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Regio- and Stereocontrolled Synthesis of 2d-Deoxy Lewis^x Pentasaccharide

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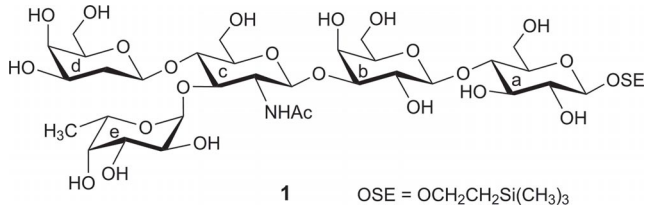
The total synthesis of 2d-deoxy Lewis^x pentasaccharide is described. Ethyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl-1-thio-α,β-D-galactopyranoside was condensed with a diol of glucosamine to regio- and stereoselectively give the disaccharide, the C-2′ position was then reduced after stereoselective fucosylation to afford a Lewis^x trisaccharide analogue. Regioselective glycosylation of a known lactoside diol with this trisaccharide provided a pentasaccharide that, after deprotection, gave the target pentasaccharide.

Introduction

Carbohydrates play an important role in many biological occurrences including recognition, adhesion and communication between cells, inflammation, and bacterial and viral infections.[1,2] A variety of these processes are known to involve not only carbohydrate–protein interactions,[3,4] but also interactions between carbohydrate molecules.[5] A typical example is the report of Hakomori, who proposed that carbohydrate–carbohydrate interaction is responsible for the initial step of cell adhesion.[6] One of the structures involved in this novel mechanism is the Lewis^x (Le^x) trisaccharide determinant (Galβ1→4[Fucα1→3]GlcNAcβ1). The interaction between Le^x and Le^x was found to be homotypic, and mediated by the presence of divalent cations such as Ca^{2+}.[7,8]

Recently, the Le^x–Le^x interaction has been studied more extensively by using a variety of techniques including nuclear magnetic resonance (NMR) spectroscopy,[9] mass spectrometry (MS),[10] vesicle adhesion,[11] atomic force microscopy (AFM),[12] and surface plasmon resonance (SPR) spectroscopy.[13] Rat basophilic leukaemia cells pre-incubated with purified Le^x-containing glycosphingolipids have been used as a model.[14] Another model system termed "Glycosylated Foldamer" was developed for the study of carbohydrate–carbohydrate interactions in terms of individual carbohydrate motifs.[15] By using a vesicle micromanipulation approach with chemically synthesized natural Le^x pentasaccharide glycosphingolipid, we have demonstrated that, in contrast to glyconeolipids,[11] which allow strong orientational freedom of the Le^x group, the natural lipid showed a restricted orientation of the Le^x group. The adhesion induced by Le^x–Le^x interactions was thereby considerably enhanced, indicating that the relative orientation of the two Le^x groups is a dominant factor in Le^x–Le^x recognition.[16] In another experiment, the Le^x trisaccharide determinant in the headgroup was replaced by its isomer Le^a trisaccharide, in which the galactose and fucose groups are permutated relative to Le^x on one vesicle surface. The adhesion energy observed for the Le^x–Le^a pair was very weak, confirming the homotypic characteristics of this type of carbohydrate–carbohydrate interaction.[16]

Based on our previous studies on Le^x–Le^x interactions,[9b,9f,11a,11b,16] we became interested in exploring the molecular mechanism involved in this new type of carbohydrate–carbohydrate interaction. To gain insight into the functions of the different hydroxyl groups on the Le^x trisaccharide molecule, we planned to generate a series of pentasaccharides in which one of the eight hydroxyl groups was replaced by a hydrogen atom, and to quantify the adhesion energy induced by interactions of these derivatives. Having synthesized the 3d-deoxy, 4d-deoxy, and 6d-deoxy Lewis^x pentasaccharides,[17,18,19] herein, we would like to report on the first total synthesis of 2d-deoxy Lewis^x pentasaccharide (**1**), which could be a useful tool for a mechanistic study of carbohydrate–carbohydrate interactions (Scheme 1).



1 OSE = $OCH_2CH_2Si(CH_3)_3$

Scheme 1. Structure of 2d-deoxy Lewis^x pentasaccharide.

Among the various deoxy sugars, 2-deoxy derivatives have been found to be significant as integral components of

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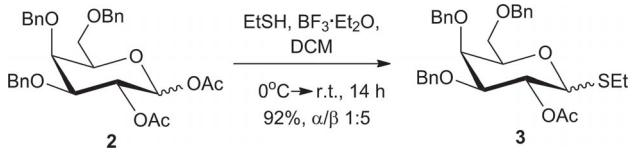
many natural products.[20] These compounds are interesting not only because of their biological profiles but also because of the synthetic challenges they present. The main challenge in the synthesis of **1** is the construction of the glucopyranosyl 2-deoxy-β-galactopyranosidic linkage. We therefore adopted an indirect synthetic method to access the 2-deoxy-β-disaccharide that entailed the use of a donor containing a participating group at C-2 to insure the desired β-glycosidic linkage; the C-2 position was then reduced after fucosylation.[21] In this approach, the desired β1→4 linked disaccharide was obtained in high yield.

Results and Discussion

For synthesis of the target **1**, the known 1,2-di-*O*-acetyl-3,4,6-tri-*O*-benzyl-D-galactopyranose (**2**; α/β, 1:1)[22] was first used to react with previously prepared diol **4**[23] in the presence of trimethylsilyl trifluoromethanesulfonate (TMSOTf) to regioselectively give the β 1→4 linked disaccharide **5** (Scheme 3), however, the yield of the reaction was not satisfactory (47%), and some starting materials were recovered. Compound **2** was then converted into the thioethyl donor **3** (Scheme 2), which was coupled with **4** in toluene using *N*-iodosuccinimide (NIS)-TfOH as promoters without affecting the SPh group of the acceptor **4**. The desired disaccharide **5** was regio- and stereoselectively obtained in 73% yield (Scheme 3). Being more nucleophilic, the SEt group displays a stronger reactivity than the SPh group as a glycosylation donor, such selective behaviour has been observed in our previous work.[17] The use of dichloromethane as solvent gave a lower yield.



Scheme 2. Synthesis of galactose building block **3**.

The ^{1}H NMR spectrum of **5** revealed the presence of 3c-H of the glucosamine residue at δ = 4.45 ppm (dd, $J_{2c,3c}$ = 10.4, $J_{3c,4c}$ = 7.8 Hz), indicating the position of the newly formed glycosidic linkage in the disaccharide **5** to be at 4-OH of acceptor **4**. This regioselectivity was further confirmed from the ^{1}H NMR spectrum of **5′** – obtained from **5** by acetylation – which revealed a deshielded signal for 3c-H at δ = 5.70 ppm (dd, $J_{2c,3c}$ = 10.1, $J_{3c,4c}$ = 8.9 Hz). The presence of the 3-OH in disaccharide **5** confirmed that the position of the new glycosidic linkage in **5** was at 4-OH of diol **4**. Its configuration was determined to be the desired β anomer on the basis of the 1d-H, 2d-H coupling constant ($J_{1d,2d}$ = 7.9 Hz). Glycosyl donor **3β** was also prepared by Thijssen et al. from 3,4,6-tri-*O*-benzyl-1,2-*O*-(1-thioethylidene)-α-D-galactopyranose by reaction with trimethylsilyl triflate.[24]

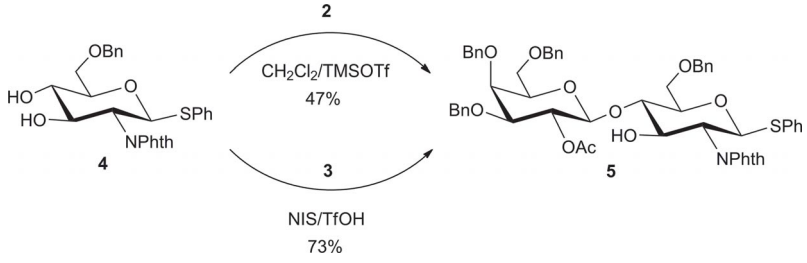
For construction of the trisaccharide, disaccharide **5** was fucosylated with 2,3,4-tri-*O*-benzyl-L-fucosyl fluoride (**6**)[19,25,26] in toluene/dichloromethane using silver triflate and stannous chloride as promoters. Compound **7** was obtained in 71% yield (Scheme 4). The configuration of the newly introduced glycosidic linkage was determined to be α on the basis of the low value of the Fuc 1-H, 2-H coupling constant ($J_{1e,2e}$ = 3.9 Hz).

Compound **8** was obtained by deacetylation with $Mg(OMe)_2$ solution[27] of trisaccharide **7**. With compound **8** in hand, we first tried to realize the deoxygenation of galactose at the 2-position by reaction with phenyl chlorothionocarbonate. However, we failed to introduce the phenoxythiocarbonyl at the desired position, with no reaction at all being observed, probably due to the steric hindrance of the phenyl chlorothionocarbonate. Alcohol **8** was then converted into the corresponding trisaccharide xanthate **9** by treatment with sodium hydride in tetrahydrofuran, carbon disulfide, and a catalytic amount of imidazole, followed by reaction with methyl iodide.[21] The radical reduction of the xanthate by tributylstannane in the presence of azobisisobutyronitrile (AIBN) gave the deoxy-derivative **10** in 87% yield (Scheme 4).

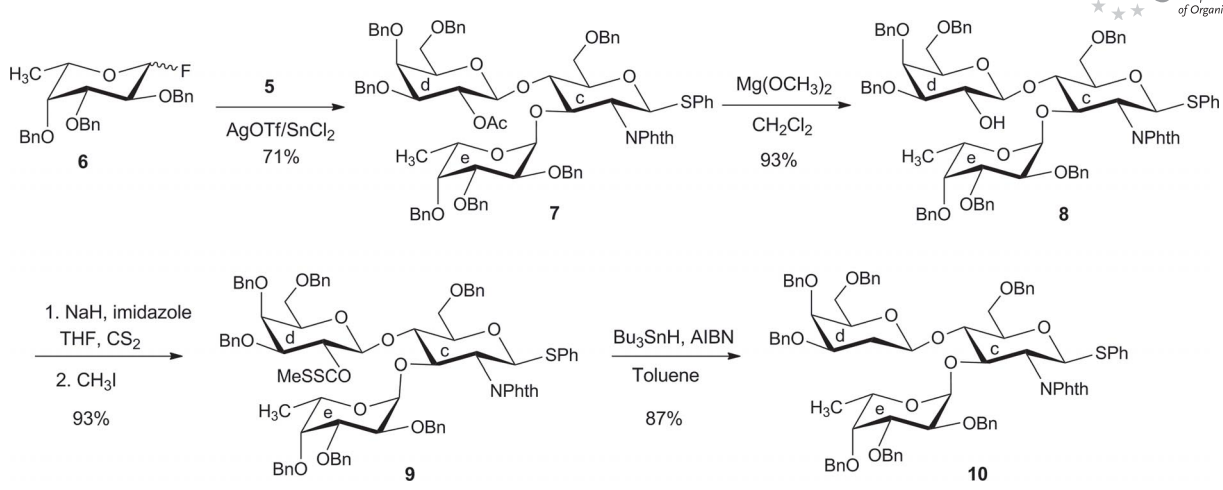
The glycosylation of diol **11**[28] with donor **10** was promoted by NIS and triflic acid to regio- and stereoselectively afford the desired pentasaccharide **12** in 86% yield (Scheme 5).

The configuration of the newly introduced linkage was determined to be β on the basis of the GlcN 1-H, 2-H coupling constant ($J_{1c,2c}$ = 8.4 Hz). The regioselectivity was confirmed from the ^{1}H NMR spectrum of **12′** – obtained from **12** by acetylation – which revealed a deshielded signal for 4b-H at δ = 5.45 ppm (d, $J_{3b,4b}$ = 3.5 Hz). The presence of 4b-OH in pentasaccharide **12** confirmed that the position of the new glycosidic linkage in **12** was at 3-OH of the diol **11**.

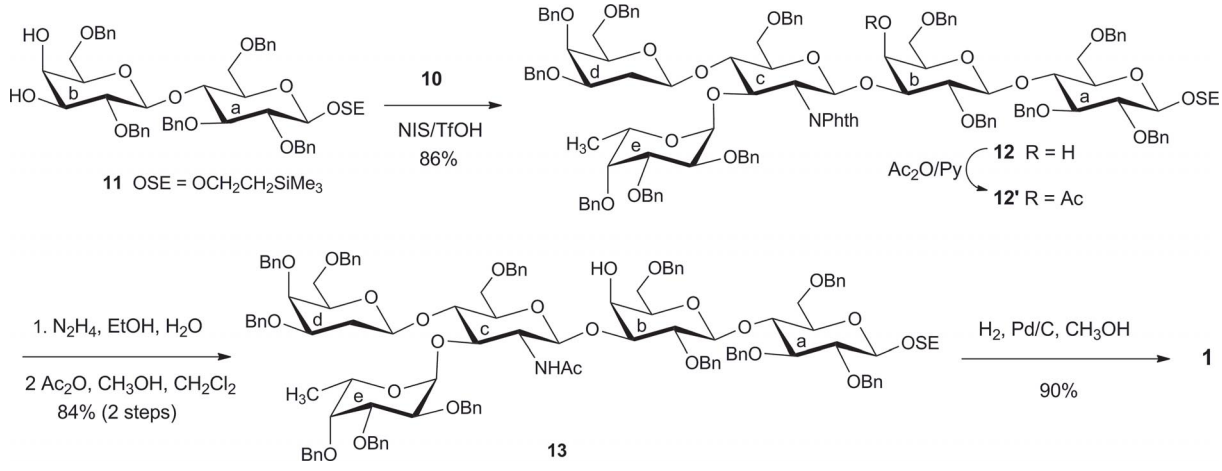
Treatment of pentasaccharide **12** with hydrazine in boiling ethanol, followed by selective *N*-acetylation, afforded compound **13** in 84% overall yield from **12**. Catalytic hy-



Scheme 3. Synthesis of lactosamine building block **5**.



Scheme 4. Synthesis of 2d-deoxy Lewis^x trisaccharide **10**.



Scheme 5. Synthesis of 2d-deoxy Lewis^x pentasaccharide **1**.

drogenolysis of **13** in methanol, followed by purification, provided the pentasaccharide **1** as a white amorphous solid in 90% yield (Scheme 5).

Compound **1** was fully characterized by ^{1}H and ^{13}C NMR analyses, as well as by HRMS.

Conclusions

Our strategy allows the facile and convergent total synthesis of 2d-deoxy Lewis^x pentasaccharide in good yield. We adopted an indirect synthetic method to construct the 2-deoxy-β-disaccharide that entailed the use of a donor containing a participation group at C-2 to insure the regioselectivity of β-glycosidic linkage formation. The 2-position of this participation group was then reduced after fucosylation, giving the 2′-deoxy derivative in high yield. Preparation of trisaccharide **7** by fucosylation of **5** with the powerful fluoride donor **6** gave the desired trisaccharide **7** in high yield. Construction of the pentasaccharide **12** was successfully achieved in very good yield by a highly regio- and stereoselective glycosylation of diol **11** with donor **10**, taking advantage of the activity difference between the 3b-OH and 4b-OH groups. After the synthesis of the 3d-deoxy, 4d-deoxy, and 6d-deoxy Lewis^x pentasaccharides,[17–19] we finally achieved the synthesis of the last member of this family, the 2d-deoxy Lewis^x pentasaccharide. These compounds will be used as useful tools for the study of carbohydrate–carbohydrate interactions.

Experimental Section

General Conditions: All chemicals were purchased as reagent grade and used without further purification. Dichloromethane (CH_2Cl_2) was freshly distilled from P_2O_5. Tetrahydrofuran (THF) was distilled from sodium/benzophenone and toluene was distilled from sodium. ^{1}H NMR spectra were recorded with a Bruker DRX 400 spectrometer at ambient temperature. Assignments were aided by COSY experiments. ^{13}C NMR spectra were recorded at 100.6 MHz with a Bruker DRX 400 spectrometer for solutions in $CDCl_3$, D_2O. High-resolution mass spectra (HRMS) were recorded with a Bruker micrOTOF spectrometer in electrospray ionization (ESI) mode. Optical rotations were measured at 589 nm (Na line) at 20 °C with a Perkin–Elmer Model 343 digital polarimeter, using a 10 cm, 1 mL cell. Reactions were monitored by thin-layer chromatography (TLC) on a precoated plate of silica gel 60 F_{254}

(Merck, 0.2 mM) and detection by charring with sulfuric acid. Flash column chromatography was performed on silica gel 60 (230–400 mesh, Merck), Sephadex G25 and Sephadex LH20 (Sigma).

Ethyl 2-*O*-Acetyl-3,4,6-tri-*O*-benzyl-1-thio-α,β-D-galactopyranoside (3): A solution of **2** (0.5 g, 0.94 mmol) in dry CH_2Cl_2 (16 mL) containing powdered molecular sieves (0.5 g, 4 Å) was cooled to 0 °C. Thioethanol (84 μL, 1.12 mmol) was added dropwise followed by addition of $BF_3{\cdot}Et_2O$ (0.36 mL, 2.84 mmol). The mixture was stirred at room temperature for 14 h, and then neutralized with saturated aqueous $NaHCO_3$ solution, washed with water, dried with $MgSO_4$ then concentrated. The residue was purified by flash column chromatography (Cy/EtOAc = 10:1) to give product **3** as a mixture of α/β isomers (0.46 g, 92%, α/β, 1:5). Data for the α-anomer: R_f = 0.50 (Cy/EtOAc = 4:1). $[a]_D^{20}$ = +114 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.35–7.25 (m, 15 H, Ar-H), 5.72 (d, *J* = 5.6 Hz, 1 H, 1-H), 5.43 (q, *J* = 5.6, 10.3 Hz, 1 H, 2-H), 4.93 (d, *J* = 11.5 Hz, 1 H, PhCH*H*), 4.68 (s, 2 H, PhCH_2), 4.57 (d, *J* = 11.5 Hz, 1 H, PhC*H*H), 4.48, 4.42 (2× d, *J* = 11.8 Hz, 2 H, PhCH_2), 4.30 (t, *J* = 6.4 Hz, 1 H, 5-H), 3.98–3.97 (m, 1 H, 4-H), 3.81 (dd, *J* = 10.3, 2.8 Hz, 1 H, 3-H), 3.63–3.54 (m, 2 H, 6-H), 2.59–2.46 (m, 2 H, CH_2CH$_3$), 2.02 (s, 3 H, Ac), 1.23 (t, *J* = 7.4 Hz, 3 H, CH_2CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 170.34 (MeC=O), 138.58, 138.39, 138.12 (Ar-C), 128.56, 128.53, 128.39, 128.29, 127.86, 127.84, 127.74, 127.57 (Ar-CH), 82.14 (C-1), 77.70 (C-3), 74.68 (C-4), 74.93, 73.61, 73.04 (3× Ph*C*H$_2$), 71.32 (C-2), 69.75 (C-5), 68.92 (C-6), 24.03 (*C*H$_2$CH$_3$), 21.18 (*C*H$_3$CO), 14.83 (CH$_2$*C*H$_3$) ppm. HRMS (ESI): calcd. for $C_{31}H_{36}O_6SNa$ $[M + Na]^+$ 559.2125; found 559.2148. Data for the β-anomer: $[a]_D^{20}$ = –1 (*c* = 1.0; $CHCl_3$) {ref. $[a]_D^{20}$ = –1 (*c* = 1.0; $CHCl_3$)}. The ^{1}H NMR spectroscopic data of the compound were in agreement with those reported in literature.[24].

Phenyl (2-*O*-Acetyl-3,4,6-tri-*O*-benzyl-β-D-galactopyranosyl)-(1→4)-6-*O*-benzyl-2-deoxy-2-phthalimido-1-thio-β-D-glucopyranoside (5). Method A (2 + 4): A mixture of **2** (50 mg, 0.09 mmol), **4** (59 mg, 0.12 mmol), and 4 Å powdered molecular sieves was stirred in dry CH_2Cl_2 (2 mL) for 30 min at room temperature under nitrogen, then cooled to 0 °C. TMSOTf (17 μL, 0.09 mmol) was added and the mixture was stirred at 0 °C for 2 h, filtered through Celite, washed with saturated $NaHCO_3$ solution and brine, dried with $MgSO_4$, filtered, and concentrated. After purification by flash column chromatography (toluene/ethyl acetate = 8:1), compound **5** was obtained (42 mg, 47%) as a white amorphous solid.

Method B (3 + 4): A mixture of **3** (0.15 g, 0.28 mmol), **4** (0.18 g, 0.37 mmol), and powdered molecular sieves (4 Å) was stirred in dry toluene (6 mL) for 30 min at room temperature under nitrogen, then cooled to –30 °C. NIS (76 mg, 0.34 mmol) and TfOH (5 μL, 0.056 mmol) were added and the mixture was stirred at –30 °C for 2 h, then neutralized with Et_3N, diluted with dichloromethane, filtered through Celite, washed with aqueous sodium thiosulfate, and brine, dried with $MgSO_4$, filtered, and concentrated. After purification by flash column chromatography (toluene/ethyl acetate = 8:1), compound **5** was obtained (0.20 g, 73%) as a white amorphous solid. R_f = 0.42 (Cy/EtOAc = 2:1). $[a]_D^{20}$ = +21 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.88–7.16 (m, 29 H, Ar-H), 5.58 (d, $J_{1,2}$ = 10.6 Hz, 1 H, 1c-H), 5.35 (dd, *J* = 8.0, 10.0 Hz, 1 H, 2d-H), 4.88 (d, *J* = 11.7 Hz, 1 H, PhCH*H*), 4.65, 4.63 (2×d, *J* = 11.9 Hz, 2 H, PhC*H*H), 4.52–4.49 (m, 3 H, PhCH_2), 4.45 (dd, *J* = 10.4, 7.8 Hz, 1 H, 3c-H), 4.39 (d, *J* = 8.0 Hz, 1 H, 1d-H), 4.38 (br. s, 1 H, exch. D_2O, 3c-OH), 4.34–4.26 (m, 2 H, PhCH_2), 4.24 (dd, *J* = 10.6, 10.4 Hz, 1 H, 2c-H), 3.85–3.84 (m, 1 H, 4d-H), 3.76–3.63 (m, 4 H, 4c-H, 5c-H, 2× 6-H), 3.56–3.54 (m, 2 H, 5d-H, 6-H), 3.45–3.38 (m, 2 H, 3d-H, 6-H), 1.91 (s, 3 H, Ac) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 169.40 (MeC=O), 168.15, 167.71 (2× C=O, NPhth), 138.55, 138.19, 137.84, 137.48, 132.37, 132.03, 131.94 (Ar-C), 134.11, 132.70, 128.94–127.61 (Ar-CH), 101.92 (C-1d), 83.55 (C-1c), 81.73 (C-4c), 80.35 (C-3d), 78.47 (C-5c), 74.62, 73.70, 73.66, 72.33 (4× Ph*C*H$_2$), 73.95 (C-5d), 72.37 (C-4d), 71.31 (C-2d), 71.01 (C-3c), 68.60, 68.56 (2C-6), 55.26 (C-2c), 21.11 (*C*H$_3$CO) ppm. HRMS (ESI): calcd. for $C_{56}H_{55}NO_{12}SNa$ $[M + Na]^+$ 988.3337; found 988.3354.

Phenyl (2-*O*-Acetyl-3,4,6-tri-*O*-benzyl-β-D-galactopyranosyl)-(1→4)-3-*O*-acetyl-6-*O*-benzyl-2-deoxy-2-phthalimido-1-thio-β-D-glucopyranoside (5′): A solution of **5** (40 mg) in pyridine (1 mL) and acetic anhydride (0.5 mL) was stirred at room temperature for 14 h and then concentrated, co-evaporated with toluene and dried. Compound **5′** was obtained in quantitative yield (41 mg). R_f = 0.47 (Cy/EtOAc = 2:1). $[a]_D^{20}$ = +25 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.86–7.18 (m, 29 H, Ar-H), 5.70 (dd, *J* = 10.1, 8.9 Hz, 1 H, 3c-H), 5.69 (d, *J* = 10.6 Hz, 1 H, 1c-H), 5.20 (dd, *J* = 7.9, 10.0 Hz, 1 H, 2d-H), 4.89 (d, *J* = 11.6 Hz, 1 H, PhCH*H*), 4.69, 4.63 (2× d, *J* = 11.9 Hz, 2 H, PhC*H*H), 4.53–4.37 (m, 5 H, PhCH_2), 4.41 (d, *J* = 7.9 Hz, 1 H, 1d-H), 4.25 (t, 1 H, *J* = 10.4 Hz, 2c-H), 3.95 (t, *J* = 9.1, 9.8 Hz, 1 H, 4c-H), 3.92–3.91 (m, 1 H, 4d-H), 3.79–3.78 (m, 2 H, 2× 6-H), 3.70 (dt, *J* = 10.0, 2.4 Hz, 1 H, 5c-H), 3.58–3.46 (m, 2 H, 2× 6-H), 3.40–3.38 (m, 1 H, 5d-H), 3.36 (dd, 1 H, *J* = 10.1, 2.8 Hz, 3d-H), 1.95, 1.73 (2× s, 6 H, 2× Ac) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 170.09, 169.25 (2× MeC=O), 167.81, 167.47 (2× C=O, NPhth), 138.66, 138.35, 138.08, 137.84, 131.93, 131.71, 131.46 (Ar-C), 134.43, 134.14, 133.09, 128.98–127.47, 123.86, 123.56 (Ar-CH), 100.93 (C-1d), 83.11 (C-1c), 80.47 (C-3d), 79.18 (C-5c), 75.21 (C-4c), 74.51, 73.67, 73.59, 71.82 (4× Ph*C*H$_2$), 73.33 (C-5d), 72.53 (C-3c), 72.34 (C-4d), 71.85 (C-2d), 68.10, 68.06 (2C-6), 54.08 (C-2c), 21.14, 20.62 (2× *C*H$_3$CO) ppm. HRMS (ESI): calcd. for $C_{58}H_{57}NO_{13}SNa$ $[M + Na]^+$ 1030.3443; found 1030.3463.

Phenyl (2-*O*-Acetyl-3,4,6-tri-*O*-benzyl-β-D-galactopyranosyl)-(1→4)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)]-6-*O*-benzyl-2-deoxy-2-phthalimido-1-thio-β-D-glucopyranoside (7): A solution of **5** (0.53 g, 0.55 mmol) and **6** (0.48 g, 1.10 mmol) in dry CH_2Cl_2 (20 mL) and dry toluene (4 mL) was stirred with 4 Å powdered molecular sieves for 30 min at room temperature under nitrogen. A mixture of stannous chloride (0.18 g, 0.96 mmol) and silver triflate (0.25 g, 0.96 mmol) was added at –15 °C and the reaction mixture was stirred for 2 h at –15 °C, then filtered through Celite and washed with CH_2Cl_2. The filtrate was washed with saturated $NaHCO_3$ solution, then with water, dried with $MgSO_4$ and concentrated. After purification by flash column chromatography (Cy/EtOAc = 6:1), compound **7** was obtained (0.54 g, 71%) as a white amorphous solid. R_f = 0.30 (Cy/EtOAc = 3:1). $[a]_D^{20}$ = –11 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.80–6.94 (m, 44 H, Ar-H), 5.47 (d, *J* = 10.5 Hz, 1 H, 1c-H), 5.27 (dd, *J* = 8.2, 10.0 Hz, 1 H, 2d-H), 4.87 (d, *J* = 10.6 Hz, 1 H, PhCH*H*), 4.78–4.71 (m, 3 H, 3c-H, PhC*H*H), 4.68 (d, *J* = 3.9 Hz, 1 H, 1e-H), 4.63–4.60 (m, 1 H, 5e-H), 4.60 (d, *J* = 8.2 Hz, 1 H, 1d-H), 4.55–4.51 (m, 2 H, PhCH_2), 4.49 (d, *J* = 10.2 Hz, 1 H, 2c-H), 4.46–4.32 (m, 7 H, PhCH_2), 4.21 (d, *J* = 12.3 Hz, 1 H, PhCH_2), 4.12 (t, *J* = 9.3 Hz, 1 H, 4c-H), 4.01–4.00 (m, 1 H, 4d-H), 3.90–3.81 (m, 4 H, 3e-H, 6-H, PhCH_2), 3.78–3.64 (m, 3 H, 2e-H, 6-H), 3.59–3.56 (m, 1 H, 5c-H), 3.38–3.33 (m, 2 H, 3d-H, 5d-H), 3.18–3.17 (m, 1 H, 4e-H), 2.03 (s, 3 H, Ac), 1.12 (d, *J* = 6.5 Hz, 3 H, 6e-H) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 169.06 (MeC=O), 139.38, 139.16, 138.80, 138.30, 138.29, 138.10, 137.94, 132.67 (Ar-C), 134.26, 132.43, 128.91, 128.86, 128.66, 128.56, 128.52, 128.32, 128.13, 128.02, 127.97, 127.86, 127.83, 127.81, 127.78, 127.74, 127.38, 127.33,

127.24, 127.14, 127.06, 123.86 (Ar-CH), 99.98 (C-1d), 97.30 (C-1e), 84.45 (C-1c), 80.93 (C-5d), 79.97 (C-5c), 79.56 (C-3e), 78.60 (C-4e), 75.53, 74.97, 73.52, 73.47, 72.82, 72.10, 72.00 (7× Ph*C*H_2), 74.16 (C-2e), 74.11 (C-4c), 73.15 (C-4d), 72.92 (C-3d), 72.63 (C-3c), 71.64 (C-2d), 68.08 (C-6c), 67.77 (C-6d), 66.77 (C-5e), 55.82 (C-2c), 21.09 (*C*H_3CO), 16.30 (C-6e) ppm. HRMS (ESI): calcd. for $C_{83}H_{83}NO_{16}SNa$ $[M + Na]^+$ 1404.5325; found 1404.5375.

Phenyl (3,4,6-Tri-*O*-benzyl-β-D-galactopyranosyl)-(1→4)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)]-6-*O*-benzyl-2-deoxy-2-phthalimido-1-thio-β-D-glucopyranoside (8): To a solution of **7** (0.45 g, 0.325 mmol) in dry CH_2Cl_2 (12 mL) was added freshly prepared $Mg(OMe)_2$ solution (12 mL, 1.4 mol/L). The reaction mixture was stirred for 72 h at room temperature under argon. The mixture was neutralized to pH 7 with acetic acid, filtered, and concentrated. The residue was dissolved in CH_2Cl_2 and washed with water, dried with $MgSO_4$, and concentrated. The residue was purified by flash column chromatography (Cy/EtOAc = 5:1). Compound **8** was obtained (0.4 g, 93%) as a white amorphous solid. R_f = 0.47 (Cy/EtOAc = 2:1). $[a]_D^{20}$ = –9 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.76–6.97 (m, 44 H, Ar-H), 5.52 (d, *J* = 10.6 Hz, 1 H, 1c-H), 4.90 (d, *J* = 10.8 Hz, 1 H, PhCH*H*), 4.82–4.80 (m, 2 H, 2c-H, PhC*H*H), 4.79 (d, *J* = 4.2 Hz, 1 H, 1e-H), 4.73, 4.72 (2× d, *J* = 11.8 Hz, 2 H, PhCH_2), 4.58–4.49 (m, 8 H, 1d-H, 2c-H, 5e-H, PhCH_2), 4.42 (d, *J* = 12.4 Hz, 1 H, PhCH*H*), 4.41 (d, *J* = 11.8 Hz, 1 H, PhC*H*H), 4.36 (d, *J* = 11.8 Hz, 1 H, PhCH*H*), 4.22–4.20 (m, 1 H, 4c-H), 4.16 (d, *J* = 12.4 Hz, 1 H, PhC*H*H), 4.09–4.05 (m, 1 H, 6c-H), 4.00 (d, *J* = 11.2 Hz, 1 H, PhCH*H*), 3.97–3.97 (m, 1 H, 4d-H), 3.93–3.88 (m, 1 H, 6c′-H), 3.86–3.85 (m, 1 H, 2d-H), 3.83–3.82 (m, 1 H, 3e-H), 3.78–3.76 (m, 1 H, 5c-H), 3.71–3.62 (m, 3 H, 2e-H, 2× 6d-H), 3.43–3.39 (m, 1 H, 5d-H), 3.34 (dd, *J* = 9.7, 2.8 Hz, 1 H, 3d-H), 3.26–3.25 (m, 1 H, 4e-H), 1.03 (d, *J* = 6.4 Hz, 3 H, 6e-H) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 139.17, 139.04, 138.91, 138.42, 138.24, 137.95, 132.53 (Ar-C), 134.15, 132.45, 128.87–127.16, 123.66 (Ar-CH), 101.69 (C-1d), 97.83 (C-1e), 84.09 (C-1c), 82.42 (C-3d), 79.65 (C-5c), 79.41 (C-3e), 78.35 (C-4e), 75.00 (C-4c), 74.34 (C-2e), 73.33 (C-4d), 72.97 (C-5d), 75.34, 74.90, 73.42, 73.24, 72.81, 72.64, 72.17 (7× Ph*C*H_2), 71.68 (C-2d), 68.66 (C-6c), 67.93 (C-6d), 66.76 (C-5e), 55.66 (C-2c), 16.50 (C-6e) ppm. HRMS (ESI): calcd. for $C_{81}H_{81}NO_{15}SNa$ $[M + Na]^+$ 1362.5219; found 1362.5253.

Phenyl [3,4,6-Tri-*O*-benzyl-2-*O*-(methylthio)thiocarbonyl-β-D-galactopyranosyl]-(1→4)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)]-6-*O*-benzyl-2-deoxy-2-phthalimido-1-thio-β-D-glucopyranoside (9): To an ice-cooled solution of **8** (118 mg, 0.088 mmol) and imidazole (1.2 mg, 0.018 mmol) in dry THF (5 mL) was added sodium hydride (6.9 mg, 0.176 mmol). The mixture was stirred for 1 h at room temperature under argon, and carbon disulfide (52 μL, 0.88 mmol) was then added. Stirring was continued for 20 min, and methyl iodide (52 μL, 0.88 mmol) was added, and the mixture was stirred for 2 h. MeOH was added at 0 °C to destroy the excess of sodium hydride. The mixture was concentrated, the residue was taken up in ether, and the extract was washed successively with water, 1 M hydrochloric acid, and water, dried with $MgSO_4$, and concentrated. After purification by flash column chromatography (Cy/EtOAc = 5:1), compound **9** was obtained (117 mg, 93%) as a white amorphous solid. R_f = 0.47 (Cy/EtOAc = 2.5:1). $[a]_D^{20}$ = –12 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.70–6.89 (m, 44 H, Ar-H), 6.12 (dd, *J* = 8.2, 9.6 Hz, 1 H, 2d-H), 5.38 (d, *J* = 10.5 Hz, 1 H, 1c-H), 4.82 (d, *J* = 10.6 Hz, 1 H, PhCH*H*), 4.71 (d, *J* = 12.0 Hz, 1 H, PhC*H*H), 4.62 (d, *J* = 3.0 Hz, 1 H, 1e-H), 4.60–4.57 (m, 2 H, 1d-H, 3c-H), 4.56–4.48 (m, 4 H, 5e-H, PhCH_2), 4.44 (d, *J* = 10.5 Hz, 1 H, 2c-H), 4.40–4.20 (m, 7 H, PhCH_2), 4.13 (d, *J* = 12.2 Hz, 1 H, PhCH*H*), 4.05 (t, *J* = 9.5 Hz, 1 H, 4c-H), 3.94–3.90 (m, 2 H, 4d-H, 6c-H), 3.80 (d, *J* = 11.2 Hz, 1 H, PhC*H*H), 3.78–3.73 (m, 2 H, 3e-H, 6c′-H), 3.67–3.55 (m, 3 H, 2e-H, 2× 6d-H), 3.50–3.48 (m, 1 H, 5c-H), 3.36 (dd, *J* = 9.6, 2.8 Hz, 1 H, 3d-H), 3.23–3.19 (m, 1 H, 5d-H), 3.10–3.09 (m, 1 H, 4e-H), 2.57 (s, 3 H, SC*H*$_3$), 1.00 (d, *J* = 6.5 Hz, 3 H, 6e-H) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 214.85 (C=S), 139.33, 139.22, 138.84, 138.38, 138.31, 138.06, 137.96, 132.75 (Ar-C), 132.38, 128.87–127.09, 123.82 (Ar-CH), 100.05 (C-1d), 96.98 (C-1e), 84.45 (C-1c), 81.13 (C-3d), 80.47 (C-2d), 79.63 (C-5c), 79.34 (C-3e), 78.77 (C-4e), 74.69 (C-4c), 74.38 (C-2e), 73.62 (C-4d), 72.82 (C-5d), 72.37 (C-3c), 75.45, 75.08, 73.39, 73.38, 72.72, 72.32, 72.06 (7× Ph*C*H_2), 68.25 (C-6c), 67.66 (C-6d), 66.72 (C-5e), 55.86 (C-2c), 19.86 (CH_3), 16.84 (C-6e) ppm. HRMS (ESI): calcd. for $C_{83}H_{83}NO_{15}S_3Na$ $[M + Na]^+$ 1452.4817; found 1452.4802.

Phenyl (3,4,6-Tri-*O*-benzyl-2-deoxy-β-D-*lyxo*-hexopyranosyl)-(1→4)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)]-6-*O*-benzyl-2-deoxy-2-phthalimido-1-thio-β-D-glucopyranoside (10): To a solution of **9** (138 mg, 0.096 mmol) in dry toluene (10 mL) containing AIBN (3.9 mg, 0.024 mmol) was added tributyltin hydride (0.26 mL, 0.96 mmol). The mixture was stirred at 80 °C for 1 h, then concentrated and purified by flash column chromatography (toluene/ethyl acetate = 30:1) to give **10** (111 mg, 87%) as a white foam. R_f = 0.44 (toluene/ethyl acetate = 10:1). $[a]_D^{20}$ = –12 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.68–6.90 (m, 44 H, Ar-H), 5.44 (d, *J* = 10.5 Hz, 1 H, 1c-H), 4.82 (d, *J* = 10.8 Hz, 1 H, PhCH*H*), 4.70–4.60 (m, 3 H, 1e-H, 3c-H, PhC*H*H), 4.57–4.51 (m, 4 H, 1d-H, 5e-H, PhCH_2), 4.48–4.43 (m, 3 H, 2c-H, PhCH_2), 4.42–4.29 (m, 6 H, PhCH_2), 4.13 (d, *J* = 12.4 Hz, 1 H, PhCH*H*), 4.05 (t, *J* = 9.5 Hz, 1 H, 4c-H), 3.87 (d, *J* = 11.2 Hz, 1 H, PhC*H*H), 3.82–3.81 (m, 1 H, 4d-H), 3.79–3.74 (m, 2 H, 3e-H, 6-H), 3.71–3.66 (m, 2 H, 2× 6-H), 3.62–3.58 (m, 3 H, 2e-H, 5c-H, 6-H), 3.35 (ddd, *J* = 9.6, 2.4 Hz, 1 H, 3d-H), 3.28–3.24 (m, 1 H, 5d-H), 3.20–3.19 (m, 1 H, 4e-H), 1.92–1.80 (m, 2 H, 2d-H), 0.95 (d, *J* = 6.4 Hz, 3 H, 6e-H) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 139.28, 139.27, 139.12, 138.38, 138.34, 138.27, 138.11, 132.59 (Ar-C), 134.18, 132.43, 128.88–127.13, 123.71 (Ar-CH), 99.46 (C-1d), 97.62 (C-1e), 84.19 (C-1c), 79.76 (C-2e), 79.48 (C-3e), 78.46 (C-4e), 77.67 (C-3d), 74.58 (C-4c), 74.38 (C-5c), 73.85 (C-3c), 73.50 (C-5d), 72.30 (C-4d), 75.17, 74.91, 73.48, 73.46, 72.80, 72.09, 70.55 (7× Ph*C*H_2), 68.93 (C-6c), 68.48 (C-6d), 66.65 (C-5e), 55.71 (C-2c), 32.90 (C-2d), 16.55 (C-6e) ppm. HRMS (ESI): calcd. for $C_{81}H_{81}NO_{14}SNa$ $[M + Na]^+$ 1346.5270; found 1346.5314.

2-(Trimethylsilyl)ethyl (3,4,6-Tri-*O*-benzyl-2-deoxy-β-D-*lyxo*-hexopyranosyl)-(1→4)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)]-6-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranosyl-(1→3)-(2,6-di-*O*-benzyl-β-D-galactopyranosyl)-(1→4)-2,3,6-tri-*O*-benzyl-β-D-glucopyranoside (12): A mixture of **10** (220 mg, 0.166 mmol), **11** (178 mg, 0.199 mmol), and powdered molecular sieves (4 Å, 400 mg) was stirred in dry CH_2Cl_2 (12 mL) for 30 min at room temperature under nitrogen, then cooled to –20 °C. NIS (83.5 mg, 0.37 mmol), then TfOH (5 μL, 0.056 mmol) were added and the temperature was raised slowly to room temperature. The mixture was neutralized with Et_3N after stirring at room temperature for an additional 1 h, filtered through Celite, and washed with aqueous sodium thiosulfate, brine and then dried with $MgSO_4$ and concentrated. After purification by flash column chromatography (Cy/EtOAc = 6:1), **12** was obtained (300 mg, 86%) as a white foam. R_f = 0.42 (Cy/EtOAc = 2.5:1). $[a]_D^{20}$ = –6 (*c* = 1.0; $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.38–6.77 (m, 64 H, Ar-H), 5.31 (d, *J* = 8.4 Hz, 1 H, 1c-H), 4.91 (d, *J* = 10.6 Hz, 1 H, PhCH*H*), 4.85 (dd, *J* = 11.3 Hz, 2 H, PhCH_2), 4.69 (d, *J* = 3.0 Hz, 1 H, 1e-H), 4.67–4.52 (m, 8 H, 1d-H, 5e-H, PhCH_2), 4.49 (d, *J* = 10.9 Hz, 1 H, PhC*H*H), 4.46–4.41 (m, 5 H, 2c-H, PhCH_2), 4.39–4.36 (m, 3 H,

PhCH_2), 4.34–4.24 (m, 5 H, 1a-H, PhCH_2), 4.22–4.20 (m, 2 H, 1b-H, PhCH*H*), 4.19 (d, *J* = 11.5 Hz, 1 H, PhC*H*H), 4.11, 4.08 (2× d, *J* = 11.4 Hz, 4 H, PhCH_2), 3.95 (d, *J* = 11.2 Hz, 1 H, PhCH*H*), 3.92–3.84 (m, 2 H, 1 H, OCH*H*), 3.81–3.76 (m, 2 H), 3.72–3.60 (m, 7 H, 6-H, 2e-H), 3.52–3.42 (m, 4 H, 1 H, OC*H*H, 6-H), 3.40–3.26 (m, 7 H, 3d-H, 6-H), 2.99–2.96 (m, 1 H), 2.77 (br. s, 1 H, OH), 1.98–1.96 (m, 2 H, 2d-H), 1.00 (d, *J* = 6.4 Hz, 3 H, 6e-H), 0.97–0.94 (m, 2 H, OCH_2CH_2Si), 0.02 (s, 9 H, $SiMe_3$) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 139.19, 139.18, 139.06, 138.92, 138.68, 138.43, 138.33, 138.30, 138.07, 137.94, 131.34 (Ar-C), 133.78–123.30 (49 Ar-CH), 103.10 (C-1b), 102.06 (C-1a), 99.44 (C-1d), 99.02 (C-1c), 97.61 (C-1e), 83.47, 82.96, 81.98, 79.37, 78.42, 78.15, 77.61, 76.08, 75.15, 74.78, 74.75, 74.58, 73.61, 72.85, 72.79, 72.22, 67.62, 66.65 (ring CH), 75.43, 75.09, 74.95, 74.87, 74.17, 73.58, 73.42, 73.04, 72.65, 72.12, 70.54 (Ph*C*H_2), 68.93, 68.66, 68.50, 67.97, 67.25 (4× C-6, O*C*H_2CH_2Si), 56.39 (C-2c), 32.78 (C-2d), 18.50 (OCH_2CH_2Si), 16.56 (C-6e), –1.34 ($SiMe_3$) ppm. HRMS (ESI): calcd. for $C_{127}H_{139}NO_{25}SiNa$ $[M + Na]^+$ 2128.9298; found 2128.9338.

2-(Trimethylsilyl)ethyl (3,4,6-Tri-*O*-benzyl-2-deoxy-β-D-*lyxo*-hexopyranosyl)-(1→4)-2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)-6-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranosyl-(1→3)-(4-*O*-acetyl-2,6-di-*O*-benzyl-β-D-galactopyranosyl)-(1→4)-2,3,6-tri-*O*-benzyl-β-D-glucopyranoside (12′): A solution of **12** (45 mg) and DMAP (20 mg) in pyridine (1 mL) and acetic anhydride (0.5 mL) was stirred at room temperature for 14 h and then concentrated, co-evaporated with toluene and dried. Compound **12′** was obtained (44 mg, 96%) as a white foam. R_f = 0.46 (Cy/EtOAc = 2.5:1). $[\alpha]_D^{20}$ = –5 (*c* = 1.0; $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.39–6.82 (m, 64 H, Ar-H), 5.45 (d, *J* = 3.5 Hz, 1 H, 4b-H), 5.23 (d, *J* = 8.3 Hz, 1 H, 1c-H), 4.89–4.81 (m, 4 H, PhCH_2), 4.75 (m, 9 H, 1d-H, 1e-H, 5e-H, PhCH_2), 4.56 (m, 13 H, 2c-H, PhCH_2), 4.27 (m, 6 H, 1a-H, 1b-H, PhCH_2), 4.14–4.10 (m, 2 H), 3.96–3.87 (m, 4 H, 1 H, OCH*H*), 3.84–3.74 (m, 5 H, 6-H), 3.67–3.59 (m, 4 H, 2e-H, 6-H), 3.54–3.43 (m, 3d-H, 1 H, OC*H*H, 6-H), 3.39–3.24 (m, 9 H, 6-H), 2.99–2.96 (m, 1 H), 2.07 (s, 3 H, Ac), 1.99–1.97 (m, 2 H, 2d-H), 1.01 (d, *J* = 6.3 Hz, 3 H, 6e-H), 0.96–0.89 (m, 2 H, OCH_2CH_2Si), 0.01 (s, 9 H, $SiMe_3$) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 170.05 (MeC=O), 139.36, 139.28, 139.22, 138.94, 138.73, 138.46, 138.39, 138.37, 138.16 (Ar-C), 128.70–126.51 (64 Ar-CH), 103.21 (C-1b), 102.16 (C-2a), 99.42 (C-1d), 99.32 (C-1c), 97.26 (C-1e), 82.80, 81.90, 79.42, 78.88, 78.80, 78.63, 77.80, 77.36, 75.90, 77.99, 75.56, 74.80, 74.63, 74.40, 73.38, 72.80, 72.37, 72.09, 70.29, 66.54 (CH), 75.26, 75.22, 75.04, 74.92, 74.24, 73.62, 73.60, 73.45, 73.18, 72.56, 72.15, 70.60 (Ph*C*H_2), 68.89, 68.49, 68.40, 67.80, 67.36 (4× C-6, OCH_2), 56.94 (C-2c), 32.99 (C-2d), 20.94 (CH_3, Ac), 18.57 (OCH_2CH_2Si), 16.56 (C-6e), –1.28 ($SiMe_3$) ppm. HRMS (ESI): calcd. for $C_{129}H_{141}NO_{26}SiNa$ $[M + Na]^+$ 2170.9403; found 2170.9469.

2-(Trimethylsilyl)ethyl (3,4,6-Tri-*O*-benzyl-2-deoxy-β-D-*lyxo*-hexopyranosyl)-(1→4)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)]-6-*O*-benzyl-2-deoxy-2-acetamido-β-D-glucopyranosyl-(1→3)-(2,6-di-*O*-benzyl-β-D-galactopyranosyl)-(1→4)-2,3,6-tri-*O*-benzyl-β-D-glucopyranoside (13): To a solution of **12** (124 mg, 0.059 mmol) in EtOH (16 mL), were added hydrazine monohydrate (1 mL) and H_2O (1 mL). The mixture was heated to reflux for 2 h. After concentration, the residue was co-evaporated with toluene and dried with P_2O_5, then dissolved in MeOH/CH_2Cl_2 (1:1, 5 mL), to which acetic anhydride (0.5 mL) was introduced. The mixture was stirred at room temperature for 2 h. After concentration, the residue was purified by flash column chromatography (Cy/EtOAc = 3:1), and then by a Sephadex column (LH-20) using MeOH/CH_2Cl_2 (1:1) as eluant. Compound **13** was obtained (100 mg, 84%, two steps) as a white amorphous solid. R_f = 0.54 (Cy/EtOAc = 1:1). $[\alpha]_D^{20}$ = –25 (*c* = 1.0; $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.44–7.16 (m, 60 H, Ar-H), 5.59 (d, *J* = 7.6 Hz, 1 H, NH), 5.30 (d, *J* = 6.7 Hz, 1 H, 1c-H), 5.01 (d, *J* = 10.6 Hz, 1 H, PhCH*H*), 4.92–4.89 (m, 3 H, 1e-H, PhCH_2), 4.83 (d, *J* = 12.1 Hz, 1 H, PhC*H*H), 4.75–4.60 (m, 10 H, PhCH_2), 4.57–4.46 (m, 5 H, 1d-H, PhCH_2), 4.44–4.29 (m, 8 H, 1a-H, 1b-H, 5e-H, PhCH_2), 4.19–4.16 (m, 2 H, 3c-H, PhCH*H*), 4.03–3.82 (m, 6 H, 2e-H, 3e-H, 4c-H, OC*H*CH_2Si), 3.77–3.59 (m, 8 H, 6-H), 3.57–3.41 (m, 9 H, 2a-H, 2c-H, 3d-H, 6-H, OC*H*CH_2Si), 3.39–3.30 (m, 4 H, 2b-H), 1.98–1.96 (m, 2 H, 2d-H), 1.36 (s, 3 H, Ac), 1.05–1.03 (m, 2 H, OCH_2CH_2Si), 1.01 (d, $J_{5,6}$ = 6.4 Hz, 3 H, 6e-H), 0.03 (s, 9 H, $SiMe_3$) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 170.34 (MeC=O), 139.30, 139.21, 139.14, 139.06, 139.00, 138.82, 138.77, 138.56, 138.36, 138.09, 138.01 (Ar-C), 128.70–127.30 (Ar-CH), 103.22 (C-1b), 102.42 (C-1a), 99.64 (C-1d), 99.56 (C-1c), 97.86 (C-1e), 83.12, 82.14, 79.88, 79.25, 78.24, 77.48, 77.36, 76.72, 76.10, 75.22, 74.82, 74.01, 73.78, 73.61, 73.00, 72.28, 67.53, 66.62 (ring CH), 75.54, 75.16, 75.06, 75.02, 74.78, 73.66, 73.54, 73.52, 73.44, 73.23, 72.35 (Ph*C*H_2), 70.53, 69.46, 68.77, 68.52, 67.41 (4× C-6, O*C*H_2CH_2), 57.23 (C-2c), 33.04 (C-2d), 23.03 (*C*H_3CO), 18.61 (OCH_2CH_2Si), 16.62 (C-6e), –1.27 ($SiMe_3$) ppm. HRMS (ESI): calcd. for $C_{121}H_{139}NO_{24}SiNa$ $[M + Na]^+$ 2040.9349; found 2040.9407.

2-(Trimethylsilyl)ethyl (2-Deoxy-β-D-*lyxo*-hexopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-deoxy-2-acetamido-β-D-glucopyranosyl-(1→3)-(β-D-galactopyranosyl)-(1→4)-β-D-glucopyranoside (1): A solution of **13** (80 mg) in MeOH (10 mL) was treated with Pd/C (10%, 35 mg) under H_2 for 20 h at 30 °C, then filtered and the solvents evaporated. The residue was purified on a Sephadex column (G25) using water as eluant. Compound **1** was obtained as a white amorphous solid (35 mg, 95%). R_f = 0.53 (2-propanol/ethyl acetate/water = 3:3:2). $[\alpha]_D^{20}$ = –28 (*c* = 1.0; MeOH). ^1H NMR (400 MHz, D_2O): δ = 5.16 (d, *J* = 4.0 Hz, 1 H, 1e-H), 4.86–4.72 (m, 3 H, 1c-H, 1d-H, 5e-H), 4.52 (d, *J* = 8.0 Hz, 1 H, 1-H), 4.46 (d, *J* = 7.8 Hz, 1 H, 1-H), 4.18 (d, *J* = 3.1 Hz, 1 H), 4.10–3.88 (m, 8 H, 2c-H, 3d-H, 6-H, OC*H*CH_2Si), 3.86–3.71 (m, 13 H, 2e-H, 6-H, OC*H*CH_2Si), 3.68–3.50 (m, 6 H, 2-H), 3.34–3.29 (m, 1 H, 2-H), 2.05 (s, 3 H, Ac), 2.03–2.02 (m, 1 H, 2d-H), 1.72–1.64 (m, 1 H, 2d′-H), 1.22 (d, *J* = 6.6 Hz, 3 H, 6e-H), 1.05 (2× dt, *J* = 12.9, *J* = 5.6 Hz, 2 H, CH_2Si), 0.06 (s, 9 H, $SiMe_3$) ppm. ^{13}C NMR (100.6 MHz, D_2O): δ = 174.70 (C=O, NHAc), 102.84, 102.50, 101.76, 101.28 (C-1a, C-1b, C-1c, C-1d), 98.43 (C-1e), 82.11, 78.30, 75.26, 74.95, 74.85, 74.81, 74.74, 74.52, 73.46, 71.94, 69.96, 69.18, 68.29, 67.74, 67.69, 66.73, 66.46 (ring, CH), 72.82 (C-2), 68.43 (O*C*H_2CH_2Si), 61.84, 60.94, 60.05, 59.87 (C-6a, C-6b, C-6c, C-6d), 55.96 (C-2c), 33.23 (C-2d), 22.26 (*C*H_3CO), 17.56 (CH_2Si), 15.36 (C-6e), –2.53 ($SiMe_3$) ppm. HRMS (ESI): calcd. for $C_{37}H_{67}NO_{24}$-SiNa $[M + Na]^+$ 960.3714; found 960.3679.

Supporting Information (see footnote on the first page of this article): ^1H NMR, ^{13}C NMR, and HR mass spectra of all compounds.

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