Synthesis of Phosphorylated and Sulfated Glycosyl Serines in the Linkage Region of the Glycosaminoglycans

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We synthesized novel acidic glycans having acidic groups located in the linkage region of the glycosaminoglycans (GAGs). The targeted compounds, β-D-Xyl(2P)-Ser (**1**), β-D-Gal(±6S)-(1→4)-β-D-Xyl(2P)-Ser (**3** and **2**), β-D-Gal(±6S)-(1→3)-β-D-Gal-(1→4)-β-D-Xyl(2P)-Ser (**5** and **4**), and β-D-Gal-(1→3)-β-D-Gal(6S)-(1→4)-β-D-Xyl(2P)-Ser (**6**) contain phosphate and/or sulfate at the specified positions. Some of them (**3**, **5**, and **6**) are the first synthesized examples of natural-type glycoconjugates that simultaneously possess phosphate and sulfate as well as carboxylic acid.

Introduction

Glycosaminoglycans are composed of a common tetrasaccharide and a repeating disaccharide region, as shown in Figure 1. The former covalently binds to the hydroxyl group of a serine residue in the so-called core protein. The latter separates GAG into two categories, chondroitin sulfate/dermatan sulfate and heparin/heparan sulfate, based on the type of hexosamine residues. The OH and NH groups on the repeating disaccharides are specifically decorated with sulfates that are responsible for the biological activities.

The common tetrasaccharide possesses sulfate[1] at *O*-4,6 of both Gals, as well as phosphate[1d,2] at *O*-2 of Xyl. The roles of these acidic groups as well as that of the common tetrasaccharide are unknown. However, a few recent efforts have suggested that their functions are related to glycan elongation.

(1) GAG extends the saccharide chain from the reducing terminus with the help of the corresponding transferase and UDP-monosaccharide. GAG is sorted into the heparin-type and chondroitin-type in the fifth saccharide transfer: α-GlcNAc and β-GalNAc, respectively. It is remarkable that we do not find sulfate at the common tetrasaccharide of heparin and heparan sulfate.[1] Thus, the sulfate in the linkage region might orient the elongation of GAG toward the chondroitin-type.

(2) The characteristic phosphate was discovered at *O*-2 of Xyl in chondroitin 4-sulfate by Oegema et al. in 1984.[2a] Fransson's,[2b] Danishefsky's,[2c] and Sugahara's[1d] groups also isolated the phosphate on Xyl from heparan sulfate or chondroitin sulfate in 1985, 1988, and 1992, respectively. In 1997, Fransson et al.[3] reported that the content of the phosphate dynamically changed along with the glycan elongation of decorin. They observed that the phosphate was gradually accumulated during elongation up to the trisaccharide (Gal-Gal-Xyl); however, the isolated tetrasaccharide (GlcA-Gal-Gal-Xyl) contained a lower amount of phosphate at *O*-2 of Xly. This fact suggests that the phosphate on Xyl is strongly related to the glycan elongation, especially to GlcA transfer.

The use of these truncated oligosaccharides having sulfate as well as phosphate will elucidate the biological mechanisms of the glycan elongation. However, naturally occurring phosphatases make it difficult to isolate the oligosaccharides having labile phosphate. Furthermore, oligosaccharides containing both phosphate and sulfate at specific positions can hardly be obtained from nature for biochemical use. These facts prompted us to synthesize the phosphorylated and sulfated oligosaccharides of GAG. We now report a facile synthesis of phosphorylated and/or sulfated mono-, di-, and triaosyl serines which model GAG at the reducing terminus (**1**−**6**, Figure 2).

Some efforts have been made to synthesize the linkage oligosaccharide of GAG containing either phosphate or sulfate. In 1992, Goto and Ogawa[4] synthesized the monosulfated oligosaccharide: GlcAβ(1→3)-Gal(4S)β-(1→3)-Galβ(1→4)-Xylβ-Ser. They also reported the synthesis of a disulfated glycosyl serine: GlcAβ(1→3)-GalNAc-(4S)β(1→4)-GlcAβ(1→3)-Gal(4S)β(1→3)-Galβ(1→4)-Xylβ-Ser in the following year.[5] In 1993, Nilsson et al.[6] synthesized the di-, tri-, and tetrasaccharides possessing phosphate at *O*-2 of Xyl as methyl glycosides: Galβ(1→4)-Xyl(2P)β-OMe, Galβ(1→3)-Galβ(1→4)-Xyl(2P)β-OMe and GlcAβ(1→3)-Galβ(1→3)-Galβ(1→4)-Xyl(2P)β-OMe. In 1994,

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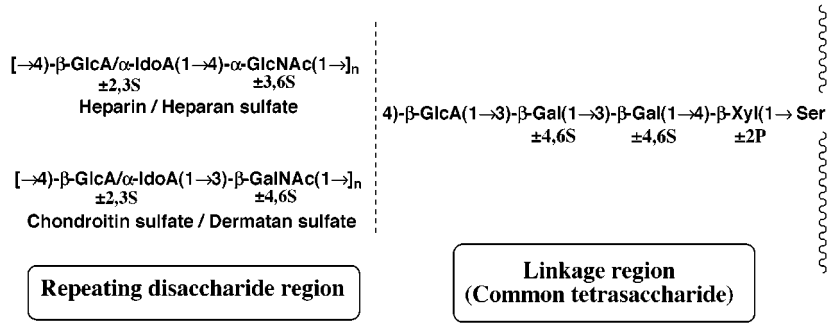


Figure 1. Structure of glycosaminoglycans.

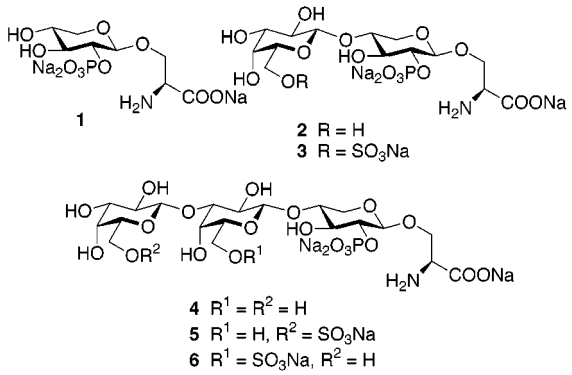


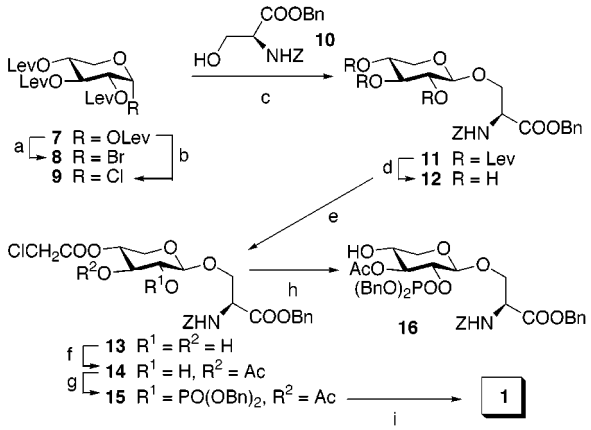
Figure 2. Targeted glycosyl serines (**1**−**6**).

Jacquinet's group[7] reported the syntheses of phosphorylated or sulfated tetraosyl serylglycins as acetamides: GlcAβ(1→3)-Galβ(1→3)-Galβ(1→4)-Xyl(2P)β-(NHAc)Ser-Gly and GlcAβ(1→3)-Gal(4S)β(1→3)-Galβ(1→4)-Xylβ-(NHAc)SerGly. Very recently, we reported the synthesis of the phosphorylated and/or sulfated diaosyl serines: Gal(±6S)β(1→4)-Xyl(2P)β-Ser.[8] This was the first synthesis of natural-type oligosaccharides containing both sulfate and phosphate.

Results and Discussion

In general, we have adopted a stepwise elongation from the reducing terminus for the effective synthesis. Our targeted compounds were also suitably designed for enzymatic studies. As shown in Scheme 1, D-xylose was levulinated with levulinic anhydride and DMAP in pyridine to give **7** in 86% yield. TMSOTf-mediated direct condensation of the known *N*-benzyloxycarbonyl-serine benzyl ester (**10**)[9] and **7** afforded the desired **11** in only 29% yield. To increase the coupling yields, the Koenigs-Knorr-type glycosylations were examined. We converted **7** to the corresponding bromide and chloride (**8** and **9**) with HBr−AcOH and $TiCl_4$ in 88 and 87% yields, respectively. These halides were immediately used for the following glycosylation with **10** in the presence of AgOTf and 4A molecular sieves (MS 4A) in DCE at 0 °C. Although the bromide **8** gave **11** only in low yield (~35%, data not shown), the chloride **9** stereoselectively afforded **11** in 73% yield. It seems that the bromide was too labile to use in the reaction. This result also proved the

Scheme 1[a]



[a] (a) HBr−AcOH, CH_2Cl_2; (b) $TiCl_4$, CH_2Cl_2; (c) AgOTf, MS 4A, DCE; (d) H_2NNH_2•AcOH, toluene−EtOH; (e) i, Bu_2SnO, dioxane; ii, $ClCH_2COCl$, CH_2Cl_2; (f) AcCl, pyridine, CH_2Cl_2; (g) i, $(i\text{-Pr})_2NP(OBn)_2$, 1*H*-tetrazole, CH_2Cl_2; ii, m-CPBA; (h) H_2NNH_2• AcOH, toluene−EtOH; (i) 1. Pd−C, AcOH, H_2, MeOH; 2. Et_3N−MeOH−H_2O.

superiority of the levulinoyl ester by exhibiting a better neighboring group effect at *O*-2 of Xyl: a similar glycosylation[7] using a xylosyl chloride containing the chloroacetyl group at *O*-2 and the hydroxyl group of L-serylglycine showed less stereoselectivity. All the levulinoyl groups of **11** were then removed with hydrazine acetate[10] to give the triol **12** (quantitative), which was purified on a column of Sephadex LH-20. Nilsson's group[6] demonstrated the regioselective monochloroacetylation at *O*-4 of methyl β-D-xylopyranoside via a stannylene acetal intermediate. We applied this procedure to the glycopeptide **12** and obtained the desired chloroacetate at *O*-4 (**13**) in 62% yield. We then regioselectively masked *O*-3 of **13** using a limited amount of acetyl chloride to afford **14** (78%). The remaining hydroxyl group at *O*-2 of **14** was phosphorylated by the phosphoramidite method,[7,11] using commercially available $(i\text{-Pr})_2NP(OBn)_2$ followed by oxidation with mCPBA[7,11] to yield **15** in 88%. We were able to obtain the first targeted compound **1** through hydrogenation in the presence of Pd−C and subsequent saponification with Et_3N in 90% yield (two steps). For further glycan elongation, we chemoselectively removed the chloroacetyl group of **15** with hydrazine acetate and obtained the common acceptor **16** in 88% yield.

For the syntheses of diaosyl serines **2** and **3**, we prepared the galactosyl donor **18** that is suitably designed

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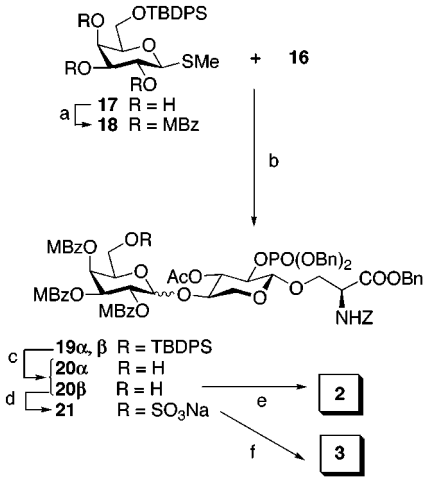
Scheme 2[a]

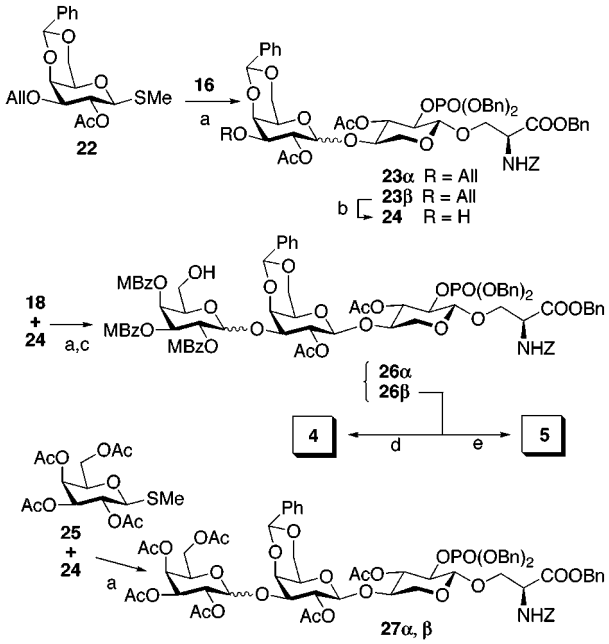


[a] (a) MBzCl, DMAP, pyridine; (b) NIS, TfOH, MS 4A, DCE−Et_2O; (c) TBAF, AcOH, THF; (d) SO_3•Me_3N, DMF; (e) 1. Pd−C, AcOH, H_2, MeOH; 2. Et_3N−MeOH−H_2O, 3. aqueous NaOH; (f) 1. Pd−C, H_2, MeOH; 2. NaOH, aqueous MeOH.

for sulfation at *O*-6, as shown in Scheme 2. Commercially available methyl 1-thio-*β*-D-galactopyranoside was regioselectively silylated at the primary position with *tert*-butylchlorodiphenylsilane (TBDPSCl) to give **17** in 92% yield. The remaining hydroxyl groups were 4-methylbenzoylated in 86% yield. We now had the pivotal galactosyl donor **18** in hand, and galactosylation was pursued. The NIS−TfOH-mediated condensation[12] with thiogalactoside **18** and the xylosyl serine **16** afforded the desired *β*-linked diaosyl serine **19***β* in 52% yield, together with the α-glycoside **19**α (18%). The TBDPS group of **19** was removed with tetrabutylammonium fluoride (TBAF) and AcOH to yield **20** in 85% yield. Removal of the benzyl groups of **20***β* by Pd-catalyzed hydrogenolysis followed by saponification with Et_3N and NaOH afforded the nonsulfated diaosyl serine **2** in 41% yield (two steps). On the other hand, we sulfated the primary hydroxyl group of **20***β* with SO_3•NMe_3 in DMF to give **21** (90%). The deprotection procedures (hydrogenolysis and saponification with NaOH) furnished the sulfated diaosyl serine **3** in 59% yield. To our knowledge, this is the first example of the synthesis of a natural-type oligosaccharide containing sulfate, phosphate, and a carboxylic acid group.[8,13]

In a similar way we synthesized triaosyl serines **4** and **5** that have no sulfate on the inner galactosyl moiety (Scheme 3). The known methyl thiogalactoside (**22**)[4] and the acceptor **16** were subjected to the same coupling conditions as described above. Different from the synthesis of **19**, we observed low stereoselectivity in this coupling reaction; the α- and *β*-glycosides **23**α and **23***β* were obtained in 46 and 37% yields, respectively. The low stereoselectivity is perhaps due to the rigid and sterically hindered benzylidene acetal on the donor which hinders the *β*-face. The allyl ether of **23***β* was then removed with iridium complex chemistry, followed by hydrolysis in high yield to give the *O*-3′ unmasked diaosyl serine **24** (95%). The final glycosylation was carried out

Scheme 3[a]



[a] (a) NIS, TfOH, MS AW300, DCE−Et_2O; (b) 1. [Ir (COD)(PMe-$Ph_2)_2PF_6$], H_2, THF; 2. I_2, $NaHCO_3$, THF−H_2O; (c) TBAF, AcOH, THF; (d) 1. Pd−C, H_2, MeOH; 2. Et_3N−MeOH−H_2O; (e) 1. SO_3•Me_3N, DMF; 2. Pd−C, H_2, MeOH; 3. NaOMe, MeOH.

with **18** and **24**. The usual NIS−TfOH-mediated coupling procedure afforded inseparable triaosyl serine isomers. Removal of the silyl ether protection on the anomeric mixture allowed us to separate the stereoisomers: **26**α and **26***β* (9 and 31% in two steps, respectively). An alternative coupling reaction using commercially available methyl 2,3,4,6-tetra-*O*-acetyl-1-thio-*β*-D-galactopyranoside (**25**) instead of **18** showed a similar tendency; **27**α and **27***β* were obtained in 11 and 39% yields, respectively. It is remarkable that the glycosylation with the corresponding imidate **34**[14] afforded no coupling products, but gave a complicated reaction mixture. To obtain nonsulfated **4**, the benzylic protecting groups of **26***β* were removed by the usual hydrogenolysis, and that product was exposed to a methanolic solution of NaOMe. To our surprise, the acetyl group remained at *O*-2 on the inner galactosyl moiety, even after longer reaction times. However, saponification with Et_3N could effectively remove all the acylic protecting groups from the same starting material to give **4** (49% in deprotection steps). On the other hand, the primary hydroxyl group of **26***β* was quantitatively sulfated as already described. The sulfate was then exposed to deprotection procedures. In contrast to the synthesis of **4**, NaOMe successfully afforded the sulfated and phosphorylated triaosyl serine **5** (53% in deprotection steps).

To synthesize the final targeted compound **6**, we employed the galactobiosyl donor **36**. As shown in Scheme 4, the known 4-methoxyphenyl 3-*O*-allyl-*β*-D-galactopyranoside[4] was acetylated in a conventional manner in order to purify it as the triacetate (**28**). Saponification of **28** with Et_3N in aqueous MeOH was carried out overnight, which left an acetate group at *O*-2. Subsequent silylation with TBDPSCl afforded **29** in 85% yield to-

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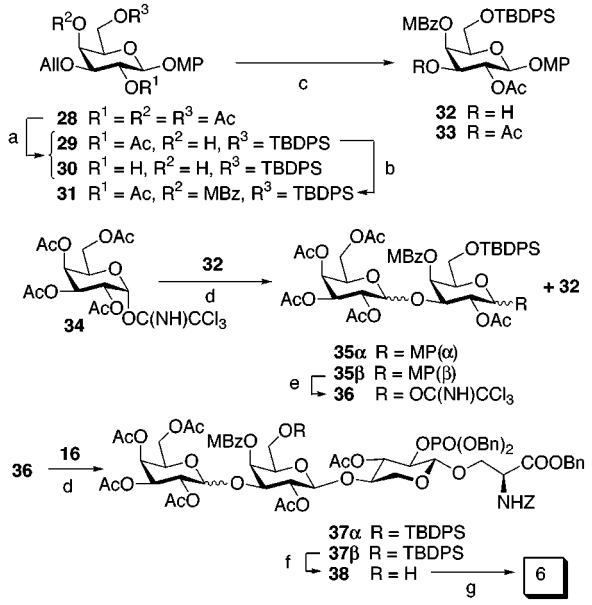
Scheme 4[a]



[a] (a) 1. $Et_3N-MeOH-H_2O$; 2. TBDPSCl, imidazole, DMF; (b) MBzCl, DMAP, pyridine; (c) 1. [Ir (COD)$(PMePh_2)_2PF_6$], H_2, THF; 2. I_2, $NaHCO_3$, $THF-H_2O$; (d) TMSOTf, MS AW300, CH_2Cl_2; (e) 1. CAN, CH_3CN-H_2O; 2. CCl_3CN, DBU, CH_2Cl_2; (f) TBAF, AcOH, THF; (g) 1. SO_3•Me_3N, DMF; 2. Pd–C, H_2, MeOH; 3. $Et_3N-MeOH-H_2O$; 4. NaOMe, MeOH; 5. aqueous NaOH.

gether with 2,4-diol **30** (10%) (two steps). The *C*-4 hydroxyl group of **29** was quantitatively 4-methylbenzoylated to give **31**, and the allyl group of **31** was also quantitatively removed as described above to afford **32**. The donor (imidate) **34** and the acceptor **32** were coupled in the presence of TMSOTf to yield galactobiosides **35**α and **35**β as well as an acetylated acceptor (**33**) in 6, 43, and 24% yields, respectively. The glycosylation with the alternative thioglycoside **25** showed a similar tendency (**35**α, 7%; **35**β, 36%; **33**, 8%). We have converted the β-anomer **35**β into the diaosyl imidate **36** via the removal of the 4-methoxyphenyl group[15] and trichloroacetimidoylation (both in 93% yields). The imidate **36** and the acceptor **16** were coupled by the TMSOTf method at −20 °C to give **37**α and **37**β in 23 and 18% yields, respectively. The TBDPS group of **37**β was chemoselectively removed as described above to give **38** in 75% yield. Sulfation at *O*-6 of the inner galactosyl moiety (93%) and the deprotection procedures [(1) Pd–C, H_2, (2) $Et_3N-MeOH-H_2O$, (3) NaOMe/MeOH, and then (4) aqueous NaOH] toward final target **6** were successfully executed (65%, from **38**). All the targeted compounds (**1**–**6**) afforded satisfactory ^{1}H NMR data which are summarized in Table 1.

Conclusion

The novel and acidic glycosyl serines of GAG (**1**–**6**) containing phosphate and/or sulfate at the specified positions were synthesized by employing sophisticated protecting groups and modern glycosylation methods. This paper is the first report of the syntheses of these glycosyl serines. These glycosyl serines can be directly utilized for enzymatic studies and will elucidate the roles of the phosphate and sulfate groups in the linkage region in the biosynthesis of GAG.

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Table 1. ^{1}H NMR Chemical Shifts of 1–6 at 400 MHz (a)

		XS P **1**	GXS P **2**	GXS SP **3**	GGXS P **4**	GGXS S P **5**	GGXS SP **6**
Xyl[1]	1-H	4.42	4.39	4.45	4.49	4.45	4.38
	2-	3.67	3.65	3.72	3.77	3.72	3.65
	3-	3.43	3.57	3.58	3.63	3.59	3.51
	4-	3.52	3.75	3.77	3.82	3.78	3.71
	5ax-	3.20	3.25	3.30	3.33	3.30	3.22
	5eq-	3.82	3.93	3.96	4.00	3.97	3.88
Gal[2]	1-H		4.30	4.35	4.42	4.39	4.34
	2-		3.33	3.36	3.56	3.52	3.45
	3-		3.46	3.51	3.70	3.64	3.60
	4-		3.73	3.82	4.07	4.09	4.03
	5-		3.50	3.78	3.59	3.56	3.72
	6a-		3.64	4.04	3.54–	3.62–	3.97
	6b-		3.55	4.04	3.72	3.68	3.97
Gal[3]	1-H				4.49	4.45	4.37
	2-				3.47	3.46	3.36
	3-				3.54	3.53	3.42
	4-				3.80	3.81	3.68
	5-				b	3.77	c
	6a-				b	4.03	c
	6b-				b	4.03	c
Ser	α	4.07	4.02	4.12	4.15	4.16	4.14
	βa	3.87	3.88	3.98	3.94	4.04	4.08
	βb	3.84	3.82	3.89	3.84	3.91	3.84

[a–c] Referenced by DHO in D_2O as (a) δ 4.65, (b) 3.54–3.72, (c) 3.42–3.57.

Experimental Section

General Methods. Optical rotations were measured at 22 ± 3 °C with a HORIBA polarimeter in solutions of the specified solvents. ^{1}H NMR assignments were supported by two-dimensional HH COSY experiments with a JEOL LA 400 MHz spectrometer. Signal assignments such as 1^3 stand for a proton at C-1 of sugar residue *3*. The FAB mass spectra were measured with a triple-stage quadrupole mass spectrometer (Finnigan MAT TSQ 700) equipped with the FAB ion source. Silica gel chromatography, analytical TLC, and preparative TLC (PTLC) were carried out on a column of silica gel 60 (E. Merck) or glass plates coated with silica Gel F_{254} (E. Merck), respectively. Gels for size-exclusion chromatography (Sephadex LH-20, Biobeads S-X1) were purchased from Pharmacia and BIO•RAD, respectively. Molecular sieves (MS) were purchased from GL Science, Inc. and activated at 180 °C under vacuum prior to use. Melting points were determined with a Yanaco melting point apparatus and are uncorrected. All reactions in organic solvents were performed under an argon atmosphere.

1,2,3,4-Tetra-*O*-levulinoyl-α-D-xylopyranose (7). To a solution of D-xylose (25.0 g, 167 mmol) in pyridine (500 mL) were added with stirring at room temperature a 1.07 M solution of levulinic anhydride in 1,2-dichloroethane (DCE) (709 mL) and a catalytic amount of DMAP. The mixture was stirred overnight and then ice was added. To the solution was added $CHCl_3$, and the organic phase was washed with aqueous $NaHCO_3$, brine, dried over anhydrous $MgSO_4$, and concentrated. The residue was eluted from a column of silica gel (1:2–1:5–1:10 toluene–EtOAc) to give syrupy **7** (77.54 g, 86%) which was used for subsequent reactions without further purification: R_f 0.60 (1:10 MeOH–EtOAc); ^{1}H NMR ($CDCl_3$) δ 6.22 (d, 1H, $J_{1,2}$ = 3.96 Hz, H-1), 5.49 (t, 1H, $J_{2,3} = J_{3,4}$ = 9.09 Hz, H-3), 5.11–4.98 (m, 1H, H-4), 5.00 (dd, 1H, H-2), 3.91 (dd, 1H, $J_{4,5eq}$= 5.94 Hz, J_{gem} = 11.21 Hz, H-5eq), 3.71 (t, 1H, $J_{4,5ax}$ = 11.21 Hz, H-5ax), 2.86–2.40 (m, 16H, CH_2), 2.21, 2.17, 2.18 (3s, 12H, 4MeCO). Anal. Calcd for $C_{25}H_{34}O_{13}$: C, 55.35; H, 6.32. Found: C, 55.29; H, 6.47.

1-Bromo-2,3,4-tetra-*O*-levulinoyl-α-D-xylopyranose (8). To a solution of **7** (2.05 g, 3.37 mmol) in DCE (21 mL) was

added 35% HBr in AcOH (16 mL) with stirring at 0 °C overnight. The organic phase was diluted with DCE, was washed with ice-cold brine, ice-cold aqueous $NaHCO_3$, and ice-cold brine again, dried over anhydrous $MgSO_4$, and concentrated to give **8** (1.69 g, 88%) as a syrup: R_f 0.50 (1:4 toluene−EtOAc). The residue was used for glycosylation without further purification.

1-Chloro-2,3,4-tetra-*O*-levulinoyl-α-D-xylopyranose (9). To a solution of **7** (1.02 g, 1.88 mmol) in DCE (7 mL) was added $TiCl_4$ (0.41 mL, 3.73 mmol) with stirring at room temperature overnight. To the solution was added $CHCl_3$. The organic phase was washed with brine, dried over anhydrous $MgSO_4$, and concentrated. The residue was eluted from a column of silica gel (1:1−1:2 toluene−EtOAc) to give **9** (751.9 mg, 87%) as a syrup: R_ff 0.70 (1:10 MeOH−EtOAc). The chloride **9** was used for glycosylation without further purification.

***N*-Benzyloxycarbonyl-*O*-(2,3,4-tetra-*O*-levulinoyl-β-D-xylopyranosyl)-L-serine Benzyl Ester (11). Method A.** *N*-Benzyloxycarbonyl-L-serine benzyl ester[9] (**10**, 357.6 mg, 1.086 mmol) and **7** (490.9 mg, 0.904 mmol) were dissolved in CH_2Cl_2 (5 mL). The solution was cooled to −20 °C, and TMSOTf (350 μL, 1.94 mmol) was added with stirring. After 6 h, saturated $NaHCO_3$ and $CHCl_3$ were added to the solution. Insoluble materials were filtered off, and the filtrate was extracted with $CHCl_3$. The residue obtained by a usual workup was eluted from columns of LH-20 (1:1 $CHCl_3$−MeOH) and silica gel (5:1−3:1−2:1−3:2−1:1−1:3−1:5−1:10 toluene−EtOAc) to give **11** (199.6 mg, 29%) as a syrup. **Method B.** To a light-shielded mixture of 4A MS (180 mg) and AgOTf (93.0 mg, 0.36 mmol) was added a solution of **10** (47.1 mg, 0.143 mmol) in DCE (2 mL) with stirring. One hour later, the suspension was cooled to 0 °C and a solution of **9** (79.1 mg, 0.171 mmol) in DCE (2 mL) was added dropwise. The mixture was stirred for 4 d at room temperature, then diluted with $CHCl_3$, aqueous $NaHCO_3$ and brine, and filtered through Celite. The filtered solution was worked up as usual. Purification on a column of LH-20 as in method A afforded **11** (79.3 mg, 73%): R_f 0.35 (1:2 toluene−EtOAc); $[\alpha]_D = -26.9$ (*c* 0.98, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.35 (bs, 10H, Ar H), 6.27 (d, 1H, J = 8.58 Hz, NH), 5.22, 5.15 (ABq, 2H, J = 8.58 Hz, $PhCH_2$), 5.11 (s, 2H, $PhCH_2$), 5.11 (m, 1H, H-3), 4.84−4.76 (m, 2H, H-2,4), 4.52 (m, 1H, Serα), 4.44 (d, 1H, $J_{1,2}$ = 6.60 Hz, H-1), 4.32 (dd, 1H, J_{gem} = 10.23 Hz, $J_{\alpha,\beta a}$ <1.0 Hz, Serβa), 3.90 (dd, 1H, $J_{4,5eq}$ = 4.95 Hz, J_{gem} = 11.88 Hz, H-5eq), 3.76 (dd, 1H, $J_{\alpha,\beta b}$ =2.97 Hz, Serβb), 3.23 (dd, 1H, $J_{4,5ax}$ = 8.25 Hz, H-5ax), 2.8−2.4 (m, 12H, CH_2), 2.17, 2.11, 2.06, (3s, 3H × 3, MeCO). Anal. Calcd for $C_{38}H_{45}NO_{15}$: C, 60.39; H, 6.00; N, 1.85. Found: C, 60.18; H, 6.06; N, 2.02.

***N*-Benzyloxycarbonyl-*O*-β-D-xylopyranosyl-L-serine Benzyl Ester (12).** To a solution of **11** (492.0 mg, 0.651 mmol) in toluene (12.5 mL) and EtOH (62.5 mL) was added hydrazine acetate (957 mg, 9.75 mmol) with stirring. After 40 min, volatiles were removed under diminished pressure and the residue was eluted from a column of LH-20 (1:1 $CHCl_3$−MeOH) to give **12** (quantitative) as a syrup, which was used for the next reaction without further purification: R_f 0.50 (1:10 MeOH−EtOAc); ^{1}H NMR (CD_3OD) δ 7.39 (bs, 10H, Ar H), 5.28, 5.19 (ABq, 2H, J = 12.54 Hz, $PhCH_2$), 5.15 (s, 2H, $PhCH_2$), 4.56 (m, 1H, Serα), 4.41 (dd, 1H, J_{gem} = 10.0 Hz, $J_{\alpha,\beta a}$ = 3.63 Hz, Serβa), 4.22 (d, 1H, $J_{1,2}$ = 7.59 Hz, H-1), 3.86 (dd, 1H, $J_{4,5eq}$ = 5.28 Hz, J_{gem} = 11.22 Hz, H-5eq), 3.78 (dd, 1H, $J_{\alpha,\beta b}$ = 3.30 Hz, Serβb), 3.59−3.46 (m, 2H, H-3,4), 3.23−3.15 (m, 2H, H-2,5ax).

***N*-Benzyloxycarbonyl-*O*-(4-*O*-chloroacetyl-β-D-xylopyranosyl)-L-serine Benzyl Ester (13).** A mixture of **12** (849.4 mg, 1.841 mmol) and Bu_2SnO (659.6 mg, 2.65 mmol) in dioxane (42.5 mL) was boiled under reflux for 1.5 h and then was evaporated to dryness. The residue was diluted with 42.5 mL of CH_2Cl_2, and a solution of chloroacetyl chloride (0.17 mL, 1.95 mmol) in CH_2Cl_2 (3.9 mL) was added with stirring. After 80 min, the reaction mixture was worked up as usual and eluted from a column of silica gel (2:1−1:1 toluene−EtOAc) to give **13** (612.4 mg, 62%) as a syrup: R_f 0.45 (1:2 toluene−EtOAc); $[\alpha]_D = -31.9$ (*c* 0.695, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.35 (bs, 10H, Ar H), 6.25 (m, 1H, NH), 5.23, 5.15 (ABq, 2H, J = 12.20 Hz, $PhCH_2$), 5.12 (s, 2H, $PhCH_2$), 4.81 (dt, 1H, $J_{3,4}$ = $J_{4,5ax}$ = 8.57 Hz, $J_{4,5eq}$ = 4.95 Hz, H-4), 4.63 (m, 1H, Serα), 4.25−4.20 (m, 2H, H-1, Serβa), 4.10 (d, 2H, J = 3.3 Hz, $ClCH_2$), 3.89 (dd, 1H, J_{gem} = 11.87 Hz, H-5eq), 3.76−3.66 (m, 1H, Serβb), 3.69 (t, 1H, $J_{2,3}$ = $J_{3,4}$ = 8.58 Hz, H-3), 3.32 (dd, 1H, $J_{1,2}$ = 6.93 Hz, H-2), 3.09 (dd, 1H, H-5ax), 1.69 (m, 2H, OH). Anal. Calcd for $C_{25}H_{28}ClNO_{10}$: C, 55.82; H, 5.25; N, 2.60; Cl, 6.59. Found: C, 55.84; H, 5.38; N, 2.36; Cl, 6.88.

***N*-Benzyloxycarbonyl-*O*-(3-*O*-acethyl-4-*O*-chloroacetyl-β-D-xylopyranosyl)-L-serine Benzyl Ester (14).** To a solution of **13** (1.70 g, 3.16 mmol) and pyridine (1.02 mL, 12.6 mmol) in CH_2Cl_2 (70 mL) was added acetyl chloride (251 μL, 3.54 mmol) with stirring at 0 °C. After 40 min, ice was added and the organic phase was washed with M HCl, brine, aqueous $NaHCO_3$, and brine again, and dried over $MgSO_4$. The crude material obtained in the usual manner was purified on a column of silica gel (7:1−6:1−3:1−1:3 toluene−EtOAc) to give **14** (1.42 g, 78%) as a syrup: R_f 0.73 (1:2 toluene−EtOAc); $[\alpha]_D$ = −19.8 (*c* 1.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.36 (bs, 10H, Ar H), 5.78 (d, 1H, J = 8.58 Hz, NH), 5.27−5.17 (m, 2H, $PhCH_2$), 5.12 (s, 2H, $PhCH_2$), 5.12 (t, 1H, $J_{2,3}$ = $J_{3,4}$ = 8.58 Hz, H-3), 4.89 (dt, 1H, $J_{3,4}$ = $J_{4,5ax}$ = 8.58 Hz, $J_{4,5eq}$ = 4.95 Hz, H-4), 4.60 (m, 1H, Serα), 4.33 (d, 1H, $J_{1,2}$ = 6.59 Hz, H-1), 4.21 (dd, 1H, J_{gem} = 10.88 Hz, $J_{\alpha,\beta a}$ = 3.96 Hz, Serβa), 4.03 (s, 2H, $ClCH_2$), 3.91 (dd, 1H, J_{gem} = 11.87 Hz, H-5eq), 3.83 (m, 1H, Serβb), 3.77 (m, 1H, OH), 3.44 (m, 1H, H-2), 3.23 (dd, 1H, H-5ax), 2.09 (s, 3H, Me). Anal. Calcd for $C_{27}H_{30}ClNO_{11}$: C, 55.91; H, 5.21; N, 2.42; Cl, 6.11. Found: C, 55.91; H, 5.26; N, 2.46; Cl, 6.31.

***N*-Benzyloxycarbonyl-*O*-(3-*O*-acetyl-4-*O*-chloroacetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)-L-serine Benzyl Ester (15).** To a solution of **14** (7.81 g, 13.47 mmol) and 1*H*-tetrazole (1.89 g, 26.9 mmol) in CH_2Cl_2 (300 mL) was added dibenzyl diisopropylphosphoramidite (6.79 mL, 20.2 mmol) in CH_2Cl_2 (50 mL) with stirring at room temperature. After 50 min, the reaction mixture was ice-cooled and *m*-CPBA (6.97 g, 40.4 mmol) was added. The reaction mixture was diluted with $CHCl_3$ after 30 min. The organic phase was washed with aqueous $Na_2S_2O_3$, aqueous $NaHCO_3$, and brine and dried over $MgSO_4$. The crude material obtained in the usual manner was eluted from a column of silica gel (8:1−7:1−6:1−5:1−5:2 toluene−EtOAc) to give **15** (9.91 g, 88%) as a syrup: R_f 0.40 (2:1 toluene−EtOAc); $[\alpha]_D$ = −14.4 (*c* 1.08, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.33−7.22 (m, 20H, Ar H), 6.99 (d, 1H, J = 8.78 Hz, NH), 5.27, 5.17 (ABq, 2H, J = 12.20 Hz, $PhCH_2$), 5.19 (dd, 1H, $J_{2,3}$ = 8.54 Hz, $J_{3,4}$ = 8.78 Hz, H-3), 5.11, 4.93, 4.91 (3s, 2H × 3, 3$PhCH_2$), 4.87 (m, 1H, H-4), 4.62 (d, 1H, $J_{\alpha,\beta a}$ = 9.03 Hz, Serα), 4.42 (m, 1H, Serβa), 4.41 (d, 1H, $J_{1,2}$ = 6.83 Hz, H-1), 4.11 (dt, 1H, $J_{2,P}$ = 8.54 Hz, H-2), 3.99 (s, 2H, $ClCH_2$), 3.91 (dd, 1H, $J_{4,5eq}$ = 5.12 Hz, J_{gem} = 11.96 Hz, H-5eq), 3.68 (dd, 1H, $J_{\alpha,\beta b}$ = 2.68 Hz, J_{gem} = 9.51 Hz, Serβb), 3.26 (dd, 1H, $J_{4,5ax}$ = 8.78 Hz, H-5ax), 1.89 (s, 3H, Me). Anal. Calcd for $C_{41}H_{43}ClNPO_{11}$: C, 58.61; H, 5.16; N, 1.67. Found: C, 58.74; H, 5.25; N, 1.68.

***N*-Benzyloxycarbonyl-*O*-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)-L-serine Benzyl Ester (16).** To a solution of **15** (460.0 mg, 547.5 μmol) in EtOH (24 mL) and toluene (6 mL) was added hydrazine acetate (151.2 mg, 1.64 mmol) with stirring. After 90 min, the volatiles were evaporated and the residue was eluted from a column of LH-20 (1:1 $CHCl_3$−MeOH) to give **16** (366.5 mg, 88%) as a syrup: R_f 0.58 (1:5 toluene−EtOAc); $[\alpha]_D = -21.3$ (*c* 0.92, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.34−7.23 (bs, 20H, Ar H), 6.98 (d, 1H, J = 9.03 Hz, NH), 5.23, 5.14 (ABq, 2H, J = 12.44 Hz, $PhCH_2$), 5.11 (s, 2H, $PhCH_2$), 4.95−4.88 (m, 4H, 2$PhCH_2$), 4.90 (t, 1H, $J_{2,3}$ = $J_{3,4}$ = 8.53 Hz, H-3), 4.61 (m, 1H, Serα), 4.43 (dd, 1H, J_{gem} = 11.49 Hz, $J_{\alpha,\beta a}$ =2.44 Hz, Serβa), 4.38 (d, 1H, $J_{1,2}$ = 6.38 Hz, H-1), 4.11 (dt, 1H, $J_{2,P}$ = 6.38 Hz, H-2), 3.89 (dd, 1H, $J_{4,5eq}$ = 4.88 Hz, J_{gem} = 11.95 Hz, H-5eq), 3.71−3.64 (m, 2H, H-4, Serβb), 3.22 (dd, 1H, $J_{4,5ax}$ = 9.27 Hz, H-5ax), 2.68 (m, 1H, J = 5.61 Hz, OH), 1.94 (s, 3H, Me). Anal. Calcd for $C_{39}H_{42}NPO_{13}$: C, 61.33; H, 5.54; N, 1.83; P, 4.06. Found: C, 61.26; H, 5.64; N, 1.77; P, 3.96.

***O*-(2-*O*-Phosphono-β-D-xylopyranosyl)-L-serine, Trisodium Salt (1).** To a solution of **15** (16.5 mg, 19.6 μmol) in

MeOH (2 mL) were added a catalytic amount of Pd−C and 3 drops of AcOH. The reaction mixture was stirred under an H_2 atmosphere for 2 d and filtered on Celite, and the volatiles were removed under diminished pressure. The residues were diluted with MeOH (0.4 mL), H_2O (0.2 mL), and Et_3N (0.2 mL) and the solution for 2 d. The volatiles were removed in a same manner as above. The crude materials were eluted from a column of LH-20 [1% $(NH_4)_2CO_3$] and AG500W-X8 (Na^+) to give **1** (5.6 mg, 90%): R_f 0.10 (1:2:1 *n*-BuOH−AcOH−H_2O); $[\alpha]_D = -34.2$ (*c* 0.79, H_2O). For ^{1}H NMR data, see Table 1. FABMS *m*/*z* 361.75 (calcd for $C_8H_{14}NPO_{10}Na_2$ 362.02, $[M - Na + 2H]^+$), 383.72 (calcd for $C_8H_{13}NPO_{10}Na_3$ 384.01, $[M + H]^+$), 405.81 (calcd for $C_8H_{12}NPO_{10}Na_4$ 405.99, $[M + Na]^+$).

Methyl 6-*O*-*tert*-Butyldiphenylsilyl-1-thio-β-D-galactopyranoside (17). To a solution of methyl 1-thio-β-D-galactopyranoside (303.4 mg, 1.44 mmol) and imidazole (223.5 mg, 3.28 mmol) in DMF (4.5 mL) was added *tert*-butylchlorodiphenylsilane (0.4 mL, 1.5 mmol) with stirring. After 4 h, the reaction mixture was diluted with EtOAc. The crude material obtained in the usual manner was eluted from a column of silica gel (3:1−1:1−1:2 toluene−EtOAc) to give **17** (592.3 mg, 92%) as a syrup: R_f 0.66 (1:4 MeOH−$CHCl_3$); $[\alpha]_D = +0.88$ (*c* 2.49, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.73−7.66 (m, 4H, Ar H), 7.47−7.38 (m, 6H, Ar H), 4.22−4.18 (m, 2H, ring H), 3.98−3.90 (m, 2H, ring H), 3.76−3.71 (m, 1H, ring H), 3.62−3.56 (m, 2H, ring H), 2.89 (d, 1H, J = 3.17 Hz, OH), 2.73 (d, 1H, J = 6.59 Hz, OH), 2.49 (d, 1H, J = 1.71 Hz, OH), 2.21 (s, 3H, Me), 1.11 (s, 9H, *t*-Bu). Anal. Calcd for $C_{23}H_{32}SiSO_5 \cdot 0.1H_2O$: C, 61.31; H, 7.22; S, 7.12. Found: C, 61.16; H, 7.27; S, 7.14.

Methyl 6-*O*-*tert*-Butyldiphenylsilyl-2,3,4-tri-*O*-(4-methylbenzoyl)-1-thio-β-D-galactopyranoside (18). To a solution of **17** (592.3 mg, 1.32 mmol) in pyridine (6 mL) were added 4-methylbenzoyl chloride (1.57 mL, 11.9 mmol) and a catalytic amount of DMAP, with stirring at 60−70 °C overnight. Then, MeOH (2 mL) was added to the reaction mixture in a water bath and stirring was continued for 2 h. The crude material obtained from the usual workup was eluted from a column of silica gel (*n*-hexane−20:1−15:1−7:1−2:1 *n*-hexanes−EtOAc) to give **18** (910.9 mg, 86%) as a syrup: R_f 0.40 (3:1 *n*-hexanes−EtOAc); $[\alpha]_D = +176.7$ (*c* 1.45, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.90−7.82 (m, 4H, Ar H), 7.69−7.64 (m, 4H, Ar H), 7.49−7.36 (m, 5H, Ar H), 7.29−7.25 (m, 3H, Ar H), 7.18−7.03 (m, 6H, Ar H), 6.05 (d, 1H, $J_{3,4}$ = 3.41 Hz, H-4), 5.76 (dd, 1H, $J_{1,2}$ = 9.76 Hz, $J_{2,3}$ = 10.01 Hz, H-2), 5.63 (dd, 1H, H-3), 4.64 (d, 1H, H-1), 4.09 (brt, 1H, H-5), 3.83 (dd, 1H, $J_{5,6a}$ = 5.85 Hz, J_{gem} = 10.24 Hz, H-6a), 3.76 (dd, 1H, $J_{5,6b}$ = 8.05 Hz, H-6b), 2.47, 2.35, 2.30, 2.26 (4s, 3H × 4, SMe, PhMe), 0.99 (s, 9H, *t*-Bu). Anal. Calcd for $C_{47}H_{50}SiSO_8 \cdot 0.1H_2O$: C, 70.12; H, 6.30; S, 3.98. Found: C, 69.91; H, 6.10; S, 3.98.

***N*-Benzyloxycarbonyl-*O*-{*O*-[2,3,4-tri-*O*-(4-methylbenzoyl)-α,β-D-galactopyranosyl]-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)}-L-serine Benzyl Ester (20α and 20β).** To a solution of **18** (406.4 mg, 0.506 mmol) and **16** (313.4 mg, 0.410 mmol) in DCE (8 mL) was added 4A MS (500 mg). After stirring at room temperature for 50 min, a solution of NIS (477 mg, 2.12 mmol) and TfOH (27 μL, 0.31 mmol) in a mixture of DCE (5 mL) and Et_2O (5 mL) was added at −20 °C and the solution stirred for 30 min. Saturated $NaHCO_3$ and $CHCl_3$ were added to the reaction mixture, and insoluble materials were filtered on Celite. The organic phase was washed with aqueous $Na_2S_2O_3$, aqueous $NaHCO_3$, and brine. The crude material obtained in the usual manner was eluted from columns of S-X1 (toluene) and then silica gel (20:1−10:1−7:1−5:1−3:1−2:1−1:1 *n*-hexanes−EtOAc) to give **19**α (R_f 0.60 (3:1 toluene−EtOAc) (10.0 mg)), **19**β (R_f 0.57 (3:1 toluene−EtOAc) (117.3 mg)), and a mixture of them (311.5 mg). The yields of **19**α and **19**β were estimated to be 18 and 52%, respectively, from the following deprotection procedure. A part of the mixture of **19**α and **19**β (37.7 mg) was diluted in THF (1 mL). To this were added AcOH (27 μL) and 1 M TBAF (0.24 mL) with stirring for 4.5 h. The reaction mixture was worked up as usual. PTLC (1:1 toluene−EtOAc) purification of the crude materials gave **20**α (8.9 mg) and **20**β (18.1 mg) (85%).

20α: R_f 0.55 (1:1 toluene−EtOAc); $[\alpha]_D = +112.4$ (*c* 0.89, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.97−7.95 (m, 2H, Ar H), 7.82−7.80 (m, 2H, Ar H), 7.67−7.65 (m, 2H, Ar H), 7.32−7.11 (m, 24H, Ar H), 7.03−7.01 (m, 2H, Ar H), 5.82 (dd, 1H, $J_{1,2}$ = 2.44 Hz, $J_{2,3}$ = 10.97 Hz, H-2^2), 5.79 (d, 1H, H-1^2), 5.59 (dd, 1H, $J_{3,4}$ = 3.36 Hz, H-3^2), 5.49 (d, 1H, H-4^2), 5.21, 5.15 (ABq, 2H, J = 12.44 Hz, $PhCH_2$), 5.18 (bt, 1H, J = 7.05 Hz, H-3^1), 5.09 (s, 2H, $PhCH_2$), 4.93−4.82 (m, 4H, $2PhCH_2$), 4.62 (dd, 1H, $J_{\alpha,\beta a}$ <1 Hz, $J_{\alpha,\beta b}$ = 7.54 Hz, Serα), 4.47 (d, 1H, J_{gem} = 9.51 Hz, Ser*β*a), 4.34 (d, 1H, $J_{1,2}$ = 7.56 Hz, H-1^1), 4.23 (brt, 1H, J = 7.07 Hz, H-5^2), 4.13 (dd, 1H, $J_{4,5eq}$ = 5.36 Hz, J_{gem} = 10.98 Hz, H-5eq^1), 4.00 (m, 1H, H-2^1), 3.78−3.67 (m, 3H, H-4^1,6a^2,Ser*β*b), 3.59 (m, 1H, H-6b^2), 3.38 (m, 1H, H-5ax^1), 2.52 (brt, 1H, J = 6.83 Hz, OH-6^2), 2.44, 2.34, 2.28 (3s, 3H × 3, 3PhMe), 1.42 (s, 3H, Me). Anal. Calcd for $C_{69}H_{70}NPO_{21}$: C, 64.72; H, 5.52; N, 1.09; P, 2.42. Found: C, 64.77; H, 5.59; N, 1.27; P, 2.70.

20*β*: R_f 0.38 (1:1 toluene−EtOAc); $[\alpha]_D = +74.7$ (*c* 0.91, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.95−7.93 (m, 2H, Ar H), 7.85−7.83 (m, 2H, Ar H), 7.69−7.67 (m, 2H, Ar H), 7.29−7.18 (m, 23H, Ar H), 7.05−6.95 (m, 3H, Ar H), 5.73 (d, 1H, $J_{3,4}$ = 3.17 Hz, H-4^2), 5.70 (dd, 1H, $J_{1,2}$ = 7.81 Hz, $J_{2,3}$ = 10.25 Hz, H-2^2), 5.59 (dd, 1H, H-3^2), 5.17−5.09 (m, 4H, $2PhCH_2$), 5.14 (m, 1H, H-3^1), 4.94−4.86 (m, 4H, $2PhCH_2$), 4.79 (d, 1H, H-1^2), 4.57 (d, 1H, $J_{\alpha,\beta b}$ = 8.78 Hz, Serα), 4.35 (d, 1H, J_{gem} = 9.51 Hz, Ser*β*a), 4.26 (d, 1H, $J_{1,2}$ = 6.83 Hz, H-1^1), 4.08 (m, 1H, H-2^1), 3.97 (t, 1H, J = 6.59 Hz, H-5^2), 3.80−3.69 (m, 3H, H-4^1,5eq^1,6a^2), 3.61−3.53 (m, 1H, H-6b^2,Ser*β*b), 3.11 (m, 1H, H-5ax^1), 3.00 (brt, 1H, J = 6.72 Hz, OH-6^2), 2.42, 2.35, 2.28 (3s, 3H × 3, 3PhMe), 1.84 (s, 3H, Me). Anal. Calcd for $C_{69}H_{70}NPO_{21}$: C, 64.72; H, 5.52; N, 1.09; P, 2.42. Found: C, 64.58; H, 5.53; N, 1.17; P, 2.58.

O*-[*O*-β-D-Galactopyranosyl-(1→4)−(2-*O*-phosphono-β-D-xylopyranosyl)]-L-serine, Trisodium Salt (2).** To a solution of **20β* (18.4 mg, 14.4 μmol) in MeOH (3 mL) were added a catalytic amount of Pd−C and 3 drops of AcOH. The reaction mixture was stirred under an H_2 atmosphere for 4.5 h and filtered on Celite, and the volatiles were removed under diminished pressure. The residue was diluted with MeOH (0.6 mL), H_2O (0.3 mL), and Et_3N (0.3 mL) and the solution for 2 h. To the reaction mixture was added 0.5 M NaOH (0.4 mL) at 0 °C. After 18 h, the reaction was worked up by adding 50% AcOH followed by evaporation. The crude materials were eluted from columns of LH-20 (1% AcOH) and AG500W-X8 (Na^+) to give **2** (6.4 mg, 82%): R_f 0.41 (1:1:1 MeOH−EtOAc−H_2O); $[\alpha]_D = -27.5$ (*c* 0.08, H_2O). For ^{1}H NMR data see Table 1. FABMS: *m*/*z* 523.80 (calcd for $C_{14}H_{25}NPO_{15}Na_2$ 524.08, $[M - Na + 2H]^+$), 545.79 (calcd for $C_{14}H_{24}NPO_{15}Na_3$ 546.06, $[M + H]^+$), 567.81 (calcd for $C_{14}H_{23}NPO_{15}Na_4$ 568.04, $[M + Na]^+$).

N*-Benzyloxycarbonyl-*O*-{*O*-[2,3,4-tri-*O*-(4-methylbenzoyl)-6-*O*-sulfo-β-D-galactopyranosyl]-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)}-L-serine Benzyl Ester, Sodium Salt (21).** To a solution of **20β* (27.6 mg, 21.6 μmol) in DMF (1.5 mL) was added $SO_3 \cdot NMe_3$ (88.9 mg, 639 μmol). The reaction mixture was stirred overnight at 50−60 °C and was subjected to columns of LH-20 (1:1 $CHCl_3$−MeOH) and AG50W-X8 (Na^+) (8:1 MeOH−H_2O) to give **21** (26.7 mg, 90%), which was used for deprotection procedure without further purification: R_f 0.63 (1:4 MeOH−EtOAc).

***O*-[O-(6-*O*-Sulfo-β-D-galactopyranosyl)−(1→4)-(2-*O*-phosphono-β-D-xylopyranosyl)]-L-serine, Tetrasodium Salt (3).** To a solution of **21** (21.1 mg, 15.3 μmol) in MeOH (3 mL) was added a catalytic amount of Pd−C. The reaction mixture was stirred under an H_2 atmosphere for 1 d and filtered on Celite, and the volatiles were removed under diminished pressure. The residue was diluted with 50% MeOH (2 mL), and 6 drops of 0.5M NaOH was added at 0 °C. After 2 d, the reaction was worked up by adding 50% AcOH and evaporation. The crude materials were purified on columns of LH-20 (1% AcOH) and AG500W-X8 (Na^+) to give **3** (5.8 mg, 59%): R_f 0.55 (1:1:1 MeOH−EtOAc−H_2O); $[\alpha]_D = -21.7$ (*c* 0.71, H_2O). For ^{1}H NMR data see Table 1. FABMS: *m*/*z* 626.3 (calcd for $C_{14}H_{24}NPSO_{18}Na_3$ 626.01, $[M - Na + 2H]^+$), 648.0 (calcd for $C_{14}H_{23}NPSO_{18}Na_4$ 648.00, $[M + H]^+$), 669.9 (calcd for $C_{14}H_{22}NPSO_{18}Na_5$ 669.98, $[M + Na]^+$).

***N*-Benzyloxycarbonyl-*O*-{*O*-(2-*O*-acetyl-3-*O*-allyl-4,6-*O*-

benzylidene-α,β-D-galactopyranosyl)-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)}-L-serine Benzyl Ester (23α and 23β). To a solution of the known methyl 2-*O*-acetyl-3-*O*-allyl-4,6-*O*-benzylidene-1-thio-β-D-galactopyranoside[4] (**22**, 98.1 mg, 258 μmol) and **16** (98.5 mg, 129 μmol) in DCE (1.4 mL) was added MS AW300 (200 mg). After stirring at room temperature for 70 min, a solution of NIS (174 mg, 774 μmol) and TfOH (14 μL, 155 μmol) in a mixture of DCE (1.2 mL) and Et_2O (1.2 mL) was added at −20 °C. After 30 min, the reaction mixture was worked up and purified as described for the synthesis of **19** to give **23**α (64.7 mg, 46%) and **23**β (52.1 mg, 37%).

23α: R_f 0.53 (1:1 toluene−EtOAc); $[\alpha]_D$ = +52.9 (*c* 1.32, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.52−7.50 (m, 2H, Ar H), 7.37−7.21 (m, 23H, Ar H), 5.94−5.85 (m, 1H, −C*H*=CH_2), 5.55 (s, 1H, PhCH), 5.50−5.27 (m, 2H, =CH_2), 5.23−5.14 (m, 2H, $PhCH_2$), 5.20 (m, 1H, H-3^1), 5.17 (m, 2H, H-1^2,2^2), 5.11 (s, 2H, $PhCH_2$), 4.94−4.88 (m, 4H, $2PhCH_2$), 4.62 (brd, 1H, *J* = 8.78 Hz, Serα), 4.46 (dd, 1H, J_{gem} = 9.51 Hz, $J_{\alpha,\beta a}$ = 2.19 Hz, Serβa), 4.33 (d, 1H, $J_{1,2}$ = 7.32 Hz, H-1^1), 4.30 (d, 1H, $J_{3,4}$ = 3.18 Hz, H-4^2), 4.24 (d, 1H, J_{gem} = 12.44 Hz, H-6a^2), 4.13 (d, 2H, OCH_2), 4.06 (m, 1H, H-6b^2), 4.02 (m, 1H, H-2^1), 3.91 (dd, 1H, $J_{4,5eq}$ = 5.37 Hz, J_{gem} = 11.46 Hz, H-5eq^1), 3.83 (dd, 1H, $J_{2,3}$ = 10.73 Hz, H-3^2), 3.78 (m, 1H, H-4^1), 3.68 (dd, 1H, $J_{\alpha,\beta b}$ = 2.93 Hz, Serβb), 3.60 (s, 1H, H-5^2), 3.28 (dd, 1H, $J_{4,5ax}$ = 10.25 Hz, H-5ax^1), 2.06, 1.88 (2s, 3H × 2, 2Me). Anal. Calcd for $C_{57}H_{62}NPO_{19}$: C, 62.46; H, 5.70; N, 1.28. Found: C, 62.25; H, 5.71; N, 1.08.

23β: R_f 0.33 (1:1 toluene−EtOAc); $[\alpha]_D$ = −17.4 (*c* 1.38, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.48−7.16 (m, 25H, Ar H), 5.89−5.79 (m, 1H, −C*H*=CH_2), 5.50 (s, 1H, PhCH), 5.27, 5.23 (m, 2H, =CH_2), 5.22−5.10 (m, 4H, $2PhCH_2$), 5.16 (m, 1H, H-2^2), 5.14 (m, 1H, H-3^1), 4.95−4.85 (m, 4H, $2PhCH_2$), 4.61 (m, 1H, Serα), 4.47 (d, 1H, $J_{1,2}$ = 7.81 Hz, H-1^2), 4.45 (dd, 1H, J_{gem} = 9.51 Hz, $J_{\alpha,\beta a}$ = 2.44 Hz, Serβa), 4.34 (d, 1H, $J_{1,2}$ = 7.56 Hz, H-1^1), 4.26 (dd, 1H, $J_{5,6a}$ < 1.0 Hz, J_{gem} = 10.98 Hz, H-6a^2), 4.23 (d, 1H, $J_{3,4}$ = 3.17 Hz, H-4^2), 4.14 (m, 1H, H-2^1), 4.07−4.02 (m, 3H, H-6b^2, OCH_2), 3.92 (dd, 1H, $J_{4,5eq}$ = 5.37 Hz, J_{gem} = 11.71 Hz, H-5eq^1), 3.80 (ddd, 1H, $J_{3,4}$ = 9.27 Hz, $J_{4,5ax}$ = 10.23 Hz, H-4^1), 3.69 (dd, 1H, $J_{\alpha,\beta b}$ = 3.41 Hz, Serβb), 3.55 (dd, 1H, $J_{2,3}$ = 10.25 Hz, H-3^2), 3.38 (s, 1H, H-5^2), 3.25 (dd, 1H, H-5ax^1), 2.06, 1.91 (2s, 3H × 2, 2Me). Anal. Calcd for $C_{57}H_{62}NPO_{19}$: C, 62.46; H, 5.70; N, 1.28; P, 2.83. Found: C, 62.50; H, 5.74; N, 1.27; P, 2.77.

***N*-Benzyloxycarbonyl-*O*-[*O*-(2-*O*-acetyl-4,6-*O*-benzylidene-β-D-galactopyranosyl)-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)]-L-serine Benzyl Ester (24).** A suspension of a catalytic amount of (1,5-cyclooctadiene)bis(methyldiphenylphosphine)iridium(I) hexafluorophosphate in THF (2.5 mL) was stirred under an H_2 atmosphere which was then replaced by argon. This manipulation was repeated a few times. Then, a solution of **23**β (99.6 mg, 90.9 μmol) in THF (4 mL) was added to the above solution of the iridium complex. After stirring for 2 h, H_2O (1.5 mL), $NaHCO_3$ (305.5 mg, 3.64 mmol), and I_2 (46.1 mg, 182 μmol) were added to the reaction mixture. The solution was stirred for 15 min and was diluted with $CHCl_3$. The organic phase was washed with aqueous $NaHCO_3$, aqueous $Na_2S_2O_3$, and brine. The crude material obtained in the usual manner was eluted from a column of silica gel (5:2−2:1−1:1−1:2−5:1 toluene−EtOAc) to give **24** (91.1 mg, 95%) as a syrup: R_f 0.30 (1:5 toluene−EtOAc); $[\alpha]_D$ = +25.7 (*c* 0.79, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.38−7.37 (m, 2H, Ar H), 7.31−7.30 (m, 3H, Ar H), 7.25−7.13 (m, 20H, Ar H), 7.02 (d, 1H, *J* = 8.78 Hz, NH), 5.45 (s, 1H, PhCH), 5.13, 5.08 (ABq, 2H, *J* = 12.44 Hz, $PhCH_2$), 5.07 (dd, 1H, $J_{2,3}$ = 9.51 Hz, $J_{3,4}$ = 9.27 Hz, H-3^1), 5.03 (s, 2H, $PhCH_2$), 4.90−4.79 (m, 4H, $2PhCH_2$), 4.88 (m, 1H, H-2^2), 4.54 (m, 1H, Serα), 4.37 (dd, 1H, J_{gem} = 9.76 Hz, $J_{\alpha,\beta a}$ = 2.20 Hz, Serβa), 4.35 (d, 1H, $J_{1,2}$ = 7.80 Hz, H-1^2), 4.29 (d, 1H, $J_{1,2}$ = 7.31 Hz, H-1^1), 4.21 (d, 1H, J_{gem} = 12.44 Hz, H-6a^2), 4.11 (d, 1H, $J_{3,4}$ = 3.90 Hz, H-4^2), 4.09 (m, 1H, H-2^1), 3.99 (d, 1H, H-6b^2), 3.85 (dd, 1H, $J_{4,5eq}$ = 5.37 Hz, J_{gem} = 11.71 Hz, H-5eq^1), 3.72 (ddd, 1H, $J_{4,5ax}$ = 9.75 Hz, H-4^1), 3.64 (dd, 1H, $J_{\alpha,\beta b}$ = 2.17 Hz, Serβb), 3.60 (m, 1H, H-3^2), 3.38 (s, 1H, H-5^2), 3.19 (dd, 1H, H-5ax^1), 2.01, 1.87 (2s, 3H × 2, 2Me). Anal. Calcd for $C_{54}H_{58}NPO_{19}$: C, 61.42; H, 5.52; N, 1.33; P, 2.93. Found: C, 61.34; H, 5.63; N, 1.29; P, 2.99.

***N*-Benzyloxycarbonyl-*O*-{*O*-[2,3,4,-tri-*O*-(4-methylbenzoyl)-α,β-D-galactopyranosyl]-(1→3)-*O*-(2-*O*-acetyl-4,6-*O*-benzylidene-β-D-galactopyranosyl)-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)}-L-serine Benzyl Ester (26α and 26β).** To a solution of **18** (96.5 mg, 120 μmol) and **24** (97.5 mg, 92.3 μmol) in DCE (2 mL) was added MS AW300 (120 mg). After stirring at room temperature for 40 min, a solution of NIS (125 mg, 554 μmol) and TfOH (8 μL, 92 μmol) in a mixture of DCE (1 mL) and Et_2O (1 mL) was added at −20 °C and the solution was stirred for 30 min. The reaction mixture was worked up and purified as described for the synthesis of **19** to give an anomeric mixture of triaosyl serines (113.6 mg). The mixture was diluted with THF (2 mL); then AcOH (36 μL) and 1 M TBAF (0.31 mL) were added to the solution. The reaction mixture was stirred for 10 h and was worked up as described for the synthesis of **20**. The crude materials obtained were eluted from a column of silica gel (2:1−3:2−1:2−1:5 toluene−EtOAc) and purified by PTLC (1:2 × 2 toluene−EtOAc) to give **26**α (12.3 mg, 9%) and **26**β (45.7 mg, 31%).

26α: R_f 0.61 (1:3 toluene−EtOAc); $[\alpha]_D$ = +126.0 (*c* 1.23, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.98−7.96 (m, 2H, Ar H), 7.69−7.65 (m, 4H, Ar H), 7.52−7.00 (m, 29H, Ar H), 6.89−6.87 (m, 2H, Ar H), 5.83−5.79 (m, 2H, H-3^3,4^3), 5.65 (d, 1H, $J_{1,2}$ = 3.66 Hz, H-1^3), 5.56 (dd, 1H, $J_{2,3}$ = 10.49 Hz, H-2^3), 5.30 (dd, 1H, $J_{1,2}$ = 8.05 Hz, $J_{2,3}$ = 10.25 Hz, H-2^2), 5.20, 5.15 (ABq, 2H, *J* = 12.44 Hz, $PhCH_2$), 5.17 (s, 1H, PhCH), 5.12 (m, 1H, H-3^1), 4.94−4.84 (m, 4H, $2PhCH_2$), 4.60 (m, 1H, Serα), 4.48 (d, 1H, H-1^2), 4.44 (dd, 1H, J_{gem} = 9.51 Hz, $J_{\alpha,\beta a}$ = 2.44 Hz, Serβa), 4.34 (d, 1H, $J_{1,2}$ = 7.32 Hz, H-1^1), 4.28 (brt, 1H, *J* = 6.96 Hz, H-5^3), 4.18 (d, 1H, J_{gem} = 10.98 Hz, H-6a^2), 4.16 (d, 1H, $J_{3,4}$ = 3.41 Hz, H-4^2), 4.13 (m, 1H, H-2^1), 3.93 (d, 1H, H-6b^2), 3.91 (dd, 1H, $J_{4,5eq}$ = 5.37 Hz, J_{gem} = 11.71 Hz, H-5eq^1), 3.85 (dd, 1H, H-3^2), 3.80 (m, 1H, H-4^1), 3.72−3.67 (m, 2H, H-6a^3,Serβb), 3.57 (m, 1H, H-6b^3), 3.35 (s, 1H, H-5^2), 3.25 (dd, 1H, $J_{4,5ax}$ = 10.24 Hz, H-5ax^1), 2.76 (m, 1H, OH-6^3), 2.43 (s, 3H, PhMe), 2.27 (s, 6H, 2PhMe), 2.21, 1.83 (2s, 3H × 2, 2Me). Anal. Calcd for $C_{84}H_{86}NPO_{27}$·0.5H_2O: C, 63.78; H, 5.56; N, 0.89; P, 1.96. Found: C, 63.90; H, 5.52; N, 0.91; P, 1.90.

26β: R_f 0.40 (1:3 toluene−EtOAc); $[\alpha]_D$ = +81.9 (*c* 1.27, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.98−7.96 (m, 2H, Ar H), 7.80−7.78 (m, 2H, Ar H), 7.67−7.65 (m, 2H, Ar H), 7.52−7.43 (m, 2H, Ar H), 7.32−7.13 (m, 27H, Ar H), 7.03−7.01 (m, 2H, Ar H), 5.79 (dd, 1H, $J_{1,2}$ = 7.81 Hz, $J_{2,3}$ = 10.49 Hz, H-2^3), 5.72 (d, 1H, $J_{3,4}$ = 3.17 Hz, H-4^3), 5.50 (dd, 1H, H-3^3), 5.41 (s, 1H, PhCH), 5.20−5.05 (m, 2H, $2PhCH_2$), 5.16 (m, 1H, H-2^2), 5.09 (d, 1H, H-1^3), 5.07 (m, 1H, H-3^1), 4.93−4.83 (m, 4H, $2PhCH_2$), 4.59 (m, 1H, Serα), 4.42 (d, 2H, *J* = 8.05 Hz, H-1^2,Serβa), 4.29 (d, 1H, $J_{1,2}$ = 7.56 Hz, H-1^1), 4.29 (brs, 1H, H-4^2), 4.23 (d, 1H, J_{gem} = 11.71 Hz, H-6a^2), 4.11 (m, 1H, H-2^1), 3.99 (d, 1H, H-6b^2), 3.96 (brt, 1H, *J* = 6.70 Hz, H-5^3), 3.90 (dd, 1H, $J_{2,3}$ = 10.49 Hz, $J_{3,4}$ = 2.97 Hz, H-3^2), 3.84 (dd, 1H, $J_{4,5eq}$ = 5.37 Hz, J_{gem} = 11.46 Hz, H-5eq^1), 3.79−3.71 (m, 2H, H-4^1,6a^3), 3.66 (dd, 1H, $J_{\alpha,\beta b}$ = 3.17 Hz, J_{gem} = 11.46 Hz, Serβb), 3.59 (m, 1H, H-6b^3), 3.38 (s, 1H, H-5^2), 3.17 (dd, 1H, $J_{4,5ax}$ = 10.25 Hz, H-5ax^1), 2.94 (m, 1H, OH-6^3), 2.43, 2.0.34, 2.27 (3s, 3H × 3, 3PhMe), 1.87, 1.64 (2s, 3H × 2, 2Me). Anal. Calcd for $C_{84}H_{86}NPO_{27}$: C, 64.16; H, 5.51; N, 0.89; P, 1.97. Found: C, 64.06; H, 5.58; N, 0.96; P, 1.96.

***N*-Benzyloxycarbonyl-*O*-[*O*-(2,3,4,6-tetra-*O*-acetyl-α,β- D-galactopyranosyl]-(1→3)-*O*-(2-O-acetyl-4,6-*O*-benzylidene-β-D-galactopyranosyl)-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl))-L-serine Benzyl Ester (27α and 27β).** To a solution of commercially available methyl 2,3,4,6-tetra-*O*-acetyl-1-thio-D-galactopyranoside (**25**, 120.3 mg, 0.318 mmol) and **24** (172.8 mg, 0.164 mmol) in DCE (6 mL) was added MS AW300 (500 mg). After stirring at room temperature for 35 min, a solution of NIS (221 mg, 0.983 mmol) and TfOH (17 μL, 0.194 mmol) in a mixture of DCE (3 mL) and Et_2O (3 mL) was added at −20 °C and the solution was stirred for 20 min. The reaction mixture was worked up as described for the synthesis of **19**. The crude materials obtained were eluted from a columns of S-X1

(toluene) and silica gel (5:1−3:1−5:2−2:1−1:1 toluene−EtOAc) and purified by PTLC (1:2 × 2 toluene−EtOAc) to give **27**α (23.9 mg, 11%) and **27**β (88.9 mg, 39%).

27α: R_f 0.41 (1:2 toluene−EtOAc); $[\alpha]_D = +34.0$ (*c* 1.20, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.47−7.19 (m, 25H, Ar H), 7.11 (d, 1H, $J = 9.87$ Hz, NH), 5.45 (d, 1H, $J_{3,4} = 3.42$ Hz, H-4^3), 5.43 (d, 1H, $J_{1,2} = 4.39$ Hz, H-1^3), 5.42 (s, 1H, PhCH), 5.22 (dd, 1H, $J_{1,2} = 8.29$ Hz, $J_{2,3} = 10.00$ Hz, H-2^2), 5.19, 5.15 (ABq, 2H, $J = 12.44$ Hz, $PhCH_2$), 5.15 (dd, 1H, $J_{2,3} = 8.78$ Hz, $J_{3,4} = 11.22$ Hz, H-3^1), 5.15 (dd, 1H, $J_{2,3} = 10.49$ Hz, H-3^3), 5.10 (s, 2H, $PhCH_2$), 4.93−4.88 (m, 4H, 2$PhCH_2$), 4.90 (m, 1H, H-2^3), 4.60 (m, 1H, Serα), 4.46 (d, 1H, H-1^2), 4.44 (m, 1H, Serβa), 4.35 (d, 1H, $J_{1,2} = 7.56$ Hz, H-1^1), 4.26 (d, 1H, $J_{gem} = 12.44$ Hz, H-6a^2), 4.23 (d, 1H, $J_{3,4} = 3.66$ Hz, H-4^2), 4.16−4.03 (m, 2H, H-6a,b^3), 4.15 (m, 1H, H-2^1), 4.12 (s, 1H, H-5^3), 4.05 (dd, 1H, H-6b^2), 3.90 (dd, 1H, $J_{4,5eq} = 5.12$ Hz, $J_{gem} = 11.47$ Hz, H-5eq^1), 3.81 (dd, 1H, H-3^2), 3.81 (m, 1H, H-4^1), 3.69 (dd, 1H, $J_{\alpha,\beta b} = 2.93$ Hz, $J_{gem} = 9.51$ Hz, Serβb), 3.39 (s, 1H, H-5^2), 3.26 (dd, 1H, $J_{4,5ax} = 10.25$ Hz, H-5ax^1), 2.12, 2.09, 2.05, 1.94, 1.90, 1.39 (6s, 3H × 6, 6Me). Anal. Calcd for $C_{68}H_{76}NPO_{28}\cdot H_2O$: C, 58.15; H, 5.61; N, 1.00. Found: C, 58.40; H, 5.75; N, 0.84.

27β: R_f 0.34 (1:2 toluene−EtOAc); $[\alpha]_D = -7.8$ (*c* 1.59, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.49−7.19 (m, 25H, Ar H), 7.11 (d, 1H, $J = 9.03$ Hz, NH), 5.52 (s, 1H, PhCH), 5.37 (d, 1H, $J_{3,4} = 3.41$ Hz, H-4^3), 5.20 (m, 1H, H-2^2), 5.19, 5.15 (ABq, 2H, $J = 12.44$ Hz, $PhCH_2$), 5.18 (m, 1H, H-2^3), 5.12 (t, 1H, $J_{2,3} = J_{3,4} = 9.03$ Hz, H-3^1), 5.12, 5.10 (2s, 2H × 2, 2$PhCH_2$), 4.95 (dd, 1H, $J_{2,3} = 10.49$ Hz, H-3^3), 4.92−4.85 (m, 4H, 2$PhCH_2$), 4.64 (d, 1H, $J_{1,2} = 8.05$ Hz, H-1^3), 4.60 (m, 1H, Serα), 4.43 (d, 1H, $J_{1,2} = 7.81$ Hz, H-1^2), 4.43 (m, 1H, Serβa), 4.34 (d, 1H, $J_{1,2} = 7.32$ Hz, H-1^1), 4.25 (d, 1H, $J_{gem} = 11.22$ Hz, H-6a^2), 4.23 (d, 1H, $J_{3,4} = 3.17$ Hz, H-4^2), 4.21 (dd, 1H, $J_{5,6a} = 5.83$ Hz, $J_{gem} = 11.23$ Hz, H-6a^3), 4.14 (m, 1H, H-2^1), 4.10 (dd, 1H, $J_{5,6b} = 7.31$ Hz, H-6b^3), 4.05 (d, 1H, H-6b^2), 3.90 (dd, 1H, $J_{4,5eq} = 5.37$ Hz, $J_{gem} = 11.46$ Hz, H-5eq^1), 3.88 (brt, 1H, $J = 6.83$ Hz, H-5^3), 3.80 (m, 1H, H-4^1), 3.79 (dd, 1H, $J_{2,3} = 10.14$ Hz, H-3^2), 3.68 (dd, 1H, $J_{\alpha,\beta b} = 3.17$ Hz, $J_{gem} = 9.51$ Hz, Serβb), 3.40 (s, 1H, H-5^2), 3.23 (dd, 1H, $J_{4,5ax} = 10.00$ Hz, H-5ax^1), 2.15, 2.06, 2.05, 1.99, 1.96, 1.89 (6s, 3H × 6, 6Me). Anal. Calcd for $C_{68}H_{76}NPO_{28}\cdot 0.5H_2O$: C, 58.53; H, 5.57; N, 1.00. Found: C, 58.85; H, 5.93; N, 1.00.

***O*-[*O*-β-D-Galactopyranosyl-(1→3)-*O*-β-D-galactopyranosyl-(1→4)-(2-*O*-phosphono-β-D-xylopyranosyl)]-L-serine, Trisodium Salt (4).** A solution of **26**β (7.7 mg, 4.9 μmol) in MeOH (2 mL) was exposed to hydrogenolytic conditions overnight as described for the synthesis of **2**. The residue was diluted with MeOH (1 mL), H_2O (0.5 mL), and Et_3N (0.5 mL) and was stirred for 5 d. The volatiles were evaporated, and the crude materials were eluted from a column of LH-20 (1% AcOH) to give **4** (1.7 mg, 49%): R_f 0.20 (1:1:1 *n*-BuOH−AcOH−H_2O); $[\alpha]_D = -14.1$ (*c* 0.17, H_2O). For ^{1}H NMR data see Table 1. FABMS of **4** eluted from AG500W-X8 (Na^+): *m*/*z* 686.3 (calcd for $C_{20}H_{35}NPO_{20}Na_2$ 686.13, $[M - Na + 2H]^+$), 708.3 (calcd for $C_{20}H_{34}NPO_{20}Na_3$ 708.11, $[M + H]^+$), 730.2 (calcd for $C_{20}H_{33}NPO_{20}Na_4$ 730.09, $[M + Na]^+$).

***O*-[*O*-(6-*O*-Sulfo-β-D-galactopyranosyl)-(1→3)-*O*-β-D-galactopyranosyl-(1→4)-(2-*O*-phosphono-β-D-xylopyranosyl)]-L-serine, Tetrasodium Salt (5).** To a solution of **26**β (12.2 mg, 7.8 μmol) in DMF (1 mL) was added $SO_3\cdot NMe_3$ (29.2 mg, 0.210 mmol). The reaction mixture was stirred for 6 h at 50−60 °Cand was subjected to columns of LH-20 (1:1 $CHCl_3$−MeOH) and AG50W-X8 (Na^+) (8:1 MeOH−H_2O) to give the sulfate quantitatively, which was used for deprotection without further purification. A solution of the sulfate in MeOH (2 mL) was exposed to hydrogenolytic conditions for 2 d as described for the synthesis of **2**. Methanolic 0.1 M NaOMe (0.25 mL) was added to the solution of the residue in MeOH (2 mL). The reaction mixture was stirred for 1 d. After neutralization with 50% AcOH, the volatiles were evaporated. The crude materials were eluted from columns of LH-20 (1% AcOH) and AG500W-X8 (Na^+) to give **5** (3.7 mg, 53%): R_f 0.47 (1:1:1 EtOAc−MeOH−H_2O); $[\alpha]_D = -13.8$ (*c* 0.13, H_2O). For ^{1}H NMR data see Table 1. FABMS: *m*/*z* 788.2 (calcd for $C_{20}H_{34}NPSO_{23}Na_3$ 788.07, $[M - Na + 2H]^+$), 810.1 (calcd for $C_{20}H_{33}NPSO_{23}Na_4$ 810.05, $[M + H]^+$), 832.1 (calcd for $C_{20}H_{32}NPSO_{23}Na_5$ 832.03, $[M + Na]^+$).

4-Methoxyphenyl 2,4,6-tri-*O*-acetyl-3-*O*-allyl-β-D-galactopyranoside (28). Crude 4-methoxyphenyl 3-*O*-allyl-β-D-galactopyranoside[4] was acetylated with pyridine and Ac_2O. After the usual workup, the crude material obtained was recrystallized from *n*-hexanes−EtOAc: mp 130−131 °C; $[\alpha]_D = +23.6$ (*c* 1.52, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 6.97−6.93 (m, 2H, Ar H), 6.83−6.79 (m, 2H, Ar H), 5.85−5.75 (m, 1H, C*H*=CH_2), 5.46 (d, 1H, $J_{3,4} = 3.66$ Hz, H-4), 5.34 (dd, 1H, $J_{1,2} = 8.05$ Hz, $J_{2,3} = 10.01$ Hz, H-2), 5.28−5.17 (m, 2H, =CH_2), 4.86 (d, 1H, H-1), 4.24−4.13 (m, 3H, H-6a, OCH_2), 3.96−3.90 (m, 2H, H-5,-6b), 3.77 (s, 3H, OMe), 3.59 (dd, 1H, H-3), 2.17, 2.11, 2.08 (3s, 3H × 3, 3MeCO). Anal. Calcd for $C_{22}H_{28}O_{10}$: C, 58.39; H, 6.25. Found: C, 58.38; H, 6.26.

4-Methoxyphenyl 2-*O*-Acetyl-3-*O*-allyl-6-*O*-*tert*-butyldiphenylsilyl-β-D-galactopyranoside (29) and 4-Methoxyphenyl 3-*O*-Allyl-6-*O*-*tert*-butyldiphenylsilyl-β-D-galactopyranoside (30). Triacetate **28** (590.6 mg, 1.31 mmol) was diluted with MeOH (4 mL), H_2O (2 mL) and Et_3N (2 mL), and the reaction mixture was stirred for 16 h at room temperature. The volatiles were removed under diminished pressure, and the residue was diluted with DMF (8 mL). To this solution were added imidazole (216.6 mg, 3.18 mmol) and *tert*-butylchlorodiphenylsilane (0.55 mL, 2.11 mmol). The reaction mixture was stirred overnight. The crude material obtained in the usual manner was eluted from a column of silica gel (20:1−10:1−8:1−3:1−1:1 toluene−EtOAc) to give **29** (670.6 mg, 85%) as a crystalline solid together with **30** (77.0 mg, 10%) as a syrup.

29: mp 116 °C (from *n*-hexanes−EtOAc); R_f 0.65 (2:1 toluene−EtOAc); $[\alpha]_D = +3.96$ (*c* 0.91, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.70−7.67 (m, 4H, Ar H), 7.66−7.33 (m, 6H, Ar H), 6.98−6.95 (m, 2H, Ar H), 6.76−6.73 (m, 2H, Ar H), 5.92−5.83 (m, 1H, C*H*=CH_2), 5.39 (dd, 1H, $J_{1,2} = 8.05$ Hz, $J_{2,3} = 10.00$ Hz, H-2), 5.31−5.20 (m, 2H, =CH_2), 4.81 (d, 1H, H-1), 4.20−4.15 (m, 1H, 1/2 = CH_2), 4.11 (brs, 1H, H-4), 4.08−4.03 (m, 1H, 1/2 = CH_2), 3.98, 3.97 (2s, 2H, H-6), 3.74 (s, 3H, OMe), 3.60 (brt, 1H, H-5), 3.51 (dd, 1H, $J_{3,4} = 3.17$ Hz, H-3), 2.56 (d, 1H, $J = 1.22$ Hz, OH), 2.11 (s, 3H, MeCO), 1.07 (s, 9H, *t*-Bu). Anal. Calcd for $C_{34}H_{42}SiO_8$: C, 67.29; H, 6.99. Found: C, 67.41; H, 7.02.

30: R_f 0.39 (2:1 toluene−EtOAc); $[\alpha]_D = -13.2$ (*c* 1.15, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.69−7.65 (m, 4H, Ar H), 7.44−7.32 (m, 6H, Ar H), 7.05−7.01 (m, 2H, Ar H), 6.79−6.74 (m, 2H, Ar H), 6.03−5.93 (m, 1H, C*H*=CH_2), 5.37−5.23 (m, 2H, =CH_2), 4.73 (d, 1H, $J_{1,2} = 7.80$ Hz, H-1), 4.28−4.19 (m, 2H, =CH_2), 4.11 (brs, 1H, H-4), 4.03−3.92 (m, 3H, H-2,6a,6b), 3.75 (s, 3H, OMe), 3.59 (brt, 1H, H-5), 3.43 (dd, 1H, $J_{2,3} = 9.51$ Hz, $J_{3,4} = 3.07$ Hz, H-3), 2.54 (d, 1H, $J = 1.95$ Hz, OH-4), 2.50 (d, 1H, $J = 2.20$ Hz, OH-2), 1.04 (s, 9H, *t*-Bu). Anal. Calcd for $C_{32}H_{40}SiO_7$: C, 68.04; H, 7.15. Found: C, 67.77; H, 7.18.

4-Methoxyphenyl 2-*O*-Acetyl-3-*O*-allyl-6-*O*-*tert*-butyldiphenylsilyl-4-*O*-(4-methylbenzoyl)-β-D-galactopyranoside (31). To a solution of **29** (497.3 mg, 0.819 mmol) in pyridine (5 mL) were added 4-methylbenzoyl chloride (0.32 mL, 2.42 mmol) and a catalytic amount of DMAP. After stirring overnight, MeOH (1.0 mL) was added. The crude material obtained by the usual workup was eluted from a column of silica gel (*n*-hexane−100:1−50:1−30:1−15:1−8:1−5:1−3:1−2:1 *n*-hexanes−EtOAc) to give **31** (576.4 mg, 97%) as a syrup: R_f 0.49 (2:1 *n*-hexanes−EtOAc); $[\alpha]_D = +33.5$ (*c* 1.55, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.96−7.94 (m, 2H, Ar H), 7.64−7.62 (m, 2H, Ar H), 7.54−7.52 (m, 2H, Ar H), 7.42−7.30 (m, 4H, Ar H), 7.26−7.13 (m, 4H, Ar H), 6.98−6.96 (m, 2H, Ar H), 6.77−6.74 (m, 2H, Ar H), 5.85−5.75 (m, 1H, C*H*=CH_2), 5.79 (d, 1H, $J_{3,4} = 3.65$ Hz, H-4), 5.39 (dd, 1H, $J_{1,2} = 8.05$ Hz, $J_{2,3} = 10.00$ Hz, H-2), 5.26−5.13 (m, 2H, =CH_2), 4.90 (d, 1H, H-1), 4.25−4.20 (m, 1H, 1/2 = CH_2), 4.03−3.92 (m, 1H, 1/2 = CH_2), 3.85−3.80 (m, 3H, H-5,6a,6b), 3.74 (s, 3H, OMe), 3.67 (dd, 1H, H-3), 2.42 (s, 3H, PhMe), 2.09 (s, 3H, MeCO), 1.02 (s, 9H, *t*-Bu). Anal. Calcd for $C_{48}H_{52}SiO_9$: C, 69.58; H, 6.69. Found: C, 69.66; H, 6.69.

4-Methoxyphenyl 2-*O*-Acetyl-6-*O*-*tert*-butyldiphenylsilyl-4-*O*-(4-methylbenzoyl)-β-D-galactopyranoside (32). A solution of **31** (346.2 mg, 0.478 mmol) in THF (6 mL) was added to a solution (5 mL) containing the iridium complex as described for the synthesis of **24**. After stirring overnight, H_2O (7.2 mL), $NaHCO_3$ (1.52 g, 18.1 mmol), and I_2 (242 mg, 0.95 mmol) were added to the reaction mixture and the solution stirred for 15 min. The crude material obtained in the same manner as described for the synthesis of **24** was eluted from a column of silica gel (30:1−10:1−5:1−2:1−1:1 *n*-hexanes−EtOAc) to give **32** (322.7 mg, 99%) as a syrup: R_f 0.48 (1:1 *n*-hexanes−EtOAc); $[\alpha]_D = -0.23$ (*c* 1.72, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.97−7.95 (m, 2H, Ar H), 7.624−7.621 (m, 2H, Ar H), 7.61−7.60 (m, 2H, Ar H), 7.52−7.50 (m, 3H, Ar H), 7.42−7.23 (m, 3H, Ar H), 7.19−7.16 (m, 3H, Ar H), 6.99−6.97 (m, 2H, Ar H), 6.79−6.76 (m, 2H, Ar H), 5.70 (d, 1H, $J_{3,4} = 3.66$ Hz, H-4), 5.28 (dd, 1H, $J_{1,2} = 8.05$ Hz, $J_{2,3} = 9.76$ Hz, H-2), 4.92 (d, 1H, H-1), 4.02 (m, 1H, H-5), 3.90−3.77 (m, 3H, H-3,-6a,6b), 3.75 (s, 3H, OMe), 2.66 (d, 1H, $J = 5.85$ Hz, OH-3), 2.44 (s, 3H, PhMe), 2.15 (s, 3H, MeCO), 1.02 (s, 9H, *t*-Bu). Anal. Calcd for $C_{39}H_{44}SiO_9 \cdot 0.1H_2O$:C, 67.89; H, 6.47. Found: C, 67.89; H, 6.45.

4-Methoxyphenyl *O*-(2,3,4,6-Tetra-*O*-acetyl-α,β-D-galactopyranosyl)-(1→3)-2-*O*-acetyl-6-*O*-*tert*-butyldiphenylsilyl-4-*O*-(4-methylbenzoyl)-β-D-galactopyranoside (35α and 35β) and 4-Methoxyphenyl 2,3-Di-*O*-acetyl-6-*O*-*tert*-butyldiphenylsilyl-4-*O*-(4-methylbenzoyl)-β-D-galactopyranoside (33). Method A. To a solution of the known 2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl trichloroacetimidate[14] (**34**, 195.9 mg, 0.398 mmol) and **32** (169.5 mg, 0.247 mmol) in CH_2Cl_2 (10 mL) was added MS AW300 (1.2 g). After stirring at room temperature for 30 min, TMSOTf (50 μL, 0.28 mmol) was added at −20 °C and the solution stirred for 2 h with the temperature gradually being raised to 8 °C. Et_3N, aqueous $NaHCO_3$, and $CHCl_3$ were added to the reaction mixture, and insoluble materials were filtered on Celite. Crude material obtained in the usual manner was eluted from columns of S-X1 (toluene) and silica gel (4:1−3:1−2:1−3:2−1:1−1:3 *n*-hexanes−EtOAc) to give **35**α (15.5 mg, 6%), **35**β (108.8 mg, 43%), and **33** (43.1 mg, 24%) as syrups. **Method B.** To a solution of **25** (97.6 mg, 0.258 mmol) and **32** (112.7 mg, 0.165 mmol) in DCE (7 mL) was added MS AW300 (1.2 g). After stirring at room temperature for 90 min, a solution of NIS (227 mg, 1.01 mmol) and TfOH (14 μL, 0.16 mmol) in a mixture of DCE (3 mL) and Et_2O (3 mL) was added at −20 °C and the solution stirred for 45 min with the temperature gradually being raised to −10 °C. The reaction mixture was worked up as described for the synthesis of **19**. The crude material obtained was purified as described in method A to give **35**α (11.0 mg, 7%), **35**β (59.5 mg, 36%), and **33** (9.2 mg, 8%).

35α: R_f 0.35 (1:1 *n*-hexanes−EtOAc); $[\alpha]_D = +56.5$ (*c* 1.08, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.95−7.94 (m, 2H, Ar H), 7.61−7.59 (m, 2H, Ar H), 7.51−7.47 (m, 2 H, Ar H), 7.41−7.24 (m, 6 H, Ar H), 7.20−7.12 (m, 2 H, Ar H), 7.01−6.94 (m, 2H, Ar H), 6.80−6.74 (m, 2H, Ar H), 5.79 (d, 1H, $J_{3,4} = 2.93$ Hz, H-4^1), 5.58 (dd, 1H, $J_{1,2} = 8.05$ Hz, $J_{2,3} = 10.24$ Hz, H-2^1), 5.47 (d, 1H, $J_{1,2} = 3.66$ Hz, H-1^2), 5.45 (d, 1H, $J_{3,4} = 3.17$ Hz, H-4^2), 5.28 (dd, 1H, $J_{2,3} = 10.73$ Hz, H-2^2), 5.08 (dd, 1H, H-3^2), 4.88 (d, 1H, H-1^1), 4.27 (brt, 1H, $J = 6.59$ Hz, H-5^2), 4.20 (dd, 1H, $J_{5,6a} = 6.83$ Hz, $J_{gem} = 10.98$ Hz, H-6a^2), 4.06 (dd, 1H, $J_{5,6b} = 6.83$ Hz, H-6b^2), 4.05 (dd, 1H, H-3^1), 3.85 (brt, 1H, $J = 6.47$ Hz, H-5^1), 3.79−3.71(m, 2H, H-6a,b^1), 3.75 (s, 3H, OMe), 2.43 (s, 3H, PhMe), 2.17, 2.13, 2.04, 1.90, 1.60 (5s, 3H × 5, 5MeCO), 1.00 (s, 9H, *t*-Bu). Anal. Calcd for $C_{53}H_{62}SiO_{18} \cdot 0.5H_2O$: C, 62.15; H, 6.21. Found: C, 62.29; H, 6.18.

35β: R_f 0.26 (1:1 *n*-hexanes−EtOAc); $[\alpha]_D = +26.4$ (*c* 1.12, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.91−7.89 (m, 2H, Ar H), 7.63−7.58 (m, 4H, Ar H), 7.38−7.21 (m, 8H, Ar H), 7.02−7.00 (m, 2H, Ar H), 6.74−6.72 (m, 2H, Ar H), 5.64 (d, 1H, $J_{3,4} = 3.41$ Hz, H-4^1), 5.55 (dd, 1H, $J_{1,2} = 8.05$ Hz, $J_{2,3} = 10.00$ Hz, H-2^1), 5.31 (d, 1H, $J_{3,4} = 3.41$ Hz, H-4^2), 5.03 (dd, 1H, $J_{1,2} = 7.81$ Hz, $J_{2,3} = 10.48$ Hz, H-2^2), 4.92 (dd, 1H, H-3^2), 4.89 (d, 1H, H-1^1), 4.63 (d, 1H, H-1^2), 4.16 (dd, 1H, $J_{5,6a} = 6.10$ Hz, $J_{gem} = 11.22$ Hz, H-6a^2), 4.03 (dd, 1H, $J_{5,6b} = 7.56$ Hz, H-6b^2), 4.00 (dd, 1H, H-3^1), 3.87−3.83 (m, 2H, H-5^1,5^2,6a^1), 3.77 (dd, 1H, $J_{5,6b} = 6.84$ Hz, $J_{gem} = 11.95$ Hz, H-6b^1), 3.73 (s, 3H, OMe), 2.41 (s, 3H, PhMe), 2.13, 2.08, 2.03, 1.94, 1.92 (5s, 3H × 5, 5MeCO), 1.04 (s, 9H, *t*-Bu). Anal. Calcd for $C_{53}H_{62}SiO_{18} \cdot 0.5H_2O$: C, 62.15; H, 6.21. Found: C, 62.24; H, 6.16.

33: R_f 0.58 (1:1 *n*-hexanes−EtOAc); $[\alpha]_D = +27.3$ (*c* 0.85, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.97−7.95 (m, 2H, Ar H), 7.62−7.61 (m, 2H, Ar H), 7.49−7.47 (m, 2H, Ar H), 7.43−7.25 (m, 6H, Ar H), 7.18−7.13 (m, 2H, Ar H), 6.98−6.95 (m, 2H, Ar H), 6.79−6.76 (m, 2H, Ar H), 5.80 (d, 1H, $J_{3,4} = 3.41$ Hz, H-4), 5.48 (dd, 1H, $J_{1,2} = 8.05$ Hz, $J_{2,3} = 10.25$ Hz, H-2), 5.19 (dd, 1H, H-3), 4.95 (d, 1H, H-1), 3.97 (brt, 1H, H-5), 3.83−3.77 (m, 2H, H-6a,b), 3.75 (s, 3H, OMe), 2.44 (s, 3H, PhMe), 2.07, 1.98 (2s, 3H × 2, 2MeCO), 0.99 (s, 9H, *t*-Bu).

***O*-(2,3,4,6-Tetra-*O*-acetyl-β-D-galactopyranosyl)-(1→3)-2-*O*-acetyl-6-*O*-*tert*-butyldiphenylsilyl-4-*O*-(4-methylbenzoyl)-α,β-D-galactopyranosyl Trichloroacetimidate (36).** To a solution of **35**β (312.0 mg, 0.307 mmol) in CH_3CN (20 mL) and H_2O (5 mL) was added CAN (843 mg, 1.54 mmol) at 0 °C. After stirring for 50 min, the reaction mixture was diluted with brine and extracted with $CHCl_3$. The organic phase was washed with brine. The crude material obtained in the usual manner was eluted from a column of silica gel (4:1−3:1−2:1−1:1−2:3−1:5 *n*-hexanes−EtOAc) to give a hemiacetal (260.5 mg, 93%) as a syrup, which was used for the next reaction without further purification: R_f 0.18 (1:1 *n*-hexanes−EtOAc). To a solution of the hemiacetal (260.5 mg, 0.287 mmol) and CCl_3CN (1.6 mL) in CH_2Cl_2 (6 mL) was added 2 drops of DBU at 0 °C. After stirring for 30 min at 0 °C and for 20 min more at room temperature, the reaction mixture was directly eluted from a column of silica gel (10:1−6:1−4:1−2:1−3:2−1:1 *n*-hexanes−EtOAc) to give **36** (279.3 mg, 93%) as an anomeric mixture. The product was used for the next reaction without further purification: R_f 0.39 and 0.29 (1:1 *n*-hexanes−EtOAc); ^{1}H NMR ($CDCl_3$) δ 8.68 (s, 1H, NHβ), 8.65 (s, 1H, NHα), 7.90, 7.88 (2s, 2H, Ar H), 7.61−7.54 (m, 4H, Ar H), 7.40−7.23 (m, 6H, Ar H), 6.62 (d, 1H, $J_{1,2} = 3.66$ Hz, Hα-1^1), 5.87 (d, 1H, $J_{1,2} = 8.29$ Hz, Hβ-1^1), 5.88 (d, 1H, $J_{3,4} = 3.42$ Hz, Hα-4^1), 5.75 (d, 1H, $J_{3,4} = 3.17$ Hz, Hβ-4^1), 5.60 (dd, 1H, $J_{2,3} = 10.00$ Hz, Hβ-2^1), 5.44 (dd, 1H, $J_{2,3} = 10.49$ Hz, Hα-2^1), 5.33 (d, 1H, $J_{3,4} = 3.42$ Hz, Hα-4^2), 5.32 (d, 1H, $J_{3,4} = 3.42$ Hz, Hβ-4^2), 5.09 (dd, 1H, $J_{1,2} = 7.81$ Hz, $J_{2,3} = 10.49$ Hz, Hα-2^2), 5.03 (dd, 1H, $J_{1,2} = 7.81$ Hz, $J_{2,3} = 10.49$ Hz, Hβ-2^2), 4.96 (dd, 1H, Hα-3^2), 4.92 (dd, 1H, Hβ-3^2), 4.72 (d, 1H, Hα-1^2), 4.65 (d, 1H, Hβ-1^2), 4.38 (dd, 1H, Hα-3^1), 4.34 (brt, 1H, $J = 6.17$ Hz, Hα-5^1), 4.19−4.04 (m, 2H, H-6a,b^2), 4.08 (dd, 1H, Hβ-3^1), 3.99 (brt, 1H, $J = 6.34$ Hz, Hβ-5^1), 3.91 (brt, 1H, $J = 7.20$ Hz, Hα-5^2), 3.87 (brt, 1H, $J = 7.57$ Hz, Hβ-5^2), 3.83 (dd, 1H, $J_{5,6a} = 5.61$ Hz, $J_{gem} = 10.73$ Hz, Hβ-6a^1), 3.77 (dd, 1H, $J_{5,6a} = 6.10$ Hz, $J_{gem} = 10.73$ Hz, Hα-6a^1), 3.74 (dd, 1H, $J_{5,6b} = 6.59$ Hz, Hβ-6b^1), 3.68 (dd, 1H, $J_{5,6b} = 6.83$ Hz, Hα-6b^1), 2.42 (s, 3H, PhMe), 2.11, 2.10, 2.08 × 3, 2.05 × 2, 1.94, 1.93, 1.92 (10s, 15H, 5MeCO), 0.99 (s, 9H, *t*-Bu).

***N*-Benzyloxycarbonyl-*O*-{*O*-(2,3,4,6-tetra-*O*-acetyl-α,β-D-galactopyranosyl)-(1→3)-*O*-[2-*O*-acetyl-6-*O*-*tert*-butyldiphenylsilyl-4-*O*-(4-methylbenzoyl)-β-D-galactopyranosyl]-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)}-L-serine Benzyl Ester (37α and 37β).** To a solution of **36** (190.5 mg, 0.181 mmol) and **16** (199.3 mg, 0.261 mmol) in CH_2Cl_2 (8 mL) was added MS AW300 (600 mg). After stirring at room temperature for 2 h, TMSOTf (23 μL, 0.13 mmol) was added at −20 °C and the reaction mixture was stirred for 1.5 h with the temperature gradually being raised to −10 °C. The workup was executed as described for the synthesis of **35**, and the crude material was eluted from columns of S-X1 (toluene) and silica gel (7:1−6:1−5:1−4:1−3:1−5:2 *n*-hexanes−EtOAc) to give **37**α (68.6 mg, 23%) and **37**β (53.9 mg, 18%) as syrups. The β-anomer [R_f 0.41 (1:1 toluene−EtOAc)] was used for the next reaction without further purification. **37**α: R_f 0.57 (1:1 toluene−EtOAc); $[\alpha]_D = +16.7$ (*c* 1.70, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.87−7.80 (m, 3H, Ar H), 7.65−7.52 (m, 6H, Ar H), 7.39−7.16 (m, 25H, Ar H), 5.64 (d, 1H, $J_{3,4} = 3.66$ Hz, H-4^2), 5.31 (d, 1H, $J_{3,4} = 2.58$ Hz, H-4^3), 5.22−5.13 (m, 5H, H-1^2,2PhCH$_2$), 5.20 (m, 1H, H-3^1), 5.12 (m, 1H, H-2^2), 5.01 (dd, 1H, $J_{1,2} = 7.80$ Hz, $J_{2,3} = 10.49$

Hz, H-2^3), 4.93−4.87 (m, 5H, H-3^3,2PhCH$_2$), 4.65 (d, 1H, H-1^3), 4.64 (m, 1H, Serα), 4.46 (m, 1H, Serβa), 4.32 (d, 1H, $J_{1,2}$ = 7.56 Hz, H-1^1), 4.19 (dd, 1H, $J_{2,3}$ = 10.00 Hz, H-3^2), 4.12 (m, 1H, H-6a^3), 4.07 (m, 1H, H-5eq^1), 4.02 (m, 2H, H-5^2,6b^3), 4.01 (m, 1H, H-2^1), 3.86 (brt, 1H, J = 7.20 Hz, H-5^3), 3.76 (dd, 1H, $J_{5,6a}$ = 4.40 Hz, J_{gem} = 10.97 Hz, H-6a^2), 3.75 (m, 1H, H-4^1), 3.66 (m, 1H, Serβb), 3.62 (dd, 1H, $J_{5,6b}$ = 7.56 Hz, H-6b^2), 3.26 (t, 1H, $J_{4,5ax}$ = J_{gem} = 10.28 Hz, H-5ax^1), 2.40 (s, 3H, PhMe), 2.10, 2.06, 2.03, 1.92, 1.89 (5s, 15H, 5MeCO), 1.00 (s, 9H, *t*-Bu).

***N*-Benzyloxycarbonyl-*O*-{*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-(1→3)-*O*-[2-*O*-acetyl-4-*O*-(4-methylbenzoyl)-β-D-galactopyranosyl]-(1→4)-(3-*O*-acetyl-2-*O*-dibenzyloxyphosphinyl-β-D-xylopyranosyl)}-L-serine Benzyl Ester (38).** To a solution of **37**β (53.9 mg, 32.6 μmol) in THF (2 mL) were added AcOH (36 μL) and 1 M TBAF (0.31 mL). The reaction mixture was stirred for 22 h and was worked up as described for the synthesis of **20**. The crude materials obtained were eluted from a column of LH-20 (1:1 MeOH−$CHCl_3$) and purified by PTLC (1:3 × 2 toluene−EtOAc) to give **38** (34.8 mg, 75%): R_f 0.37 (1:3 toluene−EtOAc); $[\alpha]_D$ = +5.05 (*c* 1.03, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.93−7.91 (m, 2H, Ar H), 7.52−7.16 (m, 22H, Ar H), 7.02 (d, 1H, J = 8.78 Hz, NH), 5.46 (d, 1H, $J_{3,4}$ = 3.17 Hz, H-4^2), 5.27 (d, 1H, $J_{3,4}$ = 3.66 Hz, H-4^3), 5.25 (dd, 1H, $J_{1,2}$ = 8.05 Hz, $J_{2,3}$ = 10.02 Hz, H-2^2), 5.20, 5.16 (ABq, 2H, J = 12.44 Hz, PhCH$_2$), 5.10 (m, 1H, H-3^1), 5.10 (s, 2H, PhCH$_2$), 5.02 (dd, 1H, $J_{1,2}$ = 7.81 Hz, $J_{2,3}$ = 10.49 Hz, H-2^3), 4.95−4.86 (m, 4H, 2 PhCH$_2$), 4.91 (m, 1H, H-3^3), 4.61 (m, 1H, Serα), 4.58 (d, 1H, H-1^3), 4.45 (d, 1H, H-1^2), 4.42 (dd, 1H, $J_{\alpha,\beta a}$ = 2.20 Hz, J_{gem} = 9.27 Hz, Serβa), 4.35 (d, 1H, $J_{1,2}$ = 7.07 Hz, H-1^1), 4.14−4.06 (m, 2H, H-2^1,6a^3), 3.93 (dd, 1H, $J_{2,3}$ = 10.00 Hz, H-3^2), 3.92 (dd, 1H, $J_{5,6b}$ = 5.61 Hz, J_{gem} = 10.00 Hz, H-6b^3), 3.84 (brt, 1H, J = 7.20 Hz, H-5^3), 3.83 (dd, 1H, $J_{4,5eq}$ = 5.61 Hz, H-5eq^1), 3.75 (m, 1H, H-4^1), 3.73−3.60 (m, 2H, H-5^2,6a^2), 3.65 (m, 1H, Serβb), 3.54 (m, 1H, OH-6^2), 3.47 (m, 1H, H-6b^2), 3.23 (dd, 1H, $J_{4,5ax}$ = 9.52 Hz, J_{gem} = 11.46 Hz, H-5ax^1), 2.41 (s, 3H, PhMe), 2.10, 2.05, 2.02, 1.96, 1.92, 1.80 (6s, 3H × 6, 6MeCO). Anal. Calcd for $C_{69}H_{78}NPO_{29}\cdot 1.5H_2O$: C, 57.41; H, 5.67; N, 0.97. Found: C, 57.79; H, 6.11; N, 1.09.

***O*-[*O*-β-D-Galactopyranosyl-(1→3)-*O*-(6-*O*-sulfo-β-D-galactopyranosyl)-(1→4)-(2-*O*-phosphono-β-D-xylopyranosyl)]-L-serine, Trisodium Salt (6).** To a solution of **38** (23.9 mg, 16.8 μmol) in DMF (3 mL) was added $SO_3\cdot NMe_3$ (73.0 mg, 0.524 mmol). The reaction mixture was stirred overnight at 50−60 °C and eluted from columns of LH-20 (1:1 $CHCl_3$−MeOH) and AG50W-X8 (Na^+) (8:1 MeOH−H_2O) to give the sulfate in 93% yield (23.9 mg), which was used for deprotection without further purification. To a solution of the sulfate in MeOH (6 mL) was added a catalytic amount of Pd−C. The reaction mixture was stirred under an H_2 atmosphere overnight and filtered on Celite, and the volatiles were removed under diminished pressure. The residue was diluted with MeOH (3 mL), H_2O (1.5 mL), and Et_3N (1.5 mL), and the reaction mixture was stirred for 3 d. Then, methanolic 0.1 M NaOMe (0.8 mL) was added to the reaction mixture with stirring overnight. After neutralization with 50% AcOH, the volatiles were evaporated. The crude materials were eluted from a column of LH-20 (1% AcOH), and the fractions containing triaosyl serines were condensed. The residue was diluted with H_2O (3 mL) and 0.5 M NaOH (0.3 mL) was added with stirring for 3 d. The same workup and purification as above afforded **6** (8.2 mg, 65% from **38**): R_f 0.18 (1:1:1 *n*-BuOH−AcOH−H_2O); $[\alpha]_D$ = −8.4 (*c* 0.67, H_2O). For ^{1}H NMR data see Table 1. FABMS: *m*/*z* 788.0 (calcd for $C_{20}H_{34}NPSO_{23}Na_3$ 788.07, $[M - Na + 2H]^+$), 810.0 (calcd for $C_{20}H_{33}NPSO_{23}Na_4$ 810.05, $[M + H]^+$).

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