 72.3, 72.0, 70.8, 69.7, 68.8, 62.4, 62.3, 38.8, 27.1; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (20H, m), 5.65 (1H, d, J = 5.5Hz), 5.45 (1H, dd, J = 7.7, 9.9Hz), 4.9−4.4 (7H, m), 4.18−4.15 (1H, m), 3.85−3.82 (2H, m), 3.70−3.57 (7H, m), 3.5−3.4 (1H, m), 1.22 (9H, s); HRFABMS calcd for $C_{44}H_{51}O_{10}N_3SNa$ (M + Na^+) 836.3193, found 836.3203.

To a solution of the above diol (125 mg, 0.154 mmol) in MeOH: THF (v/v = 3:2, 25 mL) was added LiOH·H_2O (66 mg, 1.53 mmol). After 1 week of stirring at 25 °C, the mixture was diluted in CH_2Cl_2 and washed with 1 N aqueous HCl (50 mL) and saturated aqueous $NaHCO_3$ (3 × 100 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (45% EtOAc in petroleum ether) to afford the triol (110 mg, 98%) as a white solid: R_f = 0.27 (35% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 137.9, 137.3, 132.7, 129.1, 128.5, 128.4, 128.3, 128.0, 127.9, 127.8, 127.7, 104.3, 86.7, 85.2, 81.7, 74.5, 74.2, 73.6, 73.0, 72.8, 72.3, 71.4, 70.0, 69.0, 62.5, 62.4; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−7.2 (20H, m), 4.92−4.37 (8H, m), 4.23−4.16 (1H, m), 4.08−4.00 (1H, m), 3.92 (1H, dd, J = 5.6, 9.9Hz), 3.80−3.57 (8H, m), 3.48 (1H, dd, J = 2.8, 9.6Hz), 3.40−3.33 (1H, m), 2.75 (1H, d, J = 2.6Hz), 1.89 (1H, t, J = 6.3Hz); HRFABMS calcd for $C_{39}H_{44}O_9N_3S$ (M + H^+) 730.2798, found 730.2812.

To the above triol (110 mg, 0.151 mmol), triethylamine (63 μL, 0.454 mmol), 4-dimethylaminopyridine (9 mg, 0.074 mmol) in CH_2Cl_2 (10 mL) at 25 °C was added pivaloyl chloride (28 μL, 0.23 mmol) dropwise via syringe. After 2 h of stirring at 25 °C, the reaction was quenched with MeOH (1 mL). The mixture was washed with saturated aqueous $NaHCO_3$ (3 × 100 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (25% EtOAc in petroleum ether) to afford diol **13** (92 mg, 75%) as a white solid: R_f = 0.37 (25% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 178.3, 137.9, 137.2, 133.2, 132.0, 129.1, 128.6, 128.5, 128.4, 128.3, 128.2, 128.0, 127.9, 127.7, 104.6, 86.8, 85.4, 81.7, 74.6, 74.3, 73.8, 73.1, 72.8, 71.5, 70.9, 69.6, 69.0, 63.4, 62.5, 38.8, 27.2; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−7.2 (20H, m), 5.58 (1H, d, J = 5.6Hz), 4.92−4.35 (9H, m), 4.21 (1H, dd, J = 5.9, 12.2Hz), 4.07−4.02 (1H, m), 3.92 (1H, dd, J = 5.6, 10.2Hz), 3.80 (1H, d, J = 2.6Hz), 3.73−3.54 (4H, m), 3.49 (1H, dd, J = 2.8, 9.7Hz), 3.34 (1H, dd, J = 3.3, 8.3Hz), 2.70 (1H, d, J = 2.3Hz), 1.62 (1H, s), 1.17 (9H, s); HRFABMS calcd for $C_{44}H_{52}O_{10}N_3S$ (M + H^+) 814.3373, found 814.3385.

Phenyl (2,3,4-Tri-*O*-benzyl-α-L-fucopyranosyl)-(1→4)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→2)-(3,4,6-tri-*O*-benzyl-*β*-D-galactopyranosyl)-(1→3)]-2-azido-2-deoxy-6-*O*-pivaloyl-1-thio-α-D-glucopyranoside (14). To a solution of sulfoxide **8** (114 mg, 0.210 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (132 mg, 0.630 mmol) in CH_2Cl_2 (5 mL) at −78 °C was added Tf_2O (18 μL, 0.107 mmol), and then the reaction mixture was warmed to −60 °C. After 15 min of stirring at −60 °C, nucleophile **13** (41 mg, 0.050 mmol) in CH_2Cl_2 (3 mL) was added to the mixture dropwise via syringe. After 10 min of stirring at −60 °C, the reaction was slowly warmed to −5 °C over 1 h, quenched by saturated aqueous $NaHCO_3$ (5 mL), and washed with saturated aqueous $NaHCO_3$ (2 × 100 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (20% EtOAc in petroleum ether) to afford tetrasaccharide **14** (64 mg, 82%) as a white solid: $R_f = 0.37$ (20% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.7, 139.2, 138.8, 138.7, 138.2, 138.1, 137.8, 137.5, 133.1, 132.2, 129.2, 129.0, 128.7, 128.6, 128.4, 128.2, 128.1, 128.0, 127.9, 127.8, 127.7, 127.5, 127.3, 127.2, 127.1, 126.0, 100.7, 98.7, 98.5, 87.0, 83.6, 80.3, 80.1, 78.0, 75.7, 75.2, 74.9, 74.6, 74.5, 74.3, 73.7, 73.6, 73.5, 73.2, 73.0, 72.9, 72.8, 72.4, 71.9, 71.7, 71.0, 70.9, 67.8, 67.2, 66.6, 65.6, 61.5, 38.8, 27.2, 16.3, 16.1; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−6.9 (50H, m), 5.66 (1H, d, $J = 2.9$Hz), 5.59 (1H, d, $J = 5.5$Hz), 4.98−4.34 (22H, m), 4.13−3.56 (17H, m), 3.19 (1H, brs), 1.21 (3H, d, $J = 6.6$Hz), 1.16 (3H, d, $J = 6.6$Hz), 1.10 (9H, s).

Methyl (2,3,4-Tri-*O*-acetyl-α-L-fucopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→2)-(3,4,6-tri-*O*-acetyl-*β*-D-galactopyranosyl)-(1→3)]-6-*O*-acetyl-2-acetamido-2-deoxy-α,*β*-D-glucopyranoside (15a,b). To a solution of tetrasaccharide **14** (73 mg, 0.044 mmol) in wet CH_2Cl_2 (10 mL) was added mercury(II) trifluoroacetate (57 mg, 0.131 mmol). After 20 min of stirring at 25 °C, the reaction mixture was poured into 1 N aqueous HCl (50 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (40% EtOAc in petroleum ether) to afford the lactol (48 mg, 70%) as a white solid: $R_f = 0.49$ (30% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 126 MHz) δ 177.9, 139.2, 138.8, 138.7, 138.3, 138.1, 137.8, 137.6, 129.0, 128.7, 128.6, 128.4, 128.3, 128.2, 128.1, 128.0, 127.9, 127.8, 127.7, 127.5, 127.4, 127.3, 127.2, 127.1, 126.1, 100.7, 98.7, 98.6, 96.4, 91.8, 83.6, 80.3, 80.2, 79.9, 78.0, 77.5, 75.6, 75.3, 75.1, 75.0, 74.7, 74.5, 74.4, 74.3, 74.1, 73.7, 73.1, 73.0, 72.8, 72.6, 72.5, 72.4, 72.2, 71.7, 71.0, 70.1, 68.6, 68.0, 67.8, 67.2, 66.6, 65.4, 60.6, 38.9, 29.7, 29.4, 27.2, 16.2; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.4−6.9 (m), 5.64 (1H, d, $J = 3.3$ Hz), 5.0−2.7 (m), 1.21 (3H d, $J = 6.2$Hz), 1.17 (3H, d, $J = 6.6$Hz), 1.14 (s), 1.12 (s), 1.07 (3H, d, $J = 6.2$Hz).

To a solution of the above lactol (48 mg, 0.031 mmol) and iodomethane (20 μL, 0.321 mmol) in DMF (5 mL) was added NaH (60%, 6 mg, 0.150 mmol). After 30 min of stirring at 25 °C, the mixture was diluted with CH_2Cl_2 and poured into saturated aqueous $NaHCO_3$ (50 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (20% EtOAc in petroleum ether) to afford the methyl ether (43 mg, 88%) as a white solid: ^{13}C NMR ($CDCl_3$, 126 MHz) δ 177.7, 139.2, 138.8, 138.6, 138.2, 138.1, 137.8, 137.6, 137.5, 129.0, 128.8, 128.7, 128.6, 128.4, 128.2, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 127.5, 127.4, 127.3, 127.2, 127.1, 126.1, 102.9, 100.7, 98.7, 98.6, 98.0, 83.6, 80.3, 79.9, 78.0, 77.2, 75.6, 75.2, 75.0, 74.9, 74.7, 74.5, 74.3, 73.9, 73.6, 73.2, 73.0, 72.9, 72.7, 72.5, 72.3, 71.6, 71.0, 69.6, 68.0, 67.5, 67.1, 66.6, 65.0, 61.0, 57.0, 54.9, 38.8, 27.2, 16.2; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.3−6.9 (45H, m), 5.64 (1H, d, $J = 2.6$Hz), 5.1−3.1 (26H, m), 1.2−1.0 (15H, m).

To condensed ammonia at −78 °C was added sodium beads until the dark blue color was sustained. A solution of the above methyl ether (38 mg, 0.024 mmol) in THF (1 mL) was added to the sodium−ammonia solution dropwise via syringe over 5 min. After 2 h of stirring at −78 °C, the reaction was quenched by addition of MeOH (1 mL), slowly warmed up to room temperature, and dried with stream of argon. The white residue was dissolved in MeOH (3 mL), cooled to 0 °C, and neutralized with Dowex 50x8-100 acidic resin. The resin was filtered, and the filtrate was concentrated, dried azeotropically with pyridine (3 × 5 mL), and dissolved in pyridine (3 mL). To the mixture were added Ac_2O (57 μL, 0.603 mmol) and DMAP (2 mg, 0.016 mmol). After 20 min of stirring at 25 °C, the reaction was quenched with MeOH (1 mL) and concentrated *in vacuo*. The residue was purified using flash chromatography (100% EtOAc) to give 3 mg (11%) of α anomer **15a** and 6 mg (23%) of *β* anomer as white solids. For *β*-OCH_3: $R_f = 0.34$ (5% MeOH in EtOAc); ^{13}C NMR ($CDCl_3$, 126 MHz) δ 171.0, 170.7, 170.5, 170.3, 170.2, 169.8, 99.6, 99.3, 96.8, 95.4, 74.0, 73.8, 72.4, 71.6, 71.4, 70.9, 70.6, 68.1, 67.8, 67.7, 67.5, 67.3, 64.8, 61.8, 60.6, 56.9, 29.7, 23.3, 20.8, 20.7, 16.1, 15.5; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.14 (1H, d, $J = 7.0$Hz), 5.42 (1H, d, $J = 3.7$Hz), 5.36 (1H, dd, $J = 3.3$Hz), 5.33−5.27 (6H, m), 5.05−4.95 (5H, m), 4.76 (1H, d, $J = 5.1$Hz), 4.71 (1H, q, $J = 6.6$Hz), 4.49−4.44 (2H, m), 4,36 (1H, dd, $J = 5.7$, 11.2Hz), 4.17 (1H, dd, $J = 7.6$, 11.4Hz), 3.99 (1H, dd, $J = 3.1$, 12.3Hz), 3.96−3.85 (3H, m), 3.72 (1H, brd, $J = 9.9$Hz), 3.48 (3H, s), 3.47−3.45 (1H, m), 2.17, 2.12, 2.10, 2.08, 2.05, 2.04, 2.01, 2.00, 1.99, 1.96 (33H, m), 1.23 (3H, d, $J = 6.6$Hz), 1.17 (3H, d, $J = 6.6$Hz); HRFABMS calcd for $C_{47}H_{68}NO_{29}$ ($M + H^+$): 1110.3877, found 1110.3866.

Methyl α-L-Fucopyranosyl-(1→4)-[α-L-fucopyranosyl-(1→2)-*β*-D-galactopyranosyl-(1→3)]-2-acetamido-2-deoxy-*β*-D-glucopyranoside (2). To a solution of tetrasaccharide **15b** (5 mg, 0.0045 mmol) in MeOH (5 mL) was added catalytic NaOMe. After 30 min of stirring at 25 °C, the reaction mixture was neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to give **2** (3 mg, 97%) as a white solid: ^{13}C NMR (D_2O, 126 MHz, CH_3OH as internal reference) δ 174.1, 103.0, 100.9, 99.9, 98.1, 76.8, 75.7, 75.1, 75.0, 73.9, 72.5, 72.3, 69.7, 69.4, 69.1, 68.6, 68.1, 67.3, 66.5, 61.9, 59.9, 57.5, 55.9, 22.5, 15.7, 15.6; ^{1}H NMR (D_2O, 500 MHz) δ 5.12 (1H, d, $J = 4.3$Hz), 4.99 (1H, d, $J = 3.7$Hz), 4.82 (1H, q, $J = 7.0$Hz), 4.62 (1H, d, $J = 8.7$Hz), 4.31 (1H, q, $J = 7.0$Hz), 4.30 (1H, d, $J = 8.4$Hz), 4.09 (1H, dd, $J = 10.6$, 9.2Hz), 3.96 (1H, brd, $J = 10.3$Hz), 3.90 (1H, dd, $J = 3.3$, 10.3Hz), 3.85−3.65 (15H, m), 3.59−3.52 (3H, m), 3.45 (3H, s), 2.03 (3H, s), 1.23 (6H, d, $J = 7.0$Hz); HRFABMS calcd for $C_{27}H_{47}NO_{19}Na$ ($M + Na^+$) 712.2640, found 712.2611.

Phenyl 2-Azido-2-deoxy-3-*O*-(4′-methoxybenzyl)-6-*O*-pivaloyl-1-thio-α-D-glucopyranoside (16). To a solution of the phenyl 3,4,6-tri-*O*-acetyl-2-azido-2-deoxy-1-thio-α-D-glucopyranoside[8] (2.4 g, 5.67 mmol) in MeOH (25 mL) was added catalytic amount of NaOMe. After 1 h of stirring, the reaction mixture was neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to give the crude triol as a white residue which was dried azeotropically by toluene (3 × 10 mL) and taken to next step without further purification.

To a solution of the above crude triol (5.67 mmol) and 2,2-dimethoxypropane (1.4 mL, 11.35 mmol) in DMF (25 mL) was added catalytic amount of $TsOH·H_2O$. After 24 h of stirring at 25 °C, the reaction mixture was neutralized with Amberlite IRA-400(OH). The resin was filtered off, and the filtrate was concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2 (50 mL) and washed with saturated aqueous $NaHCO_3$ (2 × 200 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (20% EtOAc in petroleum ether) to afford the ketal (1.3 g, 69%, $\alpha/\beta = 2.3$:1) as a colorless syrup: $R_f = 0.36$ (25% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 133.4, 133.0, 132.4, 131.0, 129.1, 128.5, 127.9, 100.2, 100.0, 87.7, 86.9, 74.4, 73.0, 71.2, 70.9, 65.3, 64.3, 64.0, 61.8, 61.7, 28.9, 28.8, 19.1, 19.0; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.6−7.2 (10H, m), 5.55 (1H, d, $J = 4.9$Hz), 4.50 (1H, d, $J = 10.2$Hz), 4.25−4.16 (1H, m), 3.99−3.20 (11H, m), 1.53, 1.50, 1.48, 1.43 (4 × 3H, 4s); HRMS calcd for $C_{15}H_{19}O_4N_3S$ (M^+) 337.1098, found 337.1106.

To a solution of the ketal (462 mg, 1.37 mmol) and *p*-methoxybenzyl chloride (380 μL, 2.74 mmol) in DMF (20 mL) at 25 °C was added NaH (60%, 110 mg, 2.75 mmol). After 1 h of stirring at 25 °C, the reaction was quenched with MeOH (5 mL) and concentrated *in vacuo*. The residue was dissolved with CH_2Cl_2 and washed with saturated aqueous $NaHCO_3$ (2 × 150 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (10% EtOAc in petroleum ether) to afford the *p*-methoxybenzyl ether (459 mg, 73%) as a colorless syrup: $R_f = 0.22$ (10% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 159.4, 133.1, 132.4, 130.0, 129.9, 129.1, 127.8, 113.8, 99.6, 87.9, 77.7, 75.5, 74.6, 64.7, 63.3, 62.1, 55.2, 29.2, 19.2; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−6.9 (9H, m), 5.50 (1H, d, $J = 5.3$Hz), 4.78 (2H, dd, $J = 10.6$, 34.0Hz), 4.23 (1H, dt, $J = 5.3$,

9.6Hz), 3.9−3.7 (8H, m), 1.52, 1.48 (2 × 3H, 2s); HRMS calcd for $C_{23}H_{27}O_5N_3S$ (M^+) 457.1673, found 457.1677.

To a solution of the above *p*-methoxybenzyl ether (314 mg, 0.69 mmol) in MeOH (10 mL) at 25 °C was added a catalytic amount of $TsOH\cdot H_2O$. After 1 h of stirring, the reaction mixture was neutralized with Amberlite IRA-400(OH). The resin was filtered off, and the filtrate was concentrated *in vacuo*. The residue was purified by flash chromatography (45% EtOAc in petroleum ether) to afford the diol (270 mg, 94%) as a colorless syrup: R_f = 0.43 (50% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 159.4, 133.0, 132.3, 129.8, 129.1, 127.8, 114.0, 87.1, 81.0, 75.0, 72.4, 70.4, 63.5, 61.5, 55.1; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−6.8 (9H, m), 5.45 (1H, d, J = 5.3Hz), 4.85 (1H, d, J = 10.9Hz), 4.71 (1H, d, J = 10.9Hz), 4.10 (1H, m), 3.8−3.6 (8H, m), 3.32 (1H, d, J = 3.3Hz), 2.52 (1H, m); HRMS calcd for $C_{20}H_{23}O_5N_3S$ (M^+) 417.1358, found 417.1366.

To a solution of the above diol (0.688 mmol), 4-dimethylaminopyridine (40 mg, 0.327 mmol), and triethylamine (270 μL, 1.94 mmol) in CH_2Cl_2 (5 mL) at 25 °C was added pivaloyl chloride (121 μL, 0.97 mmol) dropwise via syringe. After 2 h of stirring, the reaction was quenched by MeOH (2 mL) and washed with saturated aqueous $NaHCO_3$ (3 × 150 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (20% EtOAc in petroleum ether) to afford **16** (280 mg, 81%) as a white solid: R_f = 0.44 (25% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 179.3, 159.6, 133.3, 131.8, 130.0, 129.8, 129.1, 127.7, 114.1, 87.2, 80.5, 75.2, 71.3, 70.9, 63.5, 63.1, 55.2, 38.9, 27.1; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−6.8 (9H, m), 5.56 (1H, d, J = 5.6Hz), 4.83 (2H, dd, J = 10.9, 24.1Hz), 4.44 (1H, dd, J = 4.6, 11.9Hz), 4.35−4.30 (1H, m), 4.19 (1H, dd, J = 2.0, 12.2Hz), 3.86−3.80 (4H, m), 3.65 (1H, dd, J = 8.6, 10.2Hz), 3.47−3.39 (1H, m), 2.88 (1H, d, J = 3.6Hz), 1.18 (9H, s); HRMS calcd for $C_{25}H_{31}O_6N_3S$ (M^+) 501.1935, found 501.1932.

Phenyl (2,3,4,6-Tetra-*O*-pivaloyl-β-D-galactopyranosyl)-(1→4)-2-azido-2-deoxy-3-*O*-(4′-methoxybenzyl)-6-*O*-pivaloyl-1-thio-α-D-glucopyranoside (17). To a solution of sulfoxide **5** (300 mg, 0.481 mmol) in CH_2Cl_2 (10 mL) at −78 °C was added Tf_2O (40 μL, 0.243 mmol), and then the reaction mixture was warmed to −60 °C. After 15 min of stirring at −60 °C, nucleophile **16** (96 mg, 0.192 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (302 mg, 1.44 mmol) in CH_2Cl_2 (5 mL) were added to the mixture dropwise via syringe. After 10 min of stirring at −60 °C, the reaction was slowly warmed to 0 °C over 1 h, quenched by saturated aqueous $NaHCO_3$ (5 mL), and washed with saturated aqueous $NaHCO_3$ (2 × 100 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (15% EtOAc in petroleum ether) to afford disaccharide **17** (123 mg, 64%) as a white solid: R_f = 0.31 (15% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 177.8, 177.6, 177.3, 176.8, 176.6, 159.2, 133.4, 131.6, 130.1, 129.5, 129.1, 127.7, 113.7, 100.3, 86.9, 78.5, 77.2, 76.8, 75.1, 71.3, 70.1, 69.2, 66.6, 63.3, 62.2, 61.0, 55.2, 39.0, 38.9, 38.8, 38.7, 27.2, 27.1, 27.04; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−6.9 (9H, m), 5.51 (1H, d, J = 4.8Hz), 5.41 (1H, brd, J = 2.9Hz), 5.34 (1H, dd, J = 8.1, 10.6Hz), 5.10 (1H, d, J = 10.3Hz), 5.05 (1H, dd, J = 3.3, 10.6Hz), 4.68 (1H, d, J = 10.6Hz), 4.62 (1H, d, J = 8.1Hz), 4.33−4.30 (2H, m), 4.24 (1H, dd, J = 4.6, 11.9Hz), 4.16 (1H, dd, J = 7.0, 11.4Hz), 4.03 (1H, dd, J = 7.0, 11.0Hz), 3.95−3.89 (2H, m), 3.82−3.73 (5H, m), 1.21, 1.20, 1.17, 1.16, 1.12 (5 × 9H, 5s); HRFABMS calcd for $C_{51}H_{72}O_{15}N_3S$ ($M + Na^+$) 1022.4660, found 1022.4670.

Phenyl (2,3,4,6-Tetra-*O*-acetyl-β-D-galactopyranosyl)-(1→4)-6-*O*-acetyl-2-azido-2-deoxy-1-thio-α-D-glucopyranoside (18). To a solution of disaccharide **17** (518 mg, 0.519 mmol) in MeOH (5 mL) was added excess $LiOH\cdot H_2O$. After the solution was stirred overnight at 25 °C, the reaction mixture was neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to produce the crude pentaol as a white residue which was dried azeotropically by toluene (3 × 5 mL) and taken to next step without further purification.

To the above crude pentaol (0.067 mmol) and 4-dimethylaminopyridine (32 mg, 0.262 mmol) in pyridine (10 mL) at 25 °C was added acetic anhydride (493 μL, 5.19 mmol) dropwise via syringe. After 2 h of stirring at 25 °C, the reaction mixture was quenched with MeOH (1 mL) and concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2, washed with 1 N aqueous HCl (50 mL), and saturated aqueous $NaHCO_3$ (3 × 50 mL). The organic layers were dried over Na_2SO_4, concentrated, and purified by flash chromatography (13% Et_2O in CH_2Cl_2) to afford the pentaacetate (319 mg, 78% 2 steps) as a white solid: R_f = 0.32 (13% Et_2O in CH_2Cl_2); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 170.3, 170.1, 170.0, 169.4, 159.3, 133.1, 131.7, 129.9, 129.4, 129.1, 127.7, 113.7, 101.0, 86.7, 79.0, 77.9, 75.1, 71.0, 70.8, 69.8, 69.4, 66.6, 63.4, 62.1, 60.4, 55.2, 20.7, 20.6, 20.5; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−6.8 (9H, m), 5.56 (1H, d, J = 5.5Hz), 5.36 (1H, d, J = 3.3Hz), 5.25 (1H, dd, J = 8.1, 10.3Hz), 5.01−4.97 (2H, m), 4.74 (1H, d, J = 9.9Hz), 4.58 (1H, d, J = 8.1Hz), 4.40−4.30 (2H, m), 4.24 (1H, dd, J = 4.6, 11.9H), 4.16 (1H, dd, J = 7.0, 11.4Hz), 4.20−4.15 (1H, m), 4.07−4.03 (1H, m), 3.93−3.87 (2H, m), 3.83−3.72 (6H, m), 2.17, 2.10, 2.04, 1.99, 1.98 (5 × 3H, 5s); HRFABMS calcd for $C_{36}H_{43}O_{15}N_3SNa$ ($M + Na^+$) 812.2313, found 812.2296.

The above pentaacetate (33 mg, 0.042 mmol) was added into a solution (5 mL) of 10% trifluoroacetic acid in CH_2Cl_2 at 25 °C. The mixture gradually turned dark pink. After 30 min of stirring at 25 °C, the mixture was diluted with CH_2Cl_2 (5 mL) and poured into saturated aqueous $NaHCO_3$ (50 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 50 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (45% EtOAc in petroleum ether) to afford **18** (28 mg, 96%) as a white solid: R_f = 0.36 (45% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 170.5, 170.0, 169.9, 169.5, 132.9, 132.2, 129.1, 127.9, 102.0, 86.4, 83.3, 72.6, 71.5, 70.8, 68.7, 68.2, 66.8, 62.9, 62.6, 62.1, 20.7, 20.6, 20.4; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.5−7.2 (5H, m), 5.51 (1H, d, J = 5.3Hz), 5.41 (1H, d, J = 3.9Hz), 5.29 (1H, dd, J = 7.9, 10.6Hz), 5.03 (1H, dd, J = 3.3, 10.6Hz), 4.64 (1H, d, J = 1.6Hz), 4.58 (1H, d, J = 7.9Hz), 4.50−4.45 (1H, m), 4.23−4.00 (6H, m), 3.83 (1H, dd, J = 5.3, 10.2Hz), 3.50 (1H, dd, J = 7.9, 9.9Hz), 2.19, 2.13, 2.09, 2.06, 1.99 (5 × 3H, 5s); HRFABMS calcd for $C_{28}H_{35}O_{14}N_3S$ (M^+) 669.1839, found 669.1849.

Phenyl (2,3,4,6-Tetra-*O*-acetyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→3)]-6-*O*-acetyl-2-azido-2-deoxy-1-thio-α-D-glucopyranoside (19). To a solution of sulfoxide **8** (128 mg, 0.236 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (149 mg, 0.711 mmol) in CH_2Cl_2 (5 mL) at −78 °C was added Tf_2O (20 μL, 0.119 mmol), and then the reaction mixture was warmed to −60 °C. After 15 min of stirring at −60 °C, nucleophile **18** (27 mg, 0.040 mmol) in CH_2Cl_2 (5 mL) was added to the mixture dropwise via syringe. After 10 min of stirring at −60 °C, the reaction was slowly warmed to 0 °C over 1 h, quenched by saturated aqueous $NaHCO_3$ (5 mL), and washed with saturated aqueous $NaHCO_3$ (2 × 50 mL). The organic layer was dried over Na_2SO_4, concentrated, and purified by flash chromatography (45% EtOAc in petroleum ether) to afford trisaccharide **19** (36 mg, 83%) as a white solid: R_f = 0.29 (40% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 170.1, 170.0, 169.7, 168.8, 138.9, 138.6, 138.3, 133.3, 131.7, 129.2, 128.3, 128.2, 127.8, 127.6, 127.3, 127.0, 100.7, 98.0, 86.6, 80.0, 76.8, 75.4, 74.0, 73.7, 73.0, 72.6, 70.8, 70.7, 70.1, 68.6, 66.5, 66.3, 64.3, 61.8, 60.4, 60.0, 20.8, 20.6, 20.5, 16.8; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (20H, m), 5.65 (1H, d, J = 5.5Hz), 5.42 (1H, d, J = 3.7Hz), 5.35 (1H, d, J = 2.6Hz), 5.11 (1H, dd, J = 8.2, 10.4Hz), 4.97 (1H, d, J = 12.1Hz), 4.93 (1H, dd, J = 3.3, 10.6Hz), 4.91−4.68 (5H, m), 4.66 (1H, d, J = 6.6Hz), 4.48 (1H, d, J = 8.1Hz), 4.47 (1H, m), 4.33 (1H, m), 4.21−4.03 (5H, m), 3.93 (1H, dd, J = 2.6, 10.3Hz), 3.86−3.81 (3H, m), 3.73 (1H, brs), 2.06, 2.05, 2.02, 1.95, 1.82 (5 × 3H, 5s), 1.27 (3H, d, J = 6.6Hz); HRFABMS calcd for $C_{55}H_{63}O_{18}N_3SNa$ ($M + Na^+$) 1108.3725, found 1108.3783.

Methyl (2,3,4,6-Tetra-*O*-acetyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→3)]-2-acetamido-6-*O*-acetyl-2-deoxy-α,β-D-glucopyranoside (20a,b). To a solution of trisaccharide **19** (105 mg, 0.097 mmol) in wet CH_2Cl_2 (10 mL) was added mercury(II) trifluoroacetate (199 mg, 0.457 mmol). After 20 min of stirring at 25 °C, the mixture was poured into 1 N aqueous HCl (50 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (40% EtOAc in petroleum ether) to afford the lactol (74 mg, 77%) as a white solid: R_f = 0.39 (55% EtOAc in petroleum ether); ^{13}C NMR ($CDCl_3$, 68 MHz) δ 170.3, 170.0, 169.8, 169.7, 168.8, 139.0, 138.9, 138.5, 138.2, 128.5, 128.4, 128.3, 128.2, 128.1, 127.6, 127.5, 127.3, 127.0, 100.6, 97.4, 96.6, 91.9, 80.0, 79.9, 75.5, 74.9, 74.1, 73.4, 73.3, 72.8, 71.5, 70.8, 70.7, 70.6, 69.1, 68.6,

67.2, 66.43, 66.3, 66.2, 64.1, 61.6, 61.5, 59.9, 20.8, 20.6, 20.5, 16.7; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.5−7.2 (15H, m), 5.54 (0.5H, d, J = 4.0Hz), 5.36−5.33 (1.5H, m), 5.11−4.57 (11H, m), 4.52 (0.5H, d, J = 8.1Hz), 4.49 (0.5H, d, J = 8.1Hz), 4.18−3.82 (7.5H, m), 3.72 (1H, s), 3.65 (1H, t, J = 9.4Hz), 3.51 (1H, dd, J = 8.1, 9.9Hz), 3.46−3.41 (1.5H, m), 2.10, 2.04, 2.02, 2.01, 2.00, 1.95, 1.94, 1.81 (15H, s), 1.25 (1H, d, J = 6.2Hz); HRFABMS calcd for $C_{49}H_{59}N_3O_{19}$ (M^+) 993.3743, found 993.3749.

To a solution of the above lactol (27 mg, 0.027 mmol) and iodomethane (17 μL, 0.272 mmol) in DMF (5 mL) was added NaH (60%, 5 mg, 0.125 mmol). After 1 h of stirring at 25 °C, the mixture was diluted with CH_2Cl_2 and poured into saturated aqueous $NaHCO_3$ (50 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ (2 × 100 mL), dried over Na_2SO_4, concentrated, and purified by flash chromatography (55% EtOAc in petroleum ether) to afford the methyl ether (25 mg, 92%) as a white solid.

The above methyl ether (28 mg, 0.028 mmol) was dissolved in EtOAc (5 mL) and stirred vigorously under hydrogen (1 atm) with the Lindlar catalyst (100 mg). After the reaction was conducted overnight, the catalyst was filtered off and the filtrate was concentrated. Then, the residue was dissolved in EtOAc (5 mL) and stirred vigorously under hydrogen (1 atm) with palladium on charcoal (100 mg). After 8 h of stirring at 25 °C, the catalyst was filtered off and the filtrate was concentrated. To a solution of the residue in CH_2Cl_2 (5 mL) were added Ac_2O (27 μL, 0.28 mmol), DMAP (2 mg, 0.016 mmol), and Et_3N (58 μL, 0.42 mmol). After 10 min of stirring at 25 °C, the reaction was quenched with MeOH (1 mL) and concentrated *in vacuo*. The residue was purified by flash chromatography (100% EtOAc) to afford 8 mg (33%) of β anomer **20b** and 5 mg (20%) of α anomer **20a** as white solids. For β anomer: R_f = 0.30 (100% EtOAc); ^{13}C NMR ($CDCl_3$, 126 MHz) δ 171.0, 170.7, 170.6, 170.5, 170.4, 170.0, 169.9, 169.4, 100.9, 100.3, 94.8, 74.2, 72.7, 72.4, 71.2, 71.1, 70.7, 68.8, 68.1, 68.0, 66.6, 64.4, 62.3, 60.7, 56.6, 54.2, 29.7, 23.4, 20.9, 20.8, 20.7, 20.6, 15.9; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.63 (1H, d, J = 8.8Hz), 5.43−5.42 (2H, m), 5.36 (1H, d, J = 2.6Hz), 5.20 (1H, dd, J = 3.3, 11.0Hz), 5.11 (1H, dd, J = 8.1, 10.3Hz), 5.04−4.99 (2H, m), 4.73 (1H, q, J = 6.6Hz), 4.60 (1H, dd, J = 3.3, 12.1Hz), 4.55 (1H, d, J = 6.6Hz), 4.47 (1H, d, J = 8.1Hz), 4.45 (1H, dd, J = 6.2, 11.7Hz), 4.28 (1H, dd, J = 7.7, 11.4Hz), 4.21 (1H, dd, J = 5.0, 11.9Hz), 4.09 (1H, dd, J = 7.7, 8.1Hz), 3.88 (1H, dd, J = 7.0, 7.3Hz), 3.85 (1H, t, J = 7.7Hz), 3.82−3.75 (1H, m), 3.63−3.60 (1H, m), 3.43 (3H, s), 2.20, 2.15, 2.14, 2.11, 2.08, 2.07, 2.00, 1.99, 1.97 (9 × 3H, 9s), 1.21 (3H, d, J = 6.6Hz); HRFABMS calcd for $C_{37}H_{54}NO_{23}$ ($M + H^+$) 880.3087, found 880.3115.

Methyl β-D-Galactopyranosyl-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-acetamido-2-deoxy-β-D-glucopyranoside (3). To a solution of trisaccharide **20b** (5 mg, 0.0057 mmol) in MeOH (5 mL) was added NaOMe (1 mg, 0.019 mmol). After 30 min of stirring at 25 °C, the reaction mixture was neutralized with Dowex 50x8-100 acidic resin. The resin was filtered off, and the filtrate was concentrated to give **3** (3 mg, 97%) as a white solid: ^{13}C NMR (D_2O, 126 MHz, CH_3OH as internal reference) δ 174.8, 102.2, 102.1, 99.0, 75.7, 75.3, 75.2, 73.7, 72.7, 72.2, 71.3, 69.5, 68.6, 68.0, 67.0, 61.8, 60.0, 57.5, 55.9, 22.5, 15.6; ^{1}H NMR (D_2O, 500 MHz) δ 5.08 (1H, d, J = 4.0Hz), 4.82−4.78 (1H, m), 4.45 (1H, d, J = 8.4Hz), 4.43 (1H, d, J = 8.1Hz), 3.99 (1H, brd, J = 10.3Hz), 3.93−3.82 (6H, m), 3.77 (1H, d, J = 2.9Hz), 3.72−3.65 (3H, m), 3.64 (1H, dd, J = 3.7, 9.9Hz), 3.59−3.54 (2H, m), 3.49−3.46 (4H, m), 2.01 (3H, s), 1.16 (3H, d, J = 6.6Hz); HRFABMS calcd for $C_{21}H_{37}NO_{15}Na$ ($M + Na^+$) 566.2061, found 566.2080.

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Supporting Information Available: ^{1}H and ^{13}C NMR spectra for **1**−**9**, **10b**, **11**−**14**, **15b**, **16**−**19**, and **20b** (46 pages). See any current masthead for ordering and Internet access instructions.

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