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SYNTHESIS OF MODEL COMPOUNDS RELATED TO LINEAR β-D-(1→6)-GALACTOSYL SIDE-CHAINS OF POLYSACCHARIDES FROM *ASTRAGALUS MONGHOLICUS* BUNGE

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‡This paper is dedicated to Professor Isao Kuwajima on celebration of his 77th birthday.

Abstract – Stereocontrolled efficient syntheses of β-(1→6)-linked di-, tetra- and octa-galactans as model compounds of arabino-3,6-galactans isolated from *Astragalus mongholicus* are described. The syntheses consisted of simple glycosylation cycles: an acceptor and a donor prepared from a common compound were coupled, and the glycosylation product was converted to the acceptor and donor of the next glycosylation.

INTRODUCTION

Many plants have long been used as traditional herbal medicines, and many pharmacological activities such as immuno-stimulating, anti-tumor, anti-virus, anti-oxidation, hypoglycemic, and anti-radiation activities have been observed for polysaccharides isolated from several medicinal plants.[1] Among the pharmacological activities of plant polysaccharides, immuno-modulating activity seems to be most essential because of the accumulated evidence. Yamada *et al*.[2] reported that several plant polysaccharides are involved in modulation of several immune systems, and affect the complement system, lymphocyte proliferation, antibody production, macrophage function, and intestinal immunity. Peyer's patches are unique islands of lymphoid tissue in gut-associated lymphoid tissue (GALT), and known as an inductive site for the intestinal immune system. Regulative molecules of this organ have potential as new immuno-modulators of mucosal and systemic immune systems. Certain arabino-3,6-galactans isolated from an extract of the aerial part of *Astragalus mongholicus* Bunge were demonstrated to have potent

enhancing activity on Peyer's patch immunocompetent cells.[2e] Arabino-3,6-galactans generally consist of a backbone of (1→3)-linked β-D-galactopyranose (Gal*p*) residues, some of which are substituted at 6-position with side chains such as (1→6)-linked β-D-Gal*p* chain. The side chains are often branched or terminated with α-L-arabinofuranose or β-D-glucuronic acid. However, detailed understanding of the functions of such natural molecules is limited. Chemical synthesis has been expected to be an important tool to provide pure glycans, for elucidation of biological roles of glycans. As β-(1→6)-linked galactooligosaccharides are shown to play important role in the biological functions of arabino-3,6-galactans from *A. mongholicus*, we systematically synthesized β-(1→6)-linked di-, tetra- and octa-galactooligosaccharides (**A**—**C**, Figure 1). Kong *et al.* reported earlier the synthesis of β-(1→6)-branched β-(1→3)-linked D-galactans found from the rhizome of *Atractylodes lancea* DC, but their products had 4-methoxyphenyl group at the reducing end.[3] In this paper we synthesized free galactooligosaccharides of even number galactose units by an orthogonal synthesis.

Galβ1→6Gal· · · · · **A**
Galβ1→6Galβ1→6Galβ1→6Gal· · · · · **B**
Galβ1→6Galβ1→6Galβ1→6Galβ1→6Galβ1→6Galβ1→6Galβ1→6Gal· · · · · **C**

Figure 1. Synthesized oligosaccharides **A**—**C**

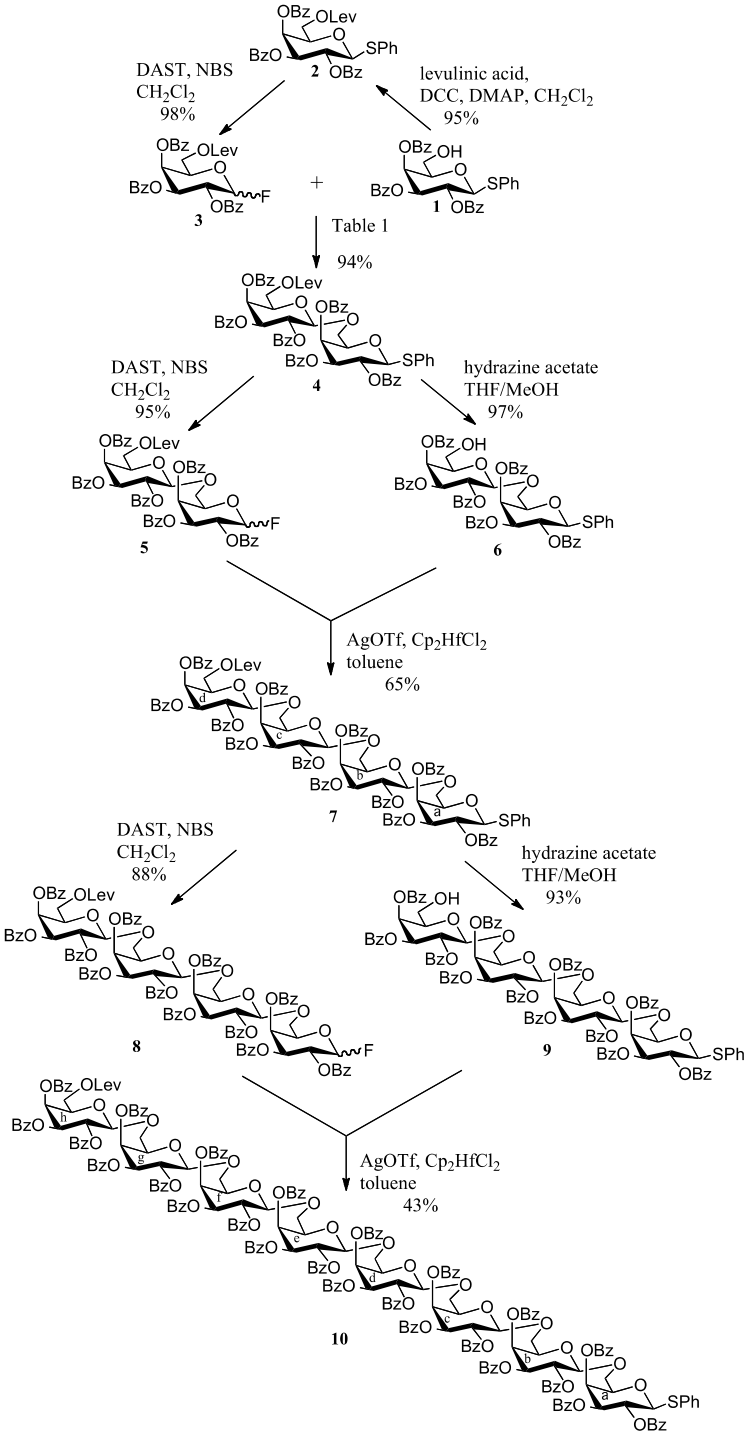
RESULTS AND DISCUSSIONS

The synthetic routes for the oligosaccharide derivatives are outlined in Scheme 1. For the synthesis of these compounds, we adopted the synthetic method reported by Pathak *et al.*[4] They synthesized linear α-(1→6)-linked octamannans using glycosyl fluoride donor and thiotolyl glycoside acceptor, which were prepared from a common intermediate. We selected monosaccharide glycosyl acceptor **1**[5] as the first common derivative for the synthesis of the oligosaccharides **A**—**C**, and levulinoyl (Lev) group for the protection of 6-position in **1**. The elongation of the carbohydrate chain consists of three reactions: glycosylation of acceptor with donor, conversion of the product to the next acceptor (deprotection of Lev group) and donor (displacement of the phenylthio group to fluorine atom[6]). For the β-glycosidic bond formation, we adopted *O*-benzoyl protecting group expecting the neighboring group participation of the 2-*O*-benzoyl group in the bond formation.[7]

The synthetic routes to the protected octasaccharide via the di- and tetra-saccharide derivatives are shown in Scheme 1. Compound **1** was levulinoylated with levulinic acid to give **2** and its phenylthio group was converted to fluoride by using *N*-bromosuccinimide (NBS) and diethylaminosulfur trifluoride (DAST) to afford **3** in nearly quantitative yield (α/β=56:44).[6] Several conditions used for the glycosylation of **1** with **3** are given in Table 1. Glycosylation using AgOTf and $SnCl_2$[8] gave no glycoside (entries 1 and 2). Combination of AgOTf and Cp_2HfCl_2[9] gave good results and the best result was obtained under the condition in which the reaction was heated to 60°C using toluene as a solvent (entry 5) to give desired disaccharide **4** in 94% yield. β-Configuration of the new glycosidic linkage was determined by the

Table 1. Conditions for glycosylation of **1** with **3**

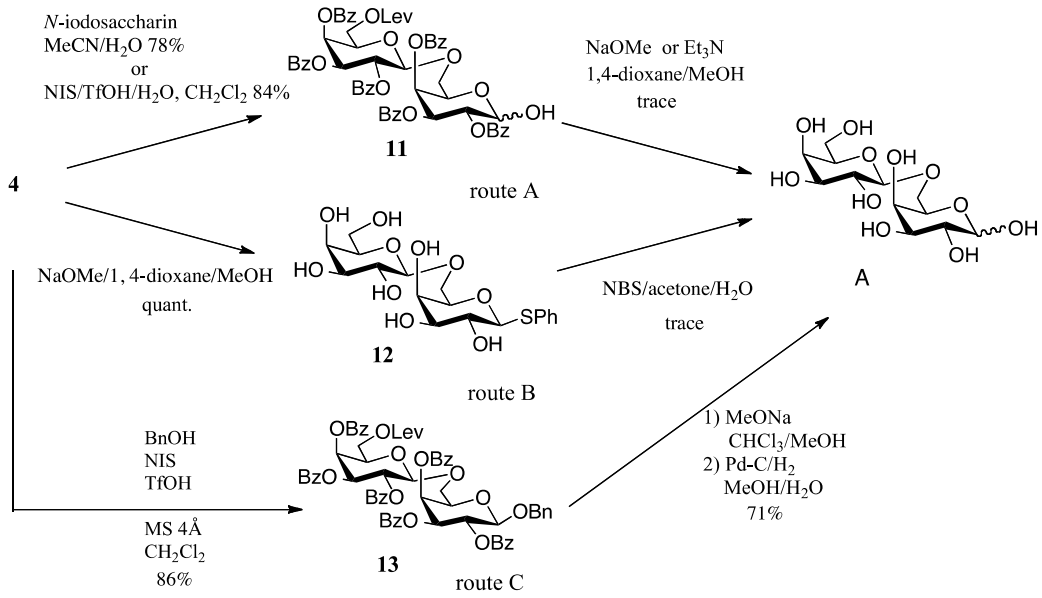
Ent. No.	Time (h)	Promoter(eq)	Solvent	Temp.(°C)	Yield %
1	18	AgOTf (5.2) / $SnCl_2$ (2.6)	CH_2Cl_2	-20	no reaction
2	3	AgOTf (5.2) / $SnCl_2$ (2.6)	CH_2Cl_2	40	no reaction
3	18	AgOTf (3.9) / Cp_2HfCl_2 (1.3)	CH_2Cl_2	0	69
4	6	AgOTf (3.0) / Cp_2HfCl_2 (1.5)	toluene	45	77
5	18	AgOTf (3.0) / Cp_2HfCl_2 (1.5)	toluene	60	94



Scheme 1. Synthesis of β-(1→6)-linked octagalactosyl thioglycoside

coupling constant of the anomeric proton (H-1 of Gal, δ = 4.91 ppm, J = 7.9 Hz). Compound **4** was converted to 1-fluoro donor **5** in 95%. Selective removal of the Lev group of **4** with hydrazine acetate afforded disaccharide acceptor **6** in 97%. Coupling of **5** and **6** gave tetrasaccharide **7** which was then converted to corresponding donor **8** and acceptor **9**, and coupled to give octasaccharide **10**.

Next, removal of the protecting groups of the oligosaccharides **4**, **7** and **10** were examined to obtain free oligosaccharides **A**—**C**. Deprotection of **4** was attempted through two routes: first deprotection of the phenylthio group at the anomeric position followed by deacylation (route A), and the other way round (route B). Unfortunately, neither route proceeded successfully (Scheme 2). Although the first deprotection steps were successful to give **11** and **12**, respectively,[10] the second steps gave complicated mixtures in both routes. These results suggested that acidic or basic conditions should be avoided in the last step. Therefore, phenylthio group in the acceptor was converted to benzyl group, which can be removed by catalytic hydrogenation (route C). Although this needed more steps, it was possible to obtain compound **A** without by-products (Scheme 2).

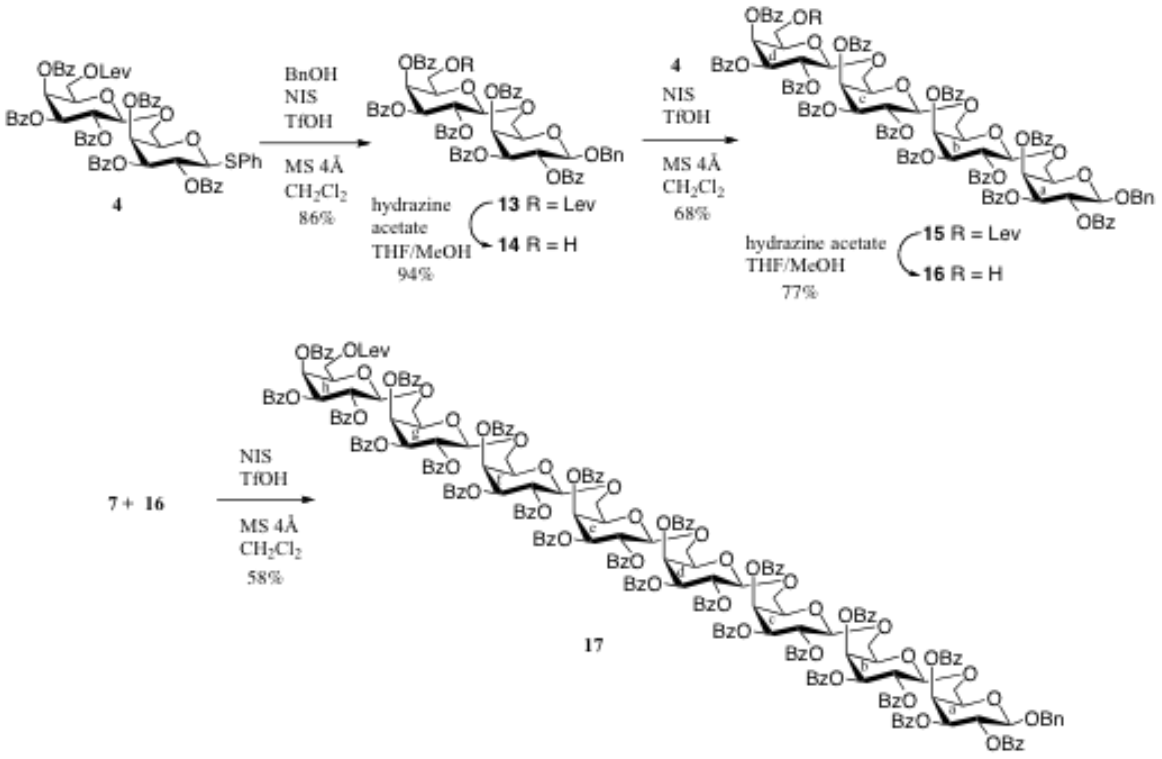


Scheme 2. Deprotection of disaccharide **4**

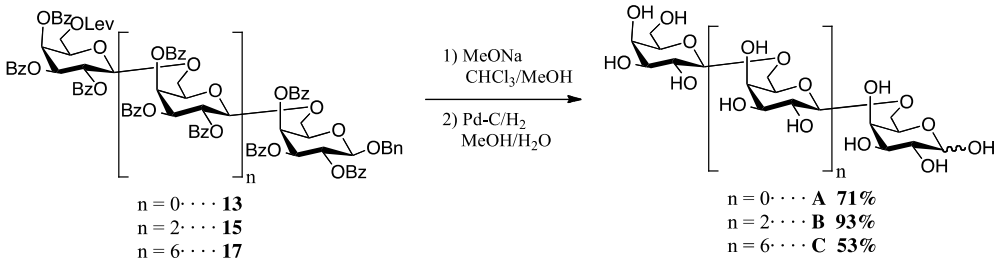
Based on this result, conversions of the phenylthio group of **7** and **10** to benzyl group were carried out, but the yields were moderate (60% and 63%, data not shown). Furthermore, the yield of the glycosylation using glycosyl fluoride donor and thioglycosyl acceptor decreased markedly when the number of sugars increased (Scheme 1). Therefore, a benzyl glycosyl acceptor and a thioglycosyl donor were used in the following glycosylations.

The new synthetic routes for the oligosaccharide derivatives and the free oligosaccharides **A**—**C** are outlined in Schemes 3 and 4. Compound **4** was converted to benzyl glycoside **13** using benzyl alcohol in the presence of NIS and TfOH.[11] The anomeric proton of the reducing end galactose unit appeared as a

doublet (J = 7.9 Hz) at δ 4.62, indicating the formation of the β-linkage. Selective removal of the Lev group in **13** with hydrazine acetate in THF/MeOH gave disaccharide acceptor **14**. Glycosylation of the disaccharide donor **4** with acceptor **14** in the presence of NIS, TfOH and MS 4Å in CH_2Cl_2 afforded desired tetrasaccharide **15** in 68% yield. The β-configuration of the new glycosidic linkage was determined by the coupling constant of the anomeric proton (δ = 4.56 ppm, J = 7.3 Hz). Removal of the Lev group in **15** with hydrazine acetate gave tetrasaccharide acceptor **16**. Glycosylation of the tetrasaccharide donor **7** with acceptor **16** afforded desired octasaccharide **17** in 58% yield. Deacylation followed by removal of the benzyl protecting groups of **15** and **17** with catalytic hydrogenation over 10% Pd-C in MeOH-AcOH provided tetrasaccharide **B** and octasaccharide **C**, respectively, which were purified by gel filtration on Sephadex LH-20 (Schemes 3 and 4).



Scheme 3. Systematic synthesis of di-, tetra- and octa-galactosyl benzyl glycosides



Scheme 4. Synthesis of oligosaccharides **A**, **B** and **C**

CONCLUSION

In conclusion, we achieved the synthesis of di-, tetra- and octa-galactans by a different method from Pathak's. We introduced benzyl group in place of the phenylthio group as a protecting group of the reducing end of the glycosyl acceptor at the stage of disaccharide and the resulted benzyl glycosides were used in the following steps, which enabled clean removal of the protecting groups in the final step to obtain free oligosaccharides. These oligosaccharides can be used as probes to elucidate the effects of arabino-3,6-galactans on immune systems.

EXPERIMENTAL

General

Optical rotations were measured with a Jasco P-1020 digital polarimeter. ^{1}H and ^{13}C NMR spectra were recorded with a Varian 500 FT NMR spectrometer. Me_4Si and acetone were used as internal standards for $CDCl_3$ and D_2O, respectively. MALDI-TOFMS was recorded on an AB SCIEX Voyager RP mass spectrometer. High-resolution mass spectra were recorded on a JEOL JMS-700 under FAB conditions. TLC was performed on Silica Gel 60 F254 (E. Merck) with detection by quenching of UV fluorescence and by charring with 10% H_2SO_4. Column chromatography was performed on columns of silica gel 60 (Kanto Kagaku, 63-210 μm). Gel filtration was performed on Sephadex LH-20 (Pharmacia). Phenyl 2,3,4-tri-*O*-benzoyl-1-thio-β-D-galactopyranoside (**1**)[5] was prepared as reported.

Phenyl 2, 3, 4-tri-*O*-benzoyl-6-*O*-levulinoyl-1-thio-β-D-galactopyranoside (2)

To a solution of **1** (359.5 mg, 0.61 mmol) in CH_2Cl_2 (2.0 mL) was added levulinic acid (68.6 μL, 0.68 mmol), DCC (228.4 mg, 1.11 mmol) and DMAP (19.2 mg, 0.16 mmol), and the reaction mixture was stirred for 3 h at 0 ºC. Toluene was added and evaporated. To a solution of this compound in pyridine was added benzoyl chloride, and the mixture was stirred for 5 h at room temperature. The reaction mixture was poured into ice-water and extracted with $CHCl_3$. The extract was washed with 5% HCl, aq. $NaHCO_3$ and water, dried ($MgSO_4$), and concentrated. The product was purified by column chromatography using 20:1 toluene-acetone as eluent to give **2** (387.6 mg, 94.7%). $[\alpha]_D^{25}$ +113.4 (*c* 0.9, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 7.98—7.20 (20H, m, Ph), 5.89 (1H, d, $J_{3,4}$=3.7 Hz, H-4), 5.71 (1H, t, $J_{1,2}$= $J_{2,3}$=9.8 Hz, H-2), 5.56 (1 H, dd, H-3), 5.01 (1H, d, H-1), 4.34 (1H, dd, $J_{5,6}$=6.1 Hz, H-6a), 4.27—4.19 (2H, m, H-5, H-6b), 2.73 (2H, t, *J* = 6.1 Hz, -COC$\underline{H_2}$CH_2-), 2.58 (2H, t, -COC$H_2\underline{CH_2}$-), 2.17 (3H, s, $COCH_3$); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 206.3, 172.1, 165.4, 165.3, 165.1, 134.3, 133.5, 133.3, 133.2, 130.7, 129.9, 129.8, 129.7, 129.3, 128.8, 128.7, 128.5, 128.4, 128.2, 85.4 (C-1), 74.9, 73.0, 68.1, 67.7, 62.0, 37.8, 29.7, 27.8; HR-FABMS: Calcd for $C_{38}H_{34}O_{10}SNa$: *m/z* 705.1770. Found: 705.1731 $[M+Na]^+$.

2, 3, 4-Tri-*O*-benzoyl-6-*O*-levulinoyl-α,β-D-galactopyranosyl fluoride (3a, 3b)

To a solution of **2** (200 mg, 0.29 mmol) in CH_2Cl_2 (5.0 mL) was added DAST (115.3 μL, 0.44 mmol) at 0 ºC and the reaction mixture was stirred for 10 h at 40 ºC. DAST (57.6 μL, 0.22 mmol, 1.5 eq) was added and the mixture was stirred for 12 h at 40 ºC. Then, NBS (52.1 mg, 0.29 mmol, 1.0 eq) was added and stirring was continued for 4 h. The mixture was extracted with AcOEt, and the extract was washed with aq. $NaHCO_3$, dried ($MgSO_4$), and concentrated to give **3a** (95.9 mg, 56%) and **3b** (74.5 mg, 44%). **3a**: $[\alpha]_D^{25}$ +181.6 (*c* 1.2, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.06—6.94 (15H, m, Ph), 6.09 (1H, dd, $J_{1,2}$=2.4 Hz, $J_{1,F}$=53.1 Hz, H-1a), 6.01 (1H, d, $J_{3,4}$=3.1 Hz, H-4a), 5.95 (1H, dd, $J_{2,3}$=10.4 Hz, H-3a), 5.73 (1H, ddd, $J_{2,F}$=23.8 Hz, H-2a), 4.68 (1H, t, $J_{5,6}$=6.7 Hz, H-5a), 4.35—4.24 (2H, m, H-6aa, H-6ba), 2.63 (2H, t, *J* = 6.7 Hz, -COC$\underline{H_2}$CH_2-), 2.47 (2H, t, -COC$H_2\underline{CH_2}$-), 2.05z (3H, s, $COCH_3$); ^{13}C-NMR (125 MHz, $CDCl_3$) d: 206.2, 188.6, 172.1, 168.7, 165.8, 165.4, 165.3, 149.0, 142.2, 139.9, 133.71, 133.66, 133.3, 129.89, 129.86, 129.7, 129.0, 128.8, 128.7, 128.6, 128.5, 128.3, 127.0, 125.3, 104.6 (d, $J_{C\text{-}1,F}$= 229.65 Hz, C-1α), 69.3, 68.5, 68.3, 67.8, 61.7, 46.6, 46.1, 37.8, 29.7, 27.8; HR-FABMS: Calcd for $C_{32}H_{29}FO_{10}Na$: *m/z* 615.1642. Found: 615.1615 $[M+Na]^+$. **3b**: $[\alpha]_D^{25}$ +154.6 (*c* 0.7, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 7.98—7.14 (15H, m, Ph), 5.85 (1H, br-s, H-4β), 5.81—5.75 (1H, m, H-2β), 5.552 (1H, dd, $J_{2,3}$= 9.8 Hz, $J_{3,4}$= 3.1 Hz, H-3β), 5.545 (1H, dd, $J_{1,2}$= 6.7 Hz, $J_{1,F}$= 51.9 Hz, H-1β), 4.33—4.26 (3H, m, H-5β, H-6aβ, H-6bβ), 2.63 (2H, t, *J* = 6.7 Hz, -COC$\underline{H_2}$CH_2-), 2.47 (2H, t, -COC$H_2\underline{CH_2}$-), 2.05 (3H, s, $COCH_3$); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 206.3, 172.0, 165.2, 165.0, 144.2, 133.6, 133.4, 133.3, 130.4, 129.8, 129.7, 129.6, 128.7, 128.62, 128.56, 128.4, 128.3, 128.2, 126.2, 107.1 (d, $J_{C\text{-}1,F}$=219 Hz, C-1β), 71.6, 70.6, 70.5, 69.8, 69.6, 67.2, 61.7, 37.7, 29.5, 27.7; HR-FABMS: Calcd for $C_{32}H_{29}FO_{10}Na$: *m/z* 615.1642. Found: 615.1602 $[M+Na]^+$.

Phenyl 2,3,4-tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-1-thio-β-D-galactopyranoside (4)

To a solution of **1** (124.0 mg, 0.21 mmol), **3** (138.3 mg, 0.23 mmol) in dry toluene (2.0 mL) was added, and the mixture was stirred with MS4Å (500 mg) for 5 h at room temperature. Cp_2HfCl_2 (132.9 mg, 0.35 mmol) and AgOTf (179.9 mg, 0.70 mmol) were added, and the mixture was stirred for 18 h at 60 °C, then neutralized with Et_3N. The precipitates were filtered off and washed with $CHCl_3$. The combined filtrate and washings were successively washed with water, dried ($MgSO_4$), and concentrated. The product was purified by column chromatography (30:1 toluene-acetone) to give **4** (229 mg, 94.3%). $[\alpha]_D^{25}$ +141.7 (*c* 1.0, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.09—7.17 (35H, m, Ph), 5.85 (1H, d, $J_{3',4'}$=3.7 Hz, H-4'), 5.84 (1H, d, $J_{3,4}$=3.7 Hz, H-4), 5.78 (1H, dd, $J_{1',2'}$=7.9 Hz, $J_{2',3'}$=10.4 Hz, H-2'), 5.68 (1H, t, $J_{1,2}$= $J_{2,3}$ =9.8 Hz, H-2), 5.52 (1H, dd, H-3'), 5.48 (1H, dd, H-3), 4.93 (1H, d, H-1), 4.91 (1H, d, H-1'), 4.33 (1H, dd, $J_{5,6a}$=4.3 Hz, $J_{5,6b}$=7.3 Hz, H-5), 4.14 (3H, s, H-5', H-6'a, H-6'b), 4.06 (1H, dd, $J_{6a,6b}$=11.6 Hz, H-6a),

3.98 (1H, dd, H-6b), 2.73 (2H, t, *J* = 6.1 Hz, -COC$\underline{H_2}$CH$_2$-), 2.52 (2H, t, -COCH$_2$C$\underline{H_2}$-), 2.14 (3H, s, COCH$_3$); ^{13}C-NMR (125 MHz, CDCl$_3$) δ: 206.7, 172.3, 165.2, 133.8, 133.5, 133.4, 133.2, 131.3, 130.0, 129.9, 129.8, 128.8, 128.6, 128.5, 128.34, 128.25, 128.18, 101.6 (C-1'), 85.4 (C-1), 77.1, 73.0, 71.8, 71.2, 69.6, 68.7, 68.6, 68.0, 67.9, 61.8, 38.0, 29.6, 27.9; HR-FABMS: Calcd for $C_{65}H_{56}O_{18}SNa$: *m/z* 1179.3085. Found: 1179.3125 $[M+Na]^+$.

2,3,4-Tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-1-α,β-D-galacto-pyranosyl fluoride (5)

To a solution of **4** (356.3 mg, 0.31 mmol) in CH_2Cl_2 (5.0 mL) was added DAST (148.9 μL, 1.14 mmol) and NBS (54.8 mg, 0.31 mmol), and the reaction mixture was refluxed for 4 h at 45 ºC. DAST (57.6 μL, 0.22 mmol, 1.5 eq) was added and the mixture was stirred for 12 h at 40 ºC. The reaction mixture was poured into iced water and extracted with AcOEt, washed with aq. $NaHCO_3$ and brine, dried ($MgSO_4$), and concentrated. The product was purified by column chromatography using 20:1 toluene-acetone as eluent to give **5** (313.2 mg, 95.3%) as a mixture of α and β isomers. $[\alpha]_D^{25}$ +171.0 (*c* 6.0, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.08—7.13 (60H, m, Ph), 6.00 (2H, d, $J_{3,4}$=3.1 Hz, H-4α, H-4β), 5.94—5.89 (3H, m, H-3α, H-4'α, β), 5.92 (0.6H, dd, $J_{1\alpha,2}$=2.4 Hz, $J_{1\alpha,F}$ =53.1 Hz, H-1α), 5.85—5.74 (3H, m, H-2β, H-2'α, β), 5.66 (1H, ddd, $J_{2,3}$=10.4 Hz, $J_{2,F}$=23.8 Hz, H-2α), 5.56—5.51 (3H, m, H-3β, H-3'α, β), 5.40 (0.4H, dd, $J_{1,2}$=7.3 Hz, $J_{1,F}$=51.8 Hz, H-1β), 4.92 (2H, t, $J_{1',2'}$=8.5 Hz, H-1'α, β), 4.72 (1H, t, $J_{5,6}$= 6.1 Hz, H-5α), 4.38—4.35 (1H, m, H-5β), 4.18—3.93 (8H, m, H-5'a, b, H-6aα, H-6bα, H-6'aα, H-6'bα, H-6aβ, H-6bβ, H-6'aβ, H-6'bβ), 2.70 (2H, t, *J* = 6.7 Hz, -COC$\underline{H_2}$CH$_2$-), 2.49 (2H, t, -COCH$_2$C$\underline{H_2}$-), 2.13 (3H, s, COCH$_3$); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 206.5, 172.1, 165.8, 165.5, 165.2, 165.1, 137.8, 133.5, 133.3, 133.2, 133.1, 130.0, 129.9, 129.84, 139.79, 129.7, 129.3, 129.1, 129.0, 128.7, 128.59, 128.56, 128.41, 128.38, 128.31, 128.25, 128.2, 125.2, 107.2 (d, $J_{C\text{-}1,F}$=219Hz, C-1β), 104.5 (d, $J_{C\text{-}1,F}$= 230 Hz, C-1α), 101.9 (C-1'β), 101.56 (C-1'α), 73.7, 71.7, 71.2, 71.13, 71.11, 71.06, 71.04, 70.8, 70.7, 70.0, 69.8, 69.6, 69.51, 69.50, 68.64, 68.58, 68.5, 68.3, 68.0, 67.9, 67.84, 67.75, 67.71, 67.69, 61.8, 61.6. 37.9, 29.6, 27.8; HR-FABMS: Calcd for $C_{59}H_{51}O_{18}FNa$: *m/z* 1089.2957. Found: 1089.2949 $[M+Na]^+$.

Phenyl 2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-1-thio-β-D-galacto-pyranoside (6)

To a solution of **4** (370.6 mg, 0.32 mmol) in THF : MeOH = 10:1 (5.5 mL) was added hydrazine acetate (88.5 mg, 0.96 mmol), and the reaction mixture was stirred for 7 h at room temperature. The mixture was diluted with $CHCl_3$, washed with, aq. $NaHCO_3$ and brine, dried ($MgSO_4$), and concentrated. The product was purified by column chromatography using 10:1 toluene-acetone as eluent to give **6** (327.7 mg,

96.6%). $[\alpha]_D^{25}$ +163.3 (*c* 2.8, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.13—7.17 (35H, m, Ph), 5.97 (1H, d, $J_{3,4}$=3.1 Hz, H-4), 5.82 (1H, dd, $J_{1',2'}$= 7.9 Hz, $J_{2',3'}$=10.4 Hz, H-2'), 5.79 (1H, d, $J_{3',4'}$=3.1 Hz, H-4'), 5.67 (1H, t, $J_{1,2}$=$J_{2,3}$=9.8 Hz, H-2), 5.55 (1H, dd, H-3'), 5.50 (1H, dd, H-3), 4.87 (1H, d, H-1), 4.87 (1H, d, H-1'), 4.20 (1H, t, $J_{5,6a}$=5.5 Hz, H-5), 4.03 (1H, dd, $J_{6a,6b}$=11.0 Hz, H-6a), 3.97—3.93 (2H, m, H-6b, H-5'), 3.64 (1H, dd, $J_{5',6'}$=6.7 Hz, $J_{6a',6b'}$=12.2 Hz, H-6'a), 3.47 (1H, dd, H-6'b); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 166.6, 165.5, 165.44, 165.2, 165.0, 134.4, 133.5, 133.3, 133.2, 133.1, 130.7, 130.1, 129.8, 129.7, 129.3, 128.8, 128.7, 128.6, 128.5, 128.4, 128.3, 128.2, 101.4 (C-1), 85.3 (C-1'), 76.8, 74.2, 73.1, 71.8, 69.9, 68.8, 68.5, 67.9, 67.8, 60.6; HR-FABMS: Calcd for $C_{60}H_{50}O_{16}SNa$: *m/z* 1081.2717. Found: 1081.2660 $[M+Na]^+$.

Phenyl 2,3,4-tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-1-thio-β-D-galactopyranoside (7)

Compound **7** was prepared from **5** (130.5 mg, 0.12 mmol) and **6** (117.8 mg, 0.11 mmol) as described for preparation of **4**. The product was purified by column chromatography (20:1 toluene-acetone) to give **7** (152.5 mg, 65.1%) as an amorphous powder. $[\alpha]_D^{25}$ +78.3 (*c* 1.1 $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.13—7.06 (65H, m, Ph), 4.85 (1H, d, $J_{1,2}$=9.8 Hz, H-1a), 4.84 (1H, d, $J_{1,2}$=7.3 Hz, H-1d), 4.59 (1H, d, $J_{1,2}$=7.9 Hz, H-1b), 4.56 (1H, d, $J_{1,2}$=7.9 Hz, H-1c), 2.69 (2H, t, *J* = 6.7 Hz, -COC$\underline{H_2}$CH$_2$-), 2.50-2.42 (2H, m, -COCH$_2$C$\underline{H_2}$-), 2.15 (3H, s, $COCH_3$); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 206.8, 172.1, 165.6, 165.4, 165.3, 165.2, 165.1, 164.9, 134.1, 133.3, 133.2, 133.1, 133.0, 130.9, 130.1, 130.0, 129.9, 129.8, 129.7, 129.6, 129.5, 129.4, 129.3, 129.0, 128.8, 128.4, 128.3, 128.2, 128.1, 125.3, 101.2 (C-1c), 101.0 (C-1d), 100.9 (C-1b), 85.4 (C-1a), 76.6, 73.0, 12.3, 72.1, 71.9, 71.60, 71.59, 71.2, 69.98, 69.96, 69.84, 69.79, 68.5, 68.0, 67.8, 67.4, 67.3, 67.2, 66.7, 61.5, 38.0, 29.6, 27.9; MALDI-TOFMS: Calcd for $C_{119}H_{100}NaO_{34}S$: *m/z* 2127.6. Found: *m/z* 2127.5 $[M+Na]^+$.

2,3,4-Tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-1-α,β-D-galactopyranosyl fluoride (8)

Compound **8** was prepared from **7** (145.8 mg, 69.2 μmol) as described for preparation of **5**. The product was purified by column chromatography (1:1 hexane-EtOAc) to give an α, β mixture of **7** (122.9 mg, 88.0%) as syrup. $[\alpha]_D^{25}$ +96.4 (*c* 3.1 $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.07—7.16 (60H, m, Ph), 5.74 (0.6H, dd, $J_{1\alpha,2}$=3.1 Hz, $J_{1\alpha,F}$=51.3 Hz, H-1aα), 5.30 (0.4H, dd, $J_{1\beta,2}$=6.7 Hz, $J_{1\alpha,F}$=52.5 Hz, H-1aβ), 4.89 (1H, t, $J_{1,2}$=2.4 Hz, H-1d of Gal), 4.64—4.57 (3H, m, H-1 Galb, H-1c of Gal); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 215.4, 206.9, 198.9, 191.3, 185.1, 173.7, 165.8, 165.6, 165.4, 165.3, 165.2, 165.1, 165.0, 164.8,

160.1, 159.2, 133.6, 133.4, 133.3, 133.2, 133.1, 130.1, 130.0, 129.94, 129.89, 129.8, 129.7, 129.6, 129.5, 129.33, 129.27, 129.0, 128.9, 128.7, 128.5, 128.43, 128.36, 128.2, 128.1, 128.0, 126.9, 122.2, 108.5, 107.2 (d, $J_{C\text{-}1\beta,\,F}$= 219 Hz, C-1aβ), 104.4 (d, $J_{C\text{-}1\alpha,\,F}$= 231 Hz, C-1aα), 101.4 (C-1b), 101.1 (C-1d), 100.9 (C-1c), 79.2, 73.23, 73.20, 72.4, 72.2, 72.1, 72.0, 71.8, 71.6, 71.4, 70.3, 70.2, 70.01, 69.98, 69.9, 69.83, 69.81, 69.8, 69.0, 68.8, 68.3, 68.1, 67.9, 67.8, 67.7, 67.5, 67.2, 67.1, 67.0, 66.3, 62.8, 60.1, 45.4, 38.1, 38.0, 29.6, 27.9, 21.3, 14.5; MALDI-TOFMS: Calcd for $C_{113}H_{95}FNaO_{34}$: *m/z* 2037.6. Found: *m/z* 2037.6 $[M+Na]^+$.

Phenyl 2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galacto-pyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-1-thio-β-D-galacto-pyranoside (9)

Compound **9** was prepared from **7** (120.7 mg, 57.3 μmol) as described for preparation of **6**. The product was purified by column chromatography (10:1 toluene-acetone) to give **9** (106.9 mg, 92.9%) as syrup. $[\alpha]_D^{25}$ +82.9 (*c* 2.7 $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.00—7.11 (65H, m, Ph), 4.85 (1H, d, $J_{1,\,2}$= 9.86 Hz, H-1a), 4.84 (1H, d, $J_{1,\,2}$= 7.3 Hz, H-1d), 4.59 (1H, d, $J_{1,\,2}$= 7.9 Hz, H-1b), 4.56 (1H, d, $J_{1,\,2}$= 7.9 Hz, H-1); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 166.5, 165.5, 165.4, 165.3, 165.11, 165.06, 164.9, 134.1, 133.5, 133.4, 133.2, 133.1, 130.9, 130.1, 129.8, 129.7, 129.64, 129.55, 129.3, 129.2, 129.0, 128.9, 128.8, 128.5, 128.4, 128.3, 128.2, 128.1, 100.99 (C-1c), 100.95 (C-1d), 100.7 (C-1b), 85.4 (C-1a), 76.7, 74.1, 73.0, 72.1, 72.0, 71.74, 71.72, 71.70, 71.6, 69.9, 69.78, 69.76, 68.7, 68.4, 67.9, 67.7, 67.23, 67.18, 66.50, 66.49, 66.1, 66.0, 60.68, 60.66; MALDI-TOFMS: Calcd for $C_{114}H_{94}NaO_{32}S$: *m/z* 2029.5. Found: *m/z* 2028.9 $[M+Na]^+$.

Phenyl 2,3,4-tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-1-thio-β-D-galactopyranoside (10)

Compound **10** was prepared from **8** (74.8 mg, 37.1 μmol) and **9** (67.7 mg, 33.8 μmol) as described for preparation of **4**. The product was purified by Bio Beads S-X1 column chromatography (5:1 toluene-acetone) to give **10** (8.1 mg, 14.5 μmol, 43.1%) as an amorphous powder. $[\alpha]_D^{25}$ −10.1 (*c* 0.9 $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 7.95—7.11 (125H, m, Ph), 4.76 (1H, d, $J_{1,\,2}$=9.8 Hz, H-1), 4.66 (1H, d, $J_{1,\,2}$=7.9 Hz, H-1), 4.39 (2H, d, $J_{1,\,2}$=7.3 Hz, H-1), 4.29 (2H, d, $J_{1,\,2}$=7.3 Hz, H-1), 4.26 (2H, d, $J_{1,2}$ =7.9 Hz, H-1), 2.58 (2H, t, *J* = 6.7 Hz, -COC$\underline{H_2}$CH_2-), 2.34-2.26 (2H, m, -COC$H_2\underline{CH_2}$-), 2.05 (3H, s, $COCH_3$); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 223.7, 206.6, 194.2, 172.1, 171.8, 165.6, 165.4, 165.2, 165.0,

164.9, 134.1, 133.4, 133.3, 133.1, 131.0, 130.0, 129.2, 129.8, 129.7, 129.4, 129.3, 129.22, 129.17, 129.1, 128.94, 128.8, 128.5, 128.4, 128.1, 101.1 (C-1), 101.0 (C-1), 100.8 (C-1), 100.71 (C-1), 100.69 (C-1), 100.66 (C-1), 100.64 (C-1), 85.4 (C-1), 73.0, 72.2, 72.1, 71.8, 71.7, 71.6, 71.0, 70.0, 69.8, 68.5, 67.9, 67.7, 67.6, 67.4, 67.2, 66.8, 65.9, 65.6, 61.3, 57.1, 44.5, 37.9, 31.9, 29.7, 29.3, 27.8; MALDI-TOFMS: Calcd for $C_{227}H_{118}NaO_{66}S$: *m/z* 4024.1. Found: 4024.7 $[M+Na]^+$.

2,3,4-Tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri–*O*-benzoyl-β-D-galacto-pyranose (11)

Entry 1: To a solution of **4** (100.0 mg, 86.4 μmol) in MeCN-H_2O (10:1, 2.2 mL) was added NISac (106.8 mg, 0.34 mmol). The mixture was stirred for 3.5 h at room temperature. After completion of the reaction, the mixture was filtered and extracted with $CHCl_3$. The solution was washed with water, dried ($MgSO_4$), and concentrated. The residue was purified by column chromatography using 10:1 toluene-acetone as eluent to give **11** (72.1 mg, 78.3%) as syrup.

Entry 2: To a solution of **4** (100.0 mg, 86.4 μmol) in CH_2Cl_2 (1.0 mL) and H_2O (3.1 μL, 0.17 mmol, 2.0 eq.) was added NIS (25.3 mg, 0.11 mmol, 1.3 eq) and TfOH (1.9 μL, 21.6 μmol, 0.25 eq) and the reaction mixture was refluxed for 18 h at 0 ºC, then neutralized with Et_3N. The reaction mixture was filtered and extracted with $CHCl_3$. The combined filtrate and washings were successively washed with saturated aqueous $Na_2S_2O_3$ and water, dried ($MgSO_4$), and concentrated. The residue was purified by silica gel column chromatography using 10:1 toluene-acetone as eluent to give **11** (77.6 mg, 84.3%) as syrup. HR-FABMS: Calcd for $C_{59}H_{52}O_{19}Na$: *m/z* 1087.3000. Found: 1087.3031 $[M+Na]^+$.

Phenyl β-D-galactopyranosyl-(1→6)-1-thio-β-D-galactopyranoside (12)

To a solution of **4** (203.4 mg, 0.18 mmol) in MeOH (2.0 mL) was added dioxane (2.0 mL) and NaOMe (20 mg) and the mixture was stirred for 18 h at 40 °C, then neutralized with Amberlite IR 120 $[H^+]$. The mixture was filtered and concentrated, and the product was purified by a gel filtration with MeOH to give **12** as white solid (76.4 mg, quant.). HR-FABMS: Calcd for $C_{18}H_{26}O_{10}SNa$: *m/z* 434.1247. Found: 434.1252 $[M+Na]^+$.

Benzyl 2,3,4-tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (13)

To a solution of **4** (298.5 mg, 0.26 mmol) and BnOH (66.5 μL, 0.64 mmol) in dry CH_2Cl_2 (2.0 mL) was added powdered MS4Å (600 mg), and the mixture was stirred under Ar atmosphere for 2 h at room temperature. NIS (145.1 mg, 0.64 mmol) and TfOH (18.4 μL, 0.21 mmol) were added to the mixture, which was stirred for 1 h at room temperature, then neutralized with Et_3N. The precipitates were filtered

off and washed with $CHCl_3$. The combined filtrate and washings were successively washed with saturated aqueous $Na_2S_2O_3$ and water, dried ($MgSO_4$), and concentrated. The product was purified by column chromatography (30:1 toluene–acetone) to give **13** (258.1 mg, 86.0%) as an amorphous powder. $[\alpha]_D^{25}$ +130.7 (*c* 4.2, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 7.99—6.99 (35H, m, Ph), 5.77—5.68 (4H, m, H-4, H-4', H-2, H-2'), 5.49 (1H, dd, $J_{2',3'}$=10.4 Hz, $J_{3',4'}$=3.1 Hz, H-3'), 5.36 (1H, dd, $J_{2,3'}$=9.4 Hz, $J_{3,4}$=3.7 Hz, H-3), 4.82 (1H, d, $J_{1',2'}$=7.9 Hz, H-1'), 4.62 (1H, d, $J_{1,2}$=7.9 Hz, H-1), 4.54 and 4.35 (2H, each d, J_{gem}=12.2 Hz, benzyl methylene), 4.15—4.05 (5H, m, H-6a, b, H-5, H-6'a, H-5'), 3.84 (1H, dd, $J_{5',6'}$=7.3 Hz, 9.8 Hz, H-6'b), 2.60 (2H, t, *J* = 6.7 Hz, -COC$\underline{H_2}$CH_2-), 2.45 (2H, m, -COC$H_2\underline{CH_2}$-), 2.15 (3H, s, $COCH_3$); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 206.3, 172.1, 165.43, 165.36, 135.3, 135.1, 136.5, 133.5, 133.4, 133.1, 133.0, 130.1, 129.9, 129.6, 129.3, 129.2, 129.0, 128.9, 128.8, 128.7, 128.5, 128.4, 128.3, 128.2, 128.1, 127.8, 127.7, 101.3 (C-1), 99.2 (C-1'), 73.1, 71.7, 71.6, 71.1, 70.0, 69.7, 68.8, 68.5, 67.9, 61.6, 38.6, 37.8, 30.3, 29.5, 28.8; HR-FABMS: Calcd for $C_{66}H_{58}NaO_{19}$: *m/z* 1177.3470. Found: 1177.3446 $[M+Na]^+$.

Benzyl 2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (14)

Compound **14** was prepared from **13** (159.0 mg, 0.14 mmol) as described for preparation of **6**. The product was purified by column chromatography (25:1 toluene-acetone) to give **14** (136.2 mg, 94%) as syrup. $[\alpha]_D^{25}$ +152.6 (*c* 1.6, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.13—7.09 (35H, m, Ph), 5.93 (1H, d, $J_{3,4}$=3.4 Hz, H-4), 5.87 (1H, dd, $J_{1',2'}$=7.9 Hz, $J_{2',3'}$=10.3 Hz, H-2'), 5.83 (1H, d, $J_{3',4'}$=3.2 Hz, H-4'), 5.67 (1H, dd, $J_{1,2}$=8.0 Hz, $J_{2,3}$=10.3 Hz, H-2), 5.60 (1H, dd, $J_{2',3'}$=10.5 Hz, $J_{3',4'}$=3.4 Hz, H-3'), 5.47 (1H, dd, $J_{2,3}$=10.3 Hz, $J_{3,4}$=3.4 Hz, H-3), 4.89 (1H, d, $J_{1',2'}$=7.9 Hz, H-1'), 4.69 (1H, d, $J_{1,2}$=8.0 Hz, H-1), 4.65 and 4.45 (2H, each d, J_{gem}=12.2 Hz, benzyl methylene), 4.19—4.14 (2H, m, H-6a, H-5), 3.99 (1H, t, $J_{5',6'a}$= $J_{5',6'b}$=6.5 Hz, H-5'), 3.91 (1H, dd, $J_{5,6b}$=5.6 Hz, $J_{6a,6b}$=9.0 Hz, H-6b), 3.68 (1H, dd, $J_{5',6'b}$=6.6 Hz, $J_{6'a,6'b}$=11.9 Hz, H-6'a), 3.52 (1H, dd, $J_{5',6'b}$=6.5 Hz, $J_{6a',6b'}$=12.0 Hz, H-6'b); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 166.5, 165.5, 165.43, 165.38, 165.2, 165.1, 136.5, 133.6, 133.5, 133.2, 133.1, 130.0, 129.9, 129.8, 129.68, 129.66, 129.63, 129.61, 129.5, 129.2, 129.0, 128.7, 128.6, 128.5, 128.33, 128.29, 128.26, 128.19, 128.17, 128.1, 127.8, 127.7, 127.6, 101.2 (C-1'), 99.3 (C-1), 74.0 (C-5'), 73.0 (C-5), 71.73 (C-3), 71.71 (C-3'), 70.1 (benzyl methylene), 69.9 (C-2'), 69.7 (C-2), 68.8 (C-4'), 68.6 (C-4), 68.2 (C-6), 60.5 (C-6'); HR-FABMS: Calcd for $C_{61}H_{52}NaO_{17}$: *m/z* 1079.3102. Found: 1079.3133$[M+Na]^+$.

β-D-Galactopyranosyl-(1→6)-β-D-galactopyranose (A)

To a solution of **13** (75.5 mg, 65.4 μmol) in dioxane (1.0 mL) was added MeOH (1.0 mL) and NaOMe (10 mg) at 40 °C. The mixture was stirred for 21 h and then neutralized with Amberlite IR 120 [H^+]. The

mixture was filtered and concentrated. The residue in MeOH (1.0 mL) was hydrogenolysed in the presence of Pd/C (100 mg) for 5 h at room temperature. The mixture was filtered and concentrated, and the residue was purified by gel filtration in 1:1 MeOH-H_2O to give **A** as white solid (15.9 mg, 71.0%). $[\alpha]_D^{25}$ 6.9 (*c* 0.3, H_2O); ^{1}H-NMR (500 MHz, D_2O) δ: 5.08 (0.4H, br-s, H-1α), 4.41 (0.6H, d, $J_{1,2}$=7.9 Hz, H-1β), 4.27 (1H, d, $J_{1,2}$=7.3 Hz, H-1'); ^{13}C-NMR (125 MHz, D_2O) δ: 102.9 (C-1'β), 102.7 (C-1'α), 96.0 (C-1β), 91.9 (C-1α), 74.7, 73.4, 72.4, 72.23, 72.19, 71.6, 70.8, 70.43, 70.35, 69.7, 69.3, 69.0, 68.9, 68.8, 68.7, 68.5, 68.4, 68.21, 68.18, 68.1, 67.8, 62.8, 62.1, 60.6; HR-FABMS: Calcd for $C_{12}H_{22}NaO_{11}$: *m/z* 365.1060. Found: 365.1051 $[M+Na]^+$.

Benzyl 2,3,4-tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (15)

To a solution of 1**4** (192.9 mg, 0.18 mmol) and **4** (253.4 mg, 0.22 mmol) in dry CH_2Cl_2 (2.0 mL) was added powdered MS4Å (600 mg), and the mixture was stirred under Ar atmosphere for 2 h at room temperature. NIS (98.5 mg, 0.44 mmol) and TfOH (3.9 μL, 0.18 mmol) were added to the mixture, which was stirred for 1 h at 0 ºC, then neutralized with Et_3N. The precipitates were filtered off and washed with $CHCl_3$. The combined filtrate and washings were successively washed with saturated aqueous $Na_2S_2O_3$ and water, dried ($MgSO_4$), and concentrated. The product was purified by column chromatography (25:1 toluene–acetone) to give **15** (255.7 mg, 67.5%) as an amorphous powder. $[\alpha]_D^{25}$ +88.6 (*c* 2.1 $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 7.95-6.97 (65H, m, Ph), 4.77 (1H, d, $J_{1,2}$=7.9 Hz, H-1 d), 4.58 (1H, d, $J_{1,2}$=7.9 Hz, H-1b), 4.56 (1H, d, $J_{1,2}$=7.3 Hz, H-1c), 4.49 and 4.29 (2H, each d, J_{gem}=12.5 Hz, benzyl methylene), 4.29 (1H, d, $J_{1,2}$=7.9 Hz, H-1a); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 206.7, 172.1, 165.6, 165.4, 165.34, 165.31, 165.28, 135.23, 165.18, 165.0, 164.9, 140.7, 136.6, 133.31, 133.25, 133.2, 133.13, 133.07, 133.02, 132.97, 129.99, 122.96, 129.73, 129.69, 129.6, 129.5, 129.41, 129.38, 129.3, 129.2, 129.0, 128.94, 128.85, 128.7, 128.4, 128.3, 128.21, 128.18, 128.10, 128.10, 127.8, 127.7, 101.3 (C-1c), 101.1 (C-1d), 100.7 (C-1b), 99.4 (C-1a), 72.8, 72.3, 72.1, 71.8, 71.72, 71.65, 71.6, 71.2, 70.07, 69.96, 69.9, 69.83, 69.76, 68.6, 68.0, 67.9, 67.8, 67.5, 66.5, 61.5, 38.0, 31.9, 29.6, 29.3, 27.9; MALDI-TOFMS: *m/z* 2125.9 $[M+Na]^+$ ($C_{120}H_{102}NaO_{35}$).

Benzyl 2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (16)

Compound **16** was prepared from **15** (283.6 mg, 0.13 mmol) as described for preparation of **6**. The product was purified by column chromatography (10:1 toluene-acetone) to give **16** (208.5 mg, 77%) as

syrup. $[\alpha]_D^{25}$ +88.9 (*c* 7.1, $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.10—7.07 (65H, m, Ph), 4.79 (1H, d, *J*=7.8 Hz, H-1), 4.66 (1H, d, $J_{1,2}$=8.0 Hz, H-1a), 4.59 and 4.40 (2H, each d, J_{gem}= 12.6 Hz, benzyl methylene), 4.57 (1H, d, *J*=7.8 Hz, H-1), 4.47 (1H, d, *J*=7.8 Hz, H-1); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 166.4, 165.4, 165.35, 165.30, 165.27, 165.23, 165.15, 165.09, 165.0, 164.89, 164.86, 136.5, 133.5, 133.33, 133.28, 133.2, 133.1, 130.0, 129.9, 129.7, 129.6, 129.5, 129.22, 129.18, 129.1, 128.9, 128.84, 128.79, 128.7, 128.6, 128.52, 128.48, 128.4, 128.33, 128.30, 128.2, 128.1, 127.8, 127.7, 125.2, 101.0 (C-1c), 100.9 (C-1d), 100.5 (C-1b), 99.2 (C-1a), 74.0, 72.7, 72.0, 71.9, 71.6, 70.0 (benzyl methylene), 69.8, 69.6, 68.6, 68.5, 67.7, 67.6, 66.5, 65.8, 60.6; MALDI-TOFMS: *m/z* 2027.7 $[M+Na]^+$ ($C_{115}H_{96}NaO_{33}$).

Benzyl 2,3,4-tri-*O*-benzoyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (17)

Compound **17** was prepared from **16** (200.0 mg, 0.10 mmol) and **7** (252.0 mg, 0.12 mmol) as described for preparation of **15**. The product was purified by ULTRA PACK SI-40B column chromatography (15:1 toluene–acetone) to give **17** (230.9 mg, 58%) as an amorphous powder. $[\alpha]_D^{25}$ +59.5 (*c* 0.6 $CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 8.02—7.06 (125H, m, Ph), 4.74 (1H, d, $J_{1,2}$=8.0 Hz, H-1), 4.62 (1H, d, $J_{1,2}$=8.0 Hz, H-1 of Gal a), 4.58 (1H, d, benzyl methylene), 4.53 (1H, d, $J_{1,2}$=8.0 Hz, H-1), 4.48 (1H, d, $J_{1,2}$=8.0 Hz, H-1), 4.39—4.33 (5H, m, H-1, benzyl methylene, H-1, H-1, H-1); ^{13}C-NMR (125 MHz, $CDCl_3$) δ: 206.7, 172.1, 165.6, 165.5, 165.42, 165.39, 165.37, 165.34, 165.3, 165.22, 165.17, 165.1, 164.98, 164.95, 164.9, 164.8, 136.6, 133.39, 133.35, 133.2, 133.1, 133.0, 130.14, 130.08, 130.04, 130.01, 129.98, 129.8, 129.7, 129.6, 129.5, 129.44, 129.40, 129.36, 129.3, 129.2, 129.07, 129.05, 128.9, 128.83, 128.77, 128.51, 128.47, 128.39, 128.39, 128.36, 128.24, 128.20, 128.17, 128.1, 127.8, 127.7, 101.2 (C-1), 101.0 (C-1), 100.7 (C-1x3), 100.63 (C-1), 100.62 (C-1), 99.3 (C-1 of Gal a), 72.8, 72.0, 71.9, 71.75, 71.69, 71.6, 71.0, 70.1 (benzyl methylene), 70.0, 69.9, 69.8, 69.7, 68.6, 67.8, 67.7, 67.6, 67.4, 61.3, 37.9, 29.7, 27.8; MALDI-TOFMS: *m/z* 4022.2 $[M+Na]^+$ ($C_{228}H_{190}NaO_{67}$).

β-D-Galactopyranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-β-D-galactopyranose (B)

Compound **B** was prepared from **15** (55.9 mg, 26.6 μmol) as described for preparation of **A**. The product was purified by gel filtration (1:1 MeOH-H_2O) to give **B** (16.4 mg, 92.6%) as syrup. $[\alpha]_D^{25}$ 6.9 (*c* 0.3, H_2O); ^{1}H-NMR (500 MHz, D_2O) δ: 5.08 (0.4H, d, $J_{1\alpha,2}$=2.4 Hz, H-1aα), 4.41 (0.6H, d, $J_{1\beta,2}$=7.9 Hz, H-1bβ), 4.28—4.26 (3H, m, H-1bα, H-1cα, H-1dα, H-1bβ, H-1cβ, H-1dβ); ^{13}C-NMR (125 MHz, D_2O)

δ: 102.9 (C-1), 102.8 (C-1), 102.7 (C-1), 96.0 (C-1), 74.7, 73.3, 72.3, 72.2, 72.1, 71.4, 70.3, 70.2, 69.1, 68.9, 68.84, 68.77, 68.5, 68.4, 68.2, 67.8, 60.6, 48.4; HR-FABMS: Calcd for $C_{24}H_{42}NaO_{21}$: *m/z* 689.2116. Found: 689.2137 $[M+Na]^+$.

β-D-Galactopyranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-D-galactopyranose (C)

Compound **C** was prepared from **17** (85.0 mg, 21.2 μmol) as described for preparation of **A**. The product was purified by gel filtration (1:1 MeOH-H_2O) to give **C** (14.8 mg, 53.3%) as syrup. $[\alpha]_D^{25}$ +2.7 (*c* 0.2, H_2O); ^{1}H-NMR (500 MHz, D_2O) δ: 5.08 (0.25H, d, $J_{1\alpha,2}$=3.6 Hz H-1aα), 4.41 (0.75H, d, $J_{1,2}$=8.0 Hz, H-1aβ), 4.31—4.26 (7H, m, H-1b-h); ^{13}C-NMR (125 MHz, D_2O) δ: 102.98 (C-1x2), 102.96 (C-1x2), 102.9 (C-1), 102.8 (C-1), 102.7 (C-1), 96.0 (C-1 β of Gal a), 91.9 (C-1 α of Gal a), 74.7, 73.3, 72.3, 72.2, 72.1, 71.4, 71.3, 70.3, 69.0, 68.9, 68.8, 68.5, 68.3, 68.2, 67.8, 60.6, 60.0; MALDI-TOFMS: *m/z* 1337.9. $[M+Na]^+$ ($C_{48}H_{82}NaO_{41}$).

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