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A convenient access to β-glycosides of *N*-acetyllactosamine

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Abstract

Iodoacetoxylation of 3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-1,5-anhydro-2-deoxy-D-*arabino*-hex-1-enitol (hexa-*O*-acetyllactal) and the corresponding hexa-*O*-benzoyl derivative, gave the α-1,2-*trans* 1-*O*-acetyl-2-deoxy-2-iodo adducts with high stereoselectivity and good yields. These were treated with an excess of trimethylsilyl azide in the presence of trimethylsilyl trifluoromethanesulfonate affording the corresponding α-1,2-*trans* 2-deoxy-2-iodoglycosyl azides. In the presence of an alcohol, a Staudinger reaction at the anomeric azide ledin situ to an iminophosphorane which rearranged with elimination of iodine at C-2. The aziridine intermediate thus obtained reacted with a suitable alcohol to afford the corresponding lactosamine β-glycosides. The reaction occurred with double inversion of configuration at C-1 and C-2. Deprotection of the amine functionality and further transformation into the acetamido derivatives could be achieved without isolation of the intermediates. © 1997 Elsevier Science Ltd.

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1. Introduction

2-Acetamido-2-deoxy-4-*O*-β-D-galactopyranosyl-D-glucose (*N*-acetyllactosamine) is a constituent of several oligosaccharides, such as glycans of *N*-glycoproteins [1], polylactosaminoglycans [2], sialyl Lewis X (sLe^X) tetrasaccharide, present on the surface of glycoproteins and glycolipids of neutrophils [3] or various blood-group antigens [4]. Numerous approaches have been developed in order to prepare lactosamine from 1,5-anhydro-2-deoxy-4-*O*-β-D-galactopyranosyl-D-*arabino*-hex-1-enitol. The most common was the azidonitration reaction, which was first achieved starting from 1,5-anhydro-2-deoxy-D-*lyxo*-hex-1-enitol series and then extended to peracetylated lactal **1** leading to the 2-azido-2-deoxylactose derivative in good yield and high stereoselectivity [5–7]. Addition of nitrosyl chloride to peracetylated lactal **1** was also reported to afford an oxime at C-2. The latter could be stereoselectively reduced to the acetamido derivative, using borane reagents [6,8].

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More recently, highly stereoselective preparation of 2-amino-2-deoxylactosides, involving cycloaddition of an azodicarboxylate on partly protected *tert*-butyldimethylsilyl lactal was described [9,10]; reaction of this adduct with 1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose afforded the expected trisaccharide in high yield. In 1992, Danishefsky et al. [11] reported the highly regio- and stereo-selective iodosulfonamidation of the lactal unit, part of a sialyl Lewis X tetrasaccharide. The 1,2-*trans* 2-deoxy-2-iodo-α-D-glycosyl sulfonamide thus obtained was further activated to afford higher oligosaccharides containing the *N*-acetyllactosamine moiety. *N*-acetyllactosamine has also been prepared in three steps from 1-*N*-benzyl-3-*O*-β-D-galactopyranosyl-D-arabinosylamine. The key step of the latter preparation was the stereoselective addition of hydrogen cyanide giving a 84% yield of the D-glucono nitrile adduct which was separated from its epimer by direct crystallization, before conversion into lactosamine by a non racemizing hydrogenation step [12,13]. The above derivatives have been further transformed into 2-amino-2-deoxylactopyranosyl donors and used in glycosylation reactions [14].

We have already reported the addition of iodine azide onto protected glycals [15,16]. Thus, starting from 3,4,6-tri-*O*-acetyl-1,5-anhydro-2-deoxy-D-*arabino*-hex-1-enitol (3,4,6-tri-*O*-acetyl-D-glucal), two separable 1,2-*trans* 2-deoxy-2-iodoglycosyl azides with α-D-*manno* and β-D-*gluco* configurations were obtained in 58 and 35% yield, respectively. Further Staudinger reaction, in the presence of a slight excess of alcohol, resulted in the 1,2-*trans* 2-amino-2-deoxy-D-glucosides and D-mannosides [16]. However, this reaction could not be extended to hexa-*O*-acetyl lactal **1** since, in this case, the addition of iodine azide afforded an unseparable mixture (53:47) of the two epimeric 1,2-*trans* 2-deoxy-2-iodoglycosyl azides. A more convenient approach is reported in the present paper, i.e. the iodoacetoxylation and subsequent substitution to an iodoazide derivative, by treatment with trimethylsilyl azide, catalyzed by a Lewis acid.

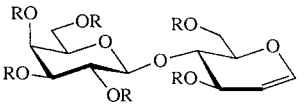
2. Results and discussion

Cohalogenation in organic synthesis has been reviewed recently [17]. As an example, *trans*-iodoacetoxylation can be achieved using either iodine and a metal acetate in acetic acid or *N*-iodosuccinimide, most often in acetic acid. These reactions have been applied to carbohydrate chemistry, in order to prepare 2-deoxy-2-iodo sugars from glycals [18]. Thus, for example, Roush et al. [19] prepared the 1-*O*-acetyl-2,6-dideoxy-2-iodo-4-*O*-isobutyryl-3-*C*-methyl-α-L-mannopyranose, intermediate in the synthesis of α-L-olivomycosides, via a highly stereoselective addition of *N*-iodosuccinimide to 1,5-anhydro-2,6-dideoxy-4-*O*-isobutyryl-3-*C*-methyl-L-*arabino*-hex-1-enitol (4-*O*-isobutyryl-L-olivomycal) in the presence of acetic acid.

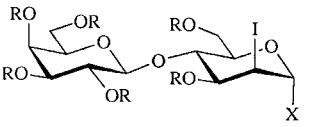
Iodoacetoxylation of partly acetylated lactal has been achieved by addition of a slight excess of iodine in the presence of cupric acetate monohydrate in acetic acid at 80 °C. The reaction showed a high stereoselectivity, affording the 1,2-*trans* 1-*O*-acetyl-2-deoxy-2-iodo-α-D-*manno* adducts in high yield [20]. Application of this procedure to hexa-*O*-acetyl lactal **1** afforded 1,3,6-tri-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-2-deoxy-2-iodo-α-D-mannopyranose (**3**) in 86% yield. Evidence for the α-D-*manno* configuration of the latter compound was obtained by ^{1}H and ^{13}C NMR ($\delta_{H\text{-}1}$ 6.34 ppm, $\delta_{H\text{-}2}$ 4.52 ppm, $J_{1,2}$ 2.3 Hz, $J_{2,3}$ 4.2 Hz, $\delta_{C\text{-}1}$ 94.49 ppm, $\delta_{C\text{-}2}$ 27.36 ppm) and by comparison with the data reported in the literature [18]. Analytically pure product **3** was easily obtained by a single recrystallization. Comparable results were obtained with hexa-*O*-benzoyl lactal **2**, leading to the iodoacetate **4**. Treatment of **3** or **4** with trimethylsilyl azide (1.75 equiv) and trimethylsilyl trifluoromethanesulfonate (0.15 equiv) afforded the corresponding 1,2-*trans* 2-deoxy-2-iodo-α-D-mannopyranosyl azide **5** or **6** in high yield. As expected, a high field chemical shift of H-1 was observed (~ 0.70 ppm), resulting from the replacement of an acetoxy by an azido group on the anomeric position. The experimental ^{1}H and ^{13}C NMR values were in agreement with those previously reported for the α-*manno* iodine azide adduct onto peracetylated-D-glucal [16]. Iodoacetoxylation could not be applied to per-*O*-benzyl lactal, under similar conditions, since a mixture of compounds was obtained. The latter contained the α-D-*manno* (~ 70%) and the β-D-*gluco* adducts (~ 20%) as major derivatives and was not purified. These results emphasize the importance of the ester functions on the stereoselectivity of the addition of lactal.

Treatment of 3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-2-deoxy-2-iodo-α-D-mannopyranosyl azide (**5**) with triphenylphosphine (1.1 equiv) and an alcohol (1.5 equiv) in methylene chloride from 0 to 20 °C afforded the corresponding [alkyl 3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-

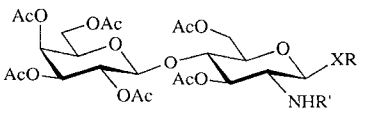
D-galactopyranosyl)-2-aminophosphonium-2-deoxy-β-D-glucopyranoside] iodide. This intermediate could be isolated and purified by column chromatography as shown for the methyl glycoside **7a**. Structural analysis of **7a** by ^{1}H NMR spectroscopy displayed coupling constants in favour of a β-D-*gluco* configuration ($J_{1,2}$ and $J_{2,3}$ 8–10 Hz). Migration of the nitrogen atom from C-1 to C-2 (Scheme 1) and formation of a glycosidic bond were ascertained by ^{13}C NMR chemical shifts of C-1 and C-2. The formation of a phosphonium salt was supported by the chemical shifts and couplings $J_{C,P}$ for C_{ipso}, C_{ortho}, C_{meta}, and C_{para} of the triphenylphosphonium moiety. The ^{31}P NMR chemical shift (δ_P 40.7) confirmed this assumption by comparison with the data reported in the literature [16,21,22]. As has already been described in the 2-deoxy-2-iodo-α-D-manno-pyranosyl azide series [16], the salt **7a** was transformed into the corresponding acetamido compound **7** (overall yield 84%) by exchange of the anion (Dowex 2X8 (OH^-)/ethanol), treatment with catalytic sodium methoxide and reacetylation under classical conditions. In order to avoid the deacetylation step, the salt **7a** was eluted in ethanol on a Dowex 2X8 (AcO^-) column to afford **7b**. The aminophosphonium acetate structure of the latter was



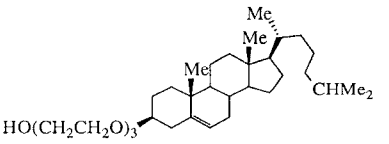
	R
1	Ac
2	Bz



	R	X
3	Ac	OAc
4	Bz	OAc
5	Ac	N_3
6	Bz	N_3



	R	R'	X
7	Me	Ac	O
7a	Me	PPh_3I	O
7b	Me	PPh_3OAc	O
8	$(CH_2)_3CH{=}CH_2$	Ac	O
9	nC_8H_{17}	Ac	O
10	$nC_{10}H_{21}$	Ac	O
11	$nC_{12}H_{25}$	Ac	O
12	$(CH_2CH_2O)_3Chol$	Ac	O
13	**18b**	Ac	O
14	**19b**	Ac	O
15	Chol	Ac	O
16	Et	Ac	S
16a	Et	PPh_3I	S



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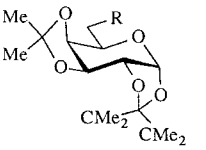
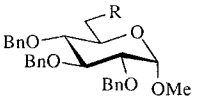


18a R = OH

18b R = -



19a R = OH

19b R = -

Scheme 1.

ascertained by ^{1}H, ^{13}C, and ^{31}P NMR (δ_P 35.3). However, the direct transformation of **7b** into the acetamido derivative **7** (heating in benzene), according to ref. [23], failed. Nevertheless, pure compound **7** was recovered by treatment of **7b** as described above from the aminophosphonium hydroxide intermediates.

The method was then extended to other primary alcohols such as pent-4-en-1-ol (pentenyl glycosides are versatile glycosyl donors [24]), octanol, decanol, dodecanol, 8-cholesteryloxy-3,6-dioxaoctan-1-ol **17** [25], 1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose **18a** [26], methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranoside **19a** [27], and cholesterol. The expected glycosides **8–15** were obtained in yields from 49 to 77% depending on the alcohol reactivity. The best yields were recorded with reactive aliphatic alcohols, the galactose derivative **18a** and cholesterol. Unfortunately, glycosylation of carbohydrate secondary hydroxyls was unsuccessful. The lower reactivity of donor **5**, compared with its monosaccharide analogue [16] could account for such a difference. Indeed, the Staudinger reaction occurs only above 15 °C and seems to be rather incompatible with the low stability of the aziridine intermediate when longer reaction periods are required.

This methodology could be extended to thioglycoside derivatives (thioglycosides of lactosamine have been used as glycosyl donors [28]) since the reaction of an excess of ethanethiol with **5**, in the presence of a slight excess of triphenylphosphine, afforded the expected aminophosphonium iodide **16a** in quantitative yield. However, any attempt to convert **16a** to its free-amino counterpart failed and the conversion to the acetamido compound **16** was rather laborious (only 45% yield).

In conclusion, the method described in the present report allowed access to several β-D-glucosides of lactosamine. It presents some limitations due to the lack of reactivity of donor **5**, which should be counterbalanced by the use of reactive acceptor alcohols. Nevertheless, the methodology is short and efficient and well suited for the preparation of tensioactive alkyl glycosides which will be reported in due course.

3. Experimental

General methods.—Pyridine was dried by boiling with CaH_2 prior to distillation. Dichloromethane was washed twice with water, dried with $CaCl_2$, and distilled from CaH_2. Methanol was refluxed with NaOMe before distillation. Pyridine and CH_2Cl_2 were stored over 4 Å molecular sieves and MeOH over 3 Å molecular sieves. Melting points were determined on a Büchi apparatus and were uncorrected. Thin layer chromatography analyses were performed on aluminium sheets coated with Silica Gel 60 F 254 (E. Merck). Compounds were visualized by spraying the TLC plates with dilute 15% aq H_2SO_4, followed by charring at 150 °C for a few min. Column chromatography was performed on Silica Gel Geduran Si 60 (E. Merck). Optical rotations were recorded on a Perkin–Elmer 241 polarimeter in a 1 dm cell at 21 °C. ^{1}H and ^{13}C NMR spectra were recorded with Bruker AC-200 or AM-300 spectrometers working at 200 or 300 MHz and 50 or 75.5 MHz, respectively, with Me_4Si as internal standard. In Experimental, ^{13}C data for the cholesteryl moiety are noted C. Elemental analyses were performed by the "Laboratoire Central d'Analyses du CNRS" (Vernaison, France).

*1,5-Anhydro-3,6-di-*O*-benzoyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-2-deoxy-*D*-arabino-hex-1-enitol* (**2**).—Hexa-*O*-acetyl lactal (**1**) [7] (2.00 g, 3.57 mmol) was treated overnight in MeOH (25 mL) containing a catalytic amount of sodium; after concentration, the residue was dissolved in C_5H_5N (20 mL) and benzoyl chloride (4.51 g, 32.13 mmol) was added dropwise at 0 °C; the solution was stirred overnight at room temperature, then poured into crushed ice and the oil was dissolved in CH_2Cl_2 (100 mL). The organic layer was successively washed with N HCl, aq $NaHCO_3$, and water, before drying and concentration. Purification of the residue by column chromatography (1:2 EtOAc–petroleum ether) afforded **2** (2.38 g, 72%) as a solid: mp 89–90 °C; $[\alpha]_D$ +47.8° (*c* 1.0, $CHCl_3$); R_f 0.83 (1:1 EtOAc–petroleum ether); ^{1}H NMR ($CDCl_3$): δ 8.58–7.17 (m, 30 H, Ph), 6.45 (dd, 1 H, $J_{1,2}$ 6.0 Hz, $J_{1,3}$ 1.3 Hz, H-1), 5.90 (m, 1 H, H-3), 5.84 (dd, 1 H, $J_{3',4'}$ 3.4 Hz, $J_{4',5'}$ 0.7 Hz, H-4'), 5.79 (dd, 1 H, $J_{1',2'}$ 7.9 Hz, $J_{2',3'}$ 10.4 Hz, H-2'), 5.10 (d, 1 H, H-1'), 4.93 (dd, 1 H, $J_{2,3}$ 3.0 Hz, H-2), 4.69 (dd, 1 H, $J_{5,6a}$ 2.8 Hz, $J_{6a,6b}$ 12.2 Hz, H-6a), 5.51–4.12 (m, 5 H, H-4,5,6b,6'a,6'b), 4.01 (ddd, 1 H, H-5'); ^{13}C NMR ($CDCl_3$): δ 165.69, 165.65, 165.53, 165.45, 165.39, 165.05 (6 C, Ph*C*O), 145.70 (C-1), 133.51, 133.27, 133.27, 129.92–128.22 (36 C, Ph), 101.31 (C-1'), 99.22 (C-2), 74.61, 74.35 (C-4,5), 71.64, 71.51 (C-3',5'), 69.93 (C-2'), 69.54 (C-3), 67.69 (C-4'), 61.82 (C-6), 61.14 (C-6'). Anal. Calcd for $C_{54}H_{44}O_{15}$ (932.89): C, 69.52; H, 4.75. Found: C, 69.26; H, 5.00.

*1,3,6-Tri-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-2-deoxy-2-iodo-α-D-mannopyra-*

nose (**3**).—Hexa-*O*-acetyl lactal (**1**) (12.40 g, 22.12 mmol), cupric acetate hydrate (4.85 g, 24.29 mmol, 1.1 equiv) and iodine (6.85 g, 26.99 mmol, 1.22 equiv) were successively added to AcOH (160 mL). The mixture was stirred for 6 h at 80 °C under an argon atmosphere, then cooled to room temperature and concentrated. Ether (250 mL) was added to the residue and the organic layer was successively washed with aq $NaHCO_3$ until neutral, water (50 mL), aq $Na_2S_2O_3$ (50 mL), and water. The clear solution was dried (Na_2SO_4) and evaporated to give a crude product containing more than 98% of the expected compound as shown by ^1H and ^{13}C NMR spectroscopy. Crystallization of the product occurred by heating in EtOH (60 mL) and cooling at room temperature. The product was recrystallized from EtOH (12.5 g, 76%). Column chromatography of the mother liquor (3:2 EtOAc–petroleum ether) afforded 1.6 g (10%) of pure **3**. Total yield 86%; mp 58–60 °C (EtOH); $[\alpha]_D$ +22.8° (*c* 1.0, $CHCl_3$); R_f 0.56; ^1H NMR ($CDCl_3$): δ 6.34 (d, 1 H, $J_{1,2}$ 2.3 Hz, H-1), 5.38 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4',5'}$ 0.8 Hz, H-4′), 5.17 (dd, 1 H, $J_{2',3'}$ 10.4 Hz, H-2′), 5.00 (d, 1 H, H-3′), 4.89 (m, 1 H, H-3), 4.66 (d, 1 H, H-1′), 4.52 (dd, 1 H, $J_{2,3}$ 4.2 Hz, H-2), 4.44 (dd, 1 H, $J_{5,6a}$ 1.2 Hz, $J_{6a,6b}$ 12.0 Hz, H-6a), 4.19 (dd, 1 H, $J_{5',6'a}$ 6.9 Hz, $J_{6'a,6'b}$ 11,1 Hz, H-6′a), 4.13–4.00 (m, 4 H, H-4,5,6b,6′b), 3.94 (ddd, 1 H, $J_{5',6'b}$ 6.4 Hz, H-5′), 2.17, 2.16, 2.15, 2.13, 2.08, 2.07, 1.98 (7s, 21 H, CH_3CO); ^{13}C NMR ($CDCl_3$): d 170.20, 170.18, 169.89, 169.78; 169.24; 169.12; 168.21 (7 C, CH_3CO), 101.38 (C-1′), 94.49 (C-1), 75.11 (C-4), 71.52 (C-5), 70.67, 70.50 (C-3′,5′), 69.07 (C-2′), 68.94 (C-3), 66.66 (C-4′), 61.53, 61.06 (C-6,6′), 27.36 (C-2), 20.78, 20.64, 20.60, 20.50, 20.40, 20.29 (7 C, CH_3CO). Anal. Calcd for $C_{26}H_{35}IO_{17}$ (746.44): C, 41.83; H, 4.73; I, 17.00. Found: C, 41.88; H, 4.53; I, 16.41.

1-O-Acetyl-3,6-di-O-benzoyl-4-O-(2,3,4,6-tetra-O-benzoyl-β-D-galactopyranosyl)-2-deoxy-2-iodo-α-D-mannopyranose (**4**).—Obtained as described above from hexa-*O*-benzoyl lactal (**2**) (0.755 g, 0.81 mmol), cupric acetate hydrate (0.178 g, 0.89 mmol, 1.10 equiv) and iodine (0.246 g, 0.97 mmol, 1.20 equiv) in AcOH (12 mL). The crude product (0.905 g) was purified by two recrystallizations from EtOH; 0.706 g (78%); mp 118–120 °C (EtOH); $[\alpha]_D$ +71.3° (*c* 1.0, $CHCl_3$); R_f 0.78 (1:2 EtOAc–petroleum ether); ^1H NMR ($CDCl_3$): δ 8.17–7.18 (m, 30 H, Ph), 6.42 (d, 1 H, $J_{1,2} < 1$ Hz, H-1), 5.80 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4',5'}$ 0.6 Hz, H-4′), 5.73 (dd, 1 H, $J_{1',2'}$ 7.9 Hz, $J_{2',3'}$ 10.4 Hz, H-2′), 5.43 (dd, 1 H, H-3′), 5.07 (dd, 1 H, $J_{2,3}$ 4.1 Hz, $J_{3,4}$ 8.8 Hz, H-3), 4.95 (d, 1 H, H-1′), 4.75 (dd, 1 H, $J_{4,5}$ 9.7 Hz, H-4), 4.63 (dd, 1 H, H-2), 4.55–4.44 (m, 2 H, H-6a,6b), 4.17–3.94 (m, 4 H, H-5,5′,6′a,6′b), 2.17 (s, 3 H, CH_3CO); ^{13}C NMR ($CDCl_3$): δ 168.47 (CH_3CO), 165.82, 165.72, 165.46, 165.29, 165.06, 164.97 (6 C, Ph*C*O), 133.65–128.29 (36 C, Ph), 101.49 (C-1′), 94.87 (C-1), 74.79 (C-4), 72.30 (C-5), 71.91 (C-3′), 71.70 (C-5′), 69.92 (C-2′), 68.82 (C-3), 67.84 (C-4′), 61.94 (2 C, C-6,6′), 28.74 (C-2), 20.92 (CH_3CO). Anal. Calcd for $C_{56}H_{47}IO_{17}$ (1118.84): C, 60.11; H, 4.23; I, 11.34. Found: C, 60.17; H, 4.27; I, 11.72.

3,6-Di-O-acetyl-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-2-deoxy-2-iodo-α-D-mannopyranosyl azide (**5**).—To a solution of iodoacetate **3** (6.80 g, 9.11 mmol) in dry CH_2Cl_2 (30 mL), were added trimethylsilyl azide (2.1 mL, 15.8 mmol, 1.75 equiv) and trimethylsilyl triflate (0.240 mL, 1.33 mmol, 0.145 equiv), under argon. Stirring was maintained until complete disappearance of the starting material (40 h). The solution was then neutralized by careful addition of aq $NaHCO_3$ and the organic layer was dried (Na_2SO_4) and concentrated to give a chromatographically homogeneous powder (6.30 g, 95%) which could be used directly without further purification. A sample was purified by column chromatography (3:2 EtOAc–petroleum ether); mp 69–70 °C; $[\alpha]_D$ +48.4° (*c* 1.0, $CHCl_3$); R_f 0.66; ^1H NMR ($CDCl_3$): δ 5.63 (d, 1 H, $J_{1,2}$ 3.1 Hz, H-1), 5.38 (dd, 1 H, $J_{3',4'}$ 3.4 Hz, $J_{4'5'}$ 1.0 Hz, H-4′), 5.16 (dd, 1 H, $J_{1',2'}$ 7.8 Hz, $J_{2',3'}$ 10.4 Hz, H-2′), 5.00 (dd, 1 H, H-3′), 4.70 (dd, 1 H, $J_{2,3}$ 4.0 Hz, $J_{3,4}$ 7.1 Hz, H-3), 4.59 (d, 1 H, H-1′), 4.46 (dd, 1 H, $J_{5,6a}$ 1.9 Hz, $J_{6a,6b}$ 11.8 Hz, H-6a), 4.42 (dd, 1 H, H-2), 4.17–3.94 (m, 4 H, H-5,6b,6′a,6′b), 3.96 (ddd, 1 H, H-5), 3.95 (dd, 1 H, H-4), 2.17, 2.15, 2.14, 2.08, 2.07, 2.04 (6 s, 18 H, CH_3CO); ^{13}C NMR ($CDCl_3$): δ 170.21, 170.18, 170.15, 169.93, 169.17, 169.03 (6 C, CH_3CO), 101.10 (C-1′), 90.53 (C-1), 75.26 (C-4), 71.50 (C-5), 70.70, 70.58 (C-3′,5′), 69.33 (C-2′), 68.88 (C-3), 66.70 (C-4′), 61.54, 61.10 (C-6,6′), 27.71 (C-2), 20.74, 20.62, 20.53, 20.43, 20.43, 20.37 (6 C, CH_3CO). Anal. Calcd for $C_{24}H_{32}IN_3O_{15}$ (729.42): C, 39.52; H, 4.42; N, 5.76. Found: C, 39.79; H, 4.51; N, 5.91.

3,6-Di-O-benzoyl-4-O-(2,3,4,6-tetra-O-benzoyl-β-D-galactopyranosyl)-2-deoxy-2-iodo-α-D-mannopyranosyl azide (**6**).—Prepared from **4** (1.000 g, 0.89 mmol) as described above for the synthesis of **5** from **3**. Compound **6** (0.896 g, 90%) was obtained as a solid after purification by column chromatography (2:5 EtOAc–petroleum ether); mp 95–96 °C; $[\alpha]_D$ +85.6°(*c* 1.0, $CHCl_3$); R_f 0.47; ^1H NMR ($CDCl_3$):

δ 8.17–7.17 (m, 30 H, Ph), 5.82 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4'5'}$ 0.5 Hz, H-4'), 5.74 (d, 1 H, $J_{1,2}$ 2.2 Hz, H-1), 5.73 (dd, 1 H, $J_{1',2'}$ 7.9 Hz, $J_{2',3'}$ 10.4 Hz, H-2'), 5.46 (dd, 1 H, H-3'), 5.01 (dd, 1 H, $J_{2,3}$ 4.0 Hz, $J_{3,4}$ 8.3 Hz, H-3), 4.96 (d, 1 H, H-1'), 4.57 (dd, 1 H, H-2), 4.55–4.04 (m, 7 H-4,5,6a,6b,5',6'a,6'b); ^{13}C NMR ($CDCl_3$): δ 165.55, 165.46, 165.18, 165.07, 164.63, 164.63 (6 C, Ph*C*O), 133.26, 133.06, 129.62–128.01 (36 C, Ph), 101.24 (C-1'), 90.95 (C-1), 74.70 (C-4), 71.87, 71.64, 71.51 (C-3',5,5'), 69.71 (C-2'), 68.60 (C-3), 67.68 (C-4'), 61.96 (C-6,6'), 29.29 (C-2). Anal. Calcd for $C_{54}H_{44}IN_3O_{15}$; H_2O (1119.83): C, 57.91; H, 3.96; N, 3.75. Found: C, 57.85; H, 4.06; N, 3.48.

*General procedure for the preparation of 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-β-*D*-glucopyranosides.*—Compound **5** (0.200 g, 0.274 mmol) and the alcohol (1.2–1.5 equiv) were dissolved in dry CH_2Cl_2 (2–3 mL) and the solution was cooled to 0 °C under argon. Then, a solution of PPh_3 (0.079 g, 1.10 equiv) in CH_2Cl_2 was added dropwise for 5 min. The reaction mixture was allowed to reach room temperature and stirred for 4 h. After concentration, the residue was dissolved in EtOH (1 mL) and the solution was applied at the top of a column of Dowex 2X8 (OH^-) in EtOH. After concentration of the eluate, the residue was treated overnight with a catalytic amount of MeONa in MeOH (10 mL). Concentration, followed by acetylation of the residue with 2:1 pyridine–Ac_2O (10 mL) afforded a crude compound which was purified by column chromatography.

*[Methyl 3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-aminotriphenylphosphonium-2-deoxy-β-*D*-glucopyranoside] iodide* (**7a**). —This intermediate, obtained from **5** (0.200 g, 0.274 mmol) and MeOH (13.3 mL, 0.329 mmol, 1.20 equiv), was isolated before the treatment with Dowex 2 × 8 (OH^-) and was characterized by ^{1}H, ^{31}P, and ^{13}C NMR. ^{1}H NMR ($CDCl_3$): δ 7.85–7.63 (m, 15 H, PhP), 5.85 (dd, 1 H, $J_{2,3}$, $J_{3,4}$ 9.5 Hz, H-3), 5.52 (d, 1 H, $J_{1,2}$ 8.0 Hz, H-1), 5.34 (dd, 1 H, $J_{3',4'}$ 3.2 Hz, $J_{4',5'}$ 0.5 Hz, H-4'), 5.09 (dd, 1 H, $J_{1',2'}$ 7.7 Hz, $J_{2',3'}$ 10.3 Hz, H-2'), 4.95 (dd, 1 H, H-3'), 4.63 (d, 1 H, H-1'), 4.41 (dd, 1 H, $J_{5,6a}$ 1.0 Hz, $J_{6a,6b}$ 10.9 Hz, H-6a), 4.18–3.95 (m, 5 H, H-5,5',6'a,6b,6'b), 3.73 (dd, 1 H, $J_{4,5}$ 9.7 Hz, H-4), 3.19 (s, 3 H, CH_3O), 3.10 (ddd, 1 H, H-2), 2.14, 2.07, 2.03, 2.01, 1.95, 1.75 (6's, 18 H, CH_3COO); ^{31}P NMR ($CDCl_3$): δ 40.7; ^{13}C NMR ($CDCl_3$): δ 170.58, 170.40, 170.26, 170.01, 169.12, 169.10 (6 C, CH_3CO), 135.10 (3 C, C_{para}), 134.11 (d, 6 C, $J_{C,P}$ 11.3 Hz, C_{ortho}), 130.00 (d, 6 C, $J_{C,P}$ 13.3 Hz, C_{meta}), 121.43 (d, 3 C, $J_{C,P}$ 104.1 Hz, C_{ipso}), 101.73 (C-1'), 99.69 (C-1), 76.41 (C-4), 73.69 (d, *J* 5.8 Hz, C-3), 72.07 (C-5), 71.31 (C-5'), 70.74 (C-3'), 69.14 (C-2'), 66.93 (C-4'), 62.63 (C-6), 60.91 (C-6'), 58.45 (C-2), 56.70 (OCH_3), 21.11, 21.06, 20.86, 20.84, 20.82, 20.61 (6 C, CH_3CO).

*[Methyl 3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-aminotriphenylphosphonium-2-deoxy-β-*D*-glucopyranoside] acetate* (**7b**). —Elution of **7a** on Dowex resin (AcO^-) with EtOH afforded quantitatively **7b**, which was characterized by ^{1}H, ^{31}P, and ^{13}C NMR. ^{1}H NMR ($CDCl_3$): δ 7.85–7.63 (m, 15 H, 3 Ph), 5.54 (dd, 1 H, $J_{2,3}$, $J_{3,4}$ 9.5 Hz, H-3), 5.33 (dd, 1 H, $J_{3',4'}$ 3.4 Hz, $J_{4',5'}$ 0.5 Hz, H-4'), 5.09 (dd, 1 H, $J_{1',2'}$ 7.8 Hz, $J_{2',3'}$ 10.3 Hz, H-2'), 4.92 (d, 1 H, $J_{1,2}$ 8.2 Hz, H-1), 4.91 (dd, 1 H, H-3'), 4.24 (d, 1 H, H-1'), 4.39 (dd, 1 H, $J_{5,6a}$ 1.0 Hz, $J_{6a,6b}$ 11.0 Hz, H-6a), 4.16–3.80 (m, 5 H, H-5,5',6'a,6b,6'b), 3.61 (dd, 1 H, $J_{4,5}$ 9.7 Hz, H-4), 3.19 (s, 3 H, CH_3O), 2.82 (ddd, 1 H, $J_{2,P}$ 15.6 Hz, H-2), 2.14, 2.06, 2.03, 2.00, 1.95, 1.95, 1.75 (7's, 21 H, CH_3CO); ^{31}P NMR ($CDCl_3$): δ 35.8; ^{13}C NMR ($CDCl_3$): δ 176.11, 170.11, 169.89, 169.80, 169.61, 168.85, 168.64 (7 C, CH_3CO), 134.01 (3 C, C_{para}), 133.57 (d, 6 C, $J_{C,P}$ 11.0 Hz, C_{ortho}), 129.26 (d, 6 C, $J_{C,P}$ 13.2 Hz, C_{meta}), 122.32 (d, 3 C, $J_{C,P}$ 104.0 Hz, C_{ipso}), 102.14 (C-1'), 99.84 (C-1), 76.13 (C-4), 74.01 (d, $J_{C,P}$ 6.9 Hz, C-3), 71.48 (C-5), 70.94 (C-5'), 70.15 (C-3'), 68.72 (C-2'), 66.48 (C-4'), 62.63 (C-6), 60.51 (C-6'), 57.87 (C-2), 56.28 (OCH_3), 22.48 (CH_3CON), 21.70, 20.61, 20.33, 20.33, 20.33, 20.21 (6 C, CH_3COO).

*Methyl 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-β-*D*-glucopyranoside* (**7**).—Obtained following the general procedure from **5** (0.200 g, 0.274 mmol) and MeOH (13.3 mL, 0.329 mmol, 1.20 equiv), the crude compound was purified by column chromatography (EtOAc, then 9:1 EtOAc–EtOH); 0.150 g (84%); mp 151–152 °C, lit. 151–153 °C [29]; $[\alpha]_D$ −13.5° (*c* 1.0, $CHCl_3$); R_f 0.64 (9:1 EtOAc–EtOH); ^{1}H NMR ($CDCl_3$): δ 5.64 (d, 1 H, $J_{2,NH}$ 9.4 Hz, N–*H*), 5.36 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4'5'}$ 0.8 Hz, H-4'), 5.13 (dd, 1 H, $J_{1',2'}$ 7.7 Hz, $J_{2',3'}$ 10.5 Hz, H-2'), 5.07 (dd, 1 H, $J_{2,3}$ 9.5 Hz, $J_{3,4}$ 8.1 Hz, H-3), 4.98 (dd, 1 H, H-3'), 4.52 (dd, 1 H, $J_{5,6a}$ 2.8 Hz, $J_{6a,6b}$ 11.2 Hz, H-6a), 4.51 (d, 1 H, H-1'), 4.36 (dd, 1 H, $J_{1,2}$ 7.5 Hz, H-1), 4.18–4.09 (m, 3 H, H-6b,6'a,6'b), 4.10 (ddd, 1 H, H-2), 3.88 (ddd, 1 H, $J_{5',6'a}$ 6.0 Hz, $J_{5',6'b}$ 6.5 Hz, H-5'), 3.80 (dd, 1 H, $J_{4,5}$ 8.6 Hz, H-4), 3.63 (ddd, 1

H, $J_{5,6b}$ 5.0 Hz, H-5), 3.46 (s, 3 H, CH_3O), 2.16, 2.12, 2.08, 2.06, 2.00, 1.97, 1.96 (7s, 21 H, CH_3CO); ^{13}C NMR ($CDCl_3$): δ 170.46, 170.40, 170.29, 169.95, 169.85, 169.15, 169.28 (7 C, CH_3CO), 101.42, 100.90 (C-1,1′), 75.93 (C-4), 72.76 (C-3), 72.37 (C-5), 70.70 (C-5′), 70.48 (C-3′), 68.95(C-2′), 66.53 (C-4′), 62.16 (C-6), 60.62 (C-6′), 56.13 (CH_3O), 52.90 (C-2), 22.98 (CH_3CON), 20.70, 20.67, 20.44, 20.44, 20.41, 20.32 (6 C, CH_3COO).

*Pent-4-enyl 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-β-*D*-glucopyranoside* (**8**).—Obtained from **5** (0.200 g, 0.274 mmol) and pent-4-en-1-ol (33.5 mL, 0.329 mmol, 1.20 equiv), the crude pentenyl glycoside **8** was purified by column chromatography (6:1 EtOAc–Me_2CO); 0.145 g (75%); mp 111–112 °C; $[\alpha]_D$ −15.5° (*c* 1.0, $CHCl_3$); R_f 0.50 (EtOAc); ^{1}H NMR ($CDCl_3$): δ 5.89–5.69 (m, 2 H, C*H*, N*H*), 5.37 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4',5'}$ 0.8 Hz, H-4′), 5.13 (dd, 1 H, $J_{1',2'}$ 7.8 Hz, $J_{2',3'}$ 10.4 Hz, H-2′), 5.04 (m, 1 H, H-3), 5.02–4.94 (m, 2 H, CH_2=), 4.99 (dd, 1 H, H-3′), 4.51 (m, 2 H, H-1′, 6a), 4.45 (d, 1 H, $J_{1,2}$ 7.7 Hz, H-1), 4.17–3.75 (m, 9 H, H-2,4,5′,6b,6′a,6′b, OC$H_a$$H_b$–, –C$H_2$–CH=$CH_2$), 3.62 (m, 1 H, H-5), 3.45 (m, 1 H, OC$H_a$$H_b$–), 2.16, 2.12, 2.08, 2.08, 2.06, 2.06, 1.97 (7 s, 21 H, CH_3CO), 1.66 (m, 2 H, OCH_2CH_2); ^{13}C NMR ($CDCl_3$): δ 170.50, 170.40, 170.28, 170.18, 170.08, 169.77, 169.28 (7 C, CH_3CO), 137.92 (*C*H=CH_2), 114.80 (CH=*C*H_2), 101.01, 100.79 (C-1,1′), 76.13 (C-4), 72.80 (C-3), 72.43 (C-5), 70.84 (C-5′), 70.53 (C-3′), 69.10 (C-2′), 68.57 (O*C*H_2), 66.71 (C-4′), 62.40 (C-6), 60 82 (C-6′), 53.22 (C-2), 29.88, 29.57 (2 C, pentenyl *C*H_2), 23.09 ($NHCOCH_3$), 20.85, 20.80, 20.57, 20.57, 20.57, 20.45 (6 C, CH_3COO). Anal. Calcd for $C_{31}H_{45}NO_{17}$ (703.68): C, 52.91; H, 6.45; N, 1.99. Found: C, 53.19; H, 6.51; N, 1.90.

*Octyl 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-β-*D*-glucopyranoside* (**9**).—Obtained from **5** (0.200 g, 0.274 mmol) and *n*-octanol (0.053 g, 0.405 mmol, 1.48 equiv), the crude compound was purified by column chromatography (EtOAc); 0.158 g (73%): mp 120 °C; $[\alpha]_D$ −18.8° (*c* 1.0, $CHCl_3$); R_f 0.56; ^{1}H NMR ($CDCl_3$): δ 5.68 (d, 1 H, $J_{2,NH}$ 9.4 Hz, N–*H*), 5.37 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4'5'}$ 0.5 Hz, H-4′), 5.13 (dd, 1 H, $J_{1',2'}$ 7.8 Hz, $J_{2',3'}$ 10.4 Hz, H-2′), 5.13 (dd, 1 H, $J_{2,3}$ 9.6 Hz, $J_{3,4}$ 8.6 Hz, H-3), 4.98 (dd, 1 H, H-3′), 4.51 (dd, 1 H, $J_{5,6a}$ 1.0 Hz, $J_{6a,6b}$ 11.0 Hz, H-6a), 4.50 (d, 1 H, H-1′), 4.44 (dd, 1 H, $J_{1,2}$ 7.8 Hz, H-1), 4.17–4.06 (m, 3 H, H-6b,5′,6′a), 4.07 (ddd, 1 H, H-2), 3.88 (dd, 1 H, $J_{5',6'b}$ 6.0 Hz, $J_{6'a,6'b}$ 7.2 Hz, H-6′b), 3.83 (ddd, 1 H, OC$H_a$$H_b$–), 3.79 (dd, 1 H, $J_{4,5}$ 9.6 Hz, H-4), 3.64 (m, 1 H, H-5), 3.42 (ddd, 1 H, *J* 9.5, 6.7, 6.7 Hz, OC$H_a$$H_b$–), 2.16, 2.12, 2.08, 2.06, 2.06, 1.97, 1.96 (7s, 21 H, CH_3CO), 1.54 (m, 2 H, octyl CH_2), 1.26 (m, 10 H, octyl CH_2), 0.87 (t, 3 H, CH_3); ^{13}C NMR ($CDCl_3$): δ 170.52, 170.38, 170.25, 170.13, 170.07, 169.94, 169.20 (7 C, CH_3CO), 101.00, 100.70 (C-1,1′), 76.23 (C-4), 72.91 (C-3), 72.38 (C-5), 70.84 (C-5′), 70.57 (C-3′), 69.31 (C-2′), 69.08 (OCH_2), 66.72 (C-4′), 62.44 (C-6), 60 82 (C-6′), 53.57 (C-2), 31.77, 29.39, 29.23, 29.18, 25.81, 22.54 (6 C, octyl *C*H_2), 23.02 (CH_3CON), 20.83, 20.77, 20.54, 20.54, 20.54, 20.42 (6 C, CH_3COO), 14.00 (octyl *C*H_3). Anal. Calcd for $C_{34}H_{53}NO_{17}$ (747.77): C, 54.61; H, 7.14; N, 1.87. Found: C, 54.71; H, 7.14; N, 2.05.

*Decyl 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-β-*D*-glucopyranoside* (**10**).—Obtained from **5** (0.200 g, 0.274 mmol) and *n*-decanol (0.065 g, 0.404 mmol, 1.47 equiv), the crude compound was purified by column chromatography (EtOAc); 0.153 g (72%): mp 124 °C; $[\alpha]_D$ −19.6° (*c* 1.0, $CHCl_3$); R_f 0.61. Anal. Calcd for $C_{36}H_{57}NO_{17}$ (775.82): C, 55.73; H, 7.40; N, 1.80. Found: C, 55.44; H, 7.51; N, 2.06.

*Dodecyl 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-β-*D*-glucopyranoside* (**11**).—Obtained from **5** (0.200 g, 0.274 mmol) and *n*-dodecanol (0.076 g, 0.408 mmol, 1.49 equiv), the crude compound was purified by column chromatography (EtOAc); 0.165 g (75%): mp 128–130 °C; $[\alpha]_D$ −17.8° (*c* 1.0, $CHCl_3$); R_f 0.65. Anal. Calcd for $C_{38}H_{61}NO_{17}$ (803.87): C, 56.77; H, 7.65; N, 1.74. Found: C, 57.01; H, 7.57; N, 1.62.

*[8-Cholesteryloxy-3,6-dioxaoctyl] 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-β-*D*-glucopyranoside* (**12**).—Obtained from **5** (0.200 g, 0.274 mmol) and 8-cholesteryloxy-3,6-dioxaoctan-1-ol **17** [25] (0.213 g, 0.411 mmol, 1.50 equiv), the crude product was purified by column chromatography (EtOAc, then 19:1 EtOAc–EtOH); 0.159 g (51%): mp 111–113 °C; $[\alpha]_D$ −20.0° (*c* 1.0, $CHCl_3$); R_f 0.52 (6:1 EtOAc–EtOH); ^{1}H NMR ($CDCl_3$): δ 6.85 (d, 1 H, $J_{2,NH}$ 9.4 Hz, N–*H*), 5.35 (m, 2 H, H-4′,6c), 5.10 (dd, 1 H, $J_{2',3'}$ 10.4 Hz, $J_{1',2'}$ 7.8 Hz, H-2′), 5.02 (dd, 1 H, $J_{2,3}$ 10.3 Hz, $J_{3,4}$ 9.5 Hz, H-3), 4.96 (dd, 1 H, $J_{3',4'}$ 3.4 Hz, H-3′), 4.67 (d, 1 H, $J_{1,2}$ 8.4 Hz, H-1), 4.50 (d, 1 H, H-1′), 4.47 (dd, 1 H, $J_{5,6a}$ 1.7 Hz, $J_{6a,6b}$ 11.7 Hz, H-6a), 4.16–3.60 (m, 19 H, H-2,4,5,6b,5′,6′a,6′b, OCH_2), 3.17 (m, 1 H, H-3$_c$), 2.14, 2.12, 2.06, 2.06,

2.05, 1.98, 1.96 (7's, 21 H, CH_3CO), 2.33–0.67 (m, 43 H, cholesteryl H); ^{13}C NMR ($CDCl_3$): δ 170.72, 170.45, 170.30, 170.25, 170.12, 170.00, 169.21 (7 C, CH_3CO), 140.75 (C-6c), 121.66 (C-5c), 101.86, 101.44 (C-1,1'), 79.43 (C-3c), 76.47 (C-4), 73.50 (C-3), 72.52 (C-5), 71.56 (OCH_2), 71.00 (C-5'), 70.84, 70.68, 70.67 (3 C, OCH_2), 70.60 (C-3'), 69.15 (C-2'), 68.69, 67.42 (2 C, OCH_2), 66.64 (C-4'), 62.40 (C-6), 60 76 (C-6'), 56.74 (C-14c), 56.12 (C-17c), 53.52 (C-2), 50.18 (C-9c), 42.30 (C-13c), 39.76 (C-16c), 39.49 (C-24c), 39.11 (C-4c), 37.17 (C-1c), 36.83 (C-10c), 36.16 (C-22c), 35.75 (C-20c), 31.91 (C-7c), 31.87 (C-8c), 29.65 (C-2c), 28.25 (C-12c), 27.97 (C-25c), 24.26 (C-15c), 23.79 (C-23c), 23.02 (CH_3CON), 22.80 (C-27c), 22.54 (C-26c), 21.06 (C-11c), 20.86, 20.86, 20.61, 20.61, 20.61, 20.47 (6 C, CH_3COO), 19.36 (C-19c), 18.71 (C-21c), 11.85 (C-18c). Anal. Calcd for $C_{59}H_{93}NO_{20}$ (1136.34): C, 62.36; H, 8.25; N, 1.23. Found: C, 61.99; H, 8.14; N, 1.18.

6-O-[2-Acetamido-3,6-di-O-acetyl-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-2-deoxy-β-D-glucopyranosyl]-1,2:3,4-bis-O-(1-methylethylidene)-α-D-galactopyranose (**13**).—Obtained from **5** (0.200 g, 0.274 mmol) and 1,2:3,4-bis-*O*-(1-methylethylidene)-α-D-galactopyranose **18a** [26] (0.107 g, 0.411 mmol, 1.50 equiv), the crude product was purified by column chromatography (7:1 EtOAc–Me_2CO); 0.185 g (77%): mp 93–95 °C; $[\alpha]_D$ −40.2° (*c* 1.0, $CHCl_3$), R_f 0.66; ^{1}H NMR ($CDCl_3$): δ 5.67 (d, 1 H, $J_{2',NH}$ 9.6 Hz, N–*H*), 5.53 (d, 1 H, $J_{1,2}$ 5.0 Hz, H-1), 5.35 (dd, 1 H, $J_{3'',4''}$ 3.3 Hz, $J_{4''5''}$ 0.5 Hz, H-4'), 5.12 (dd, 1 H, $J_{1'',2''}$ 7.7 Hz, $J_{2'',3''}$ 10.4 Hz, H-2''), 4.96 (dd, 1 H, H-3''), 4.59 (d, 1 H, H-1''), 4.58 (dd, 1 H, $J_{2,3}$ 7.9 Hz, H-2), 4.51 (dd, 1 H, H-6'a), 4.49 (d, 1 H, $J_{1',2'}$ 7.6 Hz, H-1'), 4.31 (dd, 1 H, $J_{3,4}$ 2.4 Hz, H-3), 4.16–3.58 (m, 11 H, H-4,5,6a,6b,2',4',5',6'b,5'',6''a,6''b), 2.15, 2.11, 2.07, 2.06, 2.05, 1.97, 1.97 (7s, 21 H, CH_3CO), 1.50, 1.44, 1.32, 1.32 (4s, 12 H, CH_3C); ^{13}C NMR ($CDCl_3$): δ 170.48, 170.28, 170.28, 170.18, 170.00, 169.88, 169.10 (7 C, CH_3CO), 109.16, 108.46 (2 C, $(CH_3)_2C$), 101.52, 100.84 (C-1',1''), 96.03 (C-1), 75.88 (C-4'), 73.42 (C-3'), 72.47 (C-5'), 70.85, 70.76, 70.60, 70.43, 70.06 (C-2,3,5,3'',5''), 68.93 (C-2''), 68.43 (C-6), 68.14 (C-4), 66.51 (C-4''), 62.14 (C-6'), 60.68 (C-6''), 53.12 (C-2'), 25.92, 25.77, 24.79, 24.11 (4 C, CH_3C), 23.06 (CH_3CON), 20.71, 20.71, 20.48, 20.48, 20.48, 20.34 (6 C, CH_3COO). Anal. Calcd for $C_{38}H_{55}NO_{22}$ (877.83): C, 51.99; H, 6.32; N, 1.60. Found: C, 51.90; H, 6.41; N, 1.50.

Methyl 6-O-[2-acetamido-3,6-di-O-acetyl-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-2-deoxy-β-D-glucopyranosyl]-2,3,4-tri-O-benzyl-α-D-glucopyranoside (**14**).—Obtained from **5** (0.200 g, 0.274 mmol) and methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranoside **19a** [27] (0.191 g, 0.411 mmol, 1.50 equiv), the crude product was purified by column chromatography (EtOAc); 0.146 g (49%): mp 118–119 °C (Et_2O); $[\alpha]_D$ −1.0° (*c* 1.0, $CHCl_3$); R_f 0.47; ^{1}H NMR ($CDCl_3$): δ 7.37–7.24 (m, 15 H, Ph), 5.66 (d, 1 H, $J_{2',NH}$ 9.3 Hz, N–*H*), 5.36 (dd, 1 H, $J_{3'',4''}$ 3.3 Hz, $J_{4''5''}$ 0.5 Hz, H-4''), 5.11 (dd, 1 H, $J_{1'',2''}$ 7.8 Hz, $J_{2'',3''}$ 10.5 Hz, H-2''), 4.98 (d, 1 H, *J* 11.0 Hz, C*H*Ph), 4.97 (dd, 1 H, H-3''), 4.85–4.56 (m, 5 H, C*H*Ph), 4.58 (d, 1 H, $J_{1,2}$ 3.5 Hz, H-1), 4.49 (d, 1 H, H-1''), 4.46 (dd, 1 H, $J_{5',6'a}$ 2.8 Hz, $J_{6'a,6'b}$ 12.0 Hz, H-6'a), 4.44 (d, 1 H, $J_{1',2'}$ 7.5 Hz, H-1'), 4.17–4.05 (m, 5 H, H-2',6a,6'b,6''a,6''b), 3.97 (dd, 1 H, $J_{2,3}$ 9.9 Hz, $J_{3,4}$ 9.0 Hz, H-3), 3.88 (m, 1 H, H-5''), 3.77 (m, 1 H, H-4'), 3.73 (m, 1 H, H-5), 3.65 (dd, 1 H, $J_{5,6b}$ 4.4 Hz, $J_{6a,6b}$ 10.5 Hz, H-6b), 3.60 (ddd, 1 H, $J_{4',5'}$ 5.3 Hz, $J_{5',6'b}$ 10.8 Hz, H-5'), 3.51 (dd, 1 H, H-2), 3.46 (dd, 1 H, $J_{4,5}$ 9.5 Hz, H-4), 3.35 (s, 3 H, CH_3O), 2.14, 2.06, 2.06, 2.05, 2.04, 1.97, 1.85 (7s, 21 H, CH_3CO); ^{13}C NMR ($CDCl_3$): d 170.47, 170.24, 170.23, 169.98, 169.89, 169.77, 169.24 (7 C, CH_3COO, CH_3CON), 138.64, 138.23, 137.99, 128.36–127.43 (18 C, Ph), 100.80, 100.73 (C-1',1''), 97.84 (C-1), 81.86 (C-3), 79.66 (C-2), 77.24 (C-4), 75.52 (CH_2Ph), 75.48 (C-4'), 74.46, 73.19 (2 C, CH_2Ph), 72.54 (C-3'), 72.17 (C-5'), 70.70 (C-5''), 70.61 (C-3''), 69.43 (C-5), 68.97 (C-2''), 67.47 (C-6), 66.54 (C-4''), 62.34 (C-6'), 60.73 (C-6''), 55.01 (OCH_3), 52.89 (C-2'), 23.06 ($NHCOCH_3$), 20.71, 20.69, 20.50, 20.50, 20.50, 20.39 (6 C, CH_3COO). Anal. Calcd for $C_{54}H_{69}NO_{22}$ (1084.10): C, 59.82; H, 6.41; N, 1.29. Found: C, 60.06; H, 6.27; N, 1.38.

Cholesteryl 2-acetamido-3,6-di-O-acetyl-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-2-deoxy-β-D-glucopyranoside (**15**).—Obtained from **5** (0.200 g, 0.274 mmol) and cholesterol (0.159 g, 0.411 mmol, 1.50 equiv), the crude cholesteryl glucoside was purified by column chromatography (EtOAc); 0.162 g (62%): mp 163–165 °C; $[\alpha]_D$ −21.5° (*c* 1.0, $CHCl_3$); R_f 0.60; ^{1}H NMR ($CDCl_3$): δ 5.56 (d, 1 H, $J_{2,NH}$ 9.2 Hz, N–*H*), 5.36 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4'5'}$ 0.5 Hz, H-4'), 5.35 (d, 1 H, H-6$_c$), 5.24 (m, 2 H, H-2',3), 4.97 (dd, 1 H, $J_{2',3'}$ 10.5 Hz, H-3'), 4.57 (d, 1 H, $J_{1',2'}$ 7.7 Hz, H-1'), 4.50 (d, 1 H, $J_{1,2}$ 7.6 Hz, H-1), 4.48 (dd, 1 H, $J_{5,6a}$ 1.0 Hz, $J_{6a,6b}$ 11.4 Hz, H-6a), 4.16–4.04 (m, 3 H, H-6b,5',6'a), 3.94 (ddd, 1 H, $J_{2,3}$ 9.2 Hz, H-2), 3.92 (dd, 1 H, $J_{5',6'b}$ 6.0 Hz, $J_{6'a,6'b}$ 7.0 Hz, H-6'b), 3.77 (dd, $J_{4,5}$

9.0 Hz, H-4), 3.62 (ddd, 1 H, $J_{5,6b}$ 5.2 Hz, H-5), 3.43 (m, 1 H, H-3$_c$), 2.16, 2.11, 2.08, 2.06, 2.06, 1.97, 1.97 (7s, 21 H, CH_3CO), 2.20–0.67 (m, 43 H, cholesteryl H); ^{13}C NMR ($CDCl_3$): d 170.62, 170.47, 170.34, 170.20, 170.15, 170.04, 169.35 (7 C, CH_3CO), 140.45 (C-6c), 121.95 (C-5c), 101.02 (C-1′), 99.62 (C-1), 79.32 (C-3c), 76.20 (C-4), 72.78 (C-3), 72.35 (C-5), 70.88 (C-5′), 70.64 (C-3′), 69.11 (C-2′), 66.65 (C-4′), 62.36 (C-6), 60 82 (C-6′), 56.72 (C-14c), 56.11 (C-17c), 53.73 (C-2), 50.13 (C-9c), 42.28 (C-13c), 39.72 (C-16c), 39.49 (C-24c), 39.00 (C-4c), 37.20 (C-1c), 36.65 (C-10c), 36.15 (C-22c), 35.74 (C-20c), 31.91 (C-7c), 31.81 (C-8c), 29.45 (C-2c), 28.20 (C-12c), 27.98 (C-25c), 24.25 (C-15c), 23.78 (C-23c), 23.24 (CH_3CON), 22.81 (C-27c), 22.56 (C-26c), 20.92 (C-11c), 20.64, 20.64, 20.64, 20.64, 20.52, 20.52 (6 C, CH_3COO), 19.34 (C-19c), 18.70 (C-21c), 11.85 (C-18c). Anal. Calcd for $C_{36}H_{81}NO_{17}$ (1004.19): C, 63.39; H, 8.13; N, 1.39. Found: C, 63.12; H, 8.33; N, 1.60.

*Ethyl [3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-aminotriphenylphosphonium-2-deoxy-1-thio-β-*D*-glucopyranoside] iodide* (**16a**).—Obtained from **5** (0.200 g, 0.274 mmol) and ethanethiol (101 μl, 1.370 mmol, 5.00 equiv) and isolated before the treatment with Dowex 2 × 8 (OH^-), this intermediate was purified on a short column of silica gel (5:1 EtOAc–EtOH) and characterized by ^{1}H, ^{31}P, and ^{13}C NMR; 0.267 g (95%); amorphous powder: ^{1}H NMR ($CDCl_3$): δ 8.00–7.27 (m, 15 H, PhP), 5.89 (d, 1 H, $J_{1,2}$ 9.8 Hz, H-1), 5.80 (dd, 1 H, $J_{2,3}$ 9.2 Hz, $J_{3,4}$ 9.6 Hz, H-3), 5.33 (dd, 1 H, $J_{3',4'}$ 3.2 Hz, $J_{4',5'}$ 0.5 Hz, H-4′), 5.05 (dd, 1 H, $J_{1',2'}$ 7.6 Hz, $J_{2',3'}$ 10.3 Hz, H-2′), 4.93 (dd, 1 H, H-3′), 4.52 (d, 1 H, H-1′), 4.41 (dd, 1 H, $J_{5,6a}$ 1.0 Hz, $J_{6a,6b}$ 10.0 Hz, H-6a), 4.15–3.88 (m, 5 H, H-5,5′,6′a,6b,6′b), 3.62 (dd, 1 H, $J_{4,5}$ 9.6 Hz, H-4), 3.11 (m, 1 H, H-2), 2.79 (q, 2 H, J 7.5 Hz, CH_2S), 2.12, 2.06, 2.06, 2.03, 1.95, 1.60 (6′s, 18 H, CH_3CO), 1.33 (t, 3 H, CH_3CH$_2$S); ^{31}P NMR ($CDCl_3$): δ 40.1; ^{13}C NMR ($CDCl_3$): δ 169.97, 169.78, 169.58, 169.42, 168.35; 168.15 (6 C, CH_3CO), 134.10 (3 C, C_{meta}), 133.79 (d, 6 C, $J_{C,P}$ 11.2 Hz, C_{para}), 129.45 (d, 6 C, $J_{C,P}$ 13.4 Hz, C_{ortho}), 120.64 (d, 3 C, $J_{C,P}$ 104.2 Hz, C_{ipso}), 99.23 (C-1′), 84.37 (C-1), 75.85 (C-4), 75.49 (C-3), 74.41 (C-5), 70.56 (C-3′), 70.34 (C-5′), 68.55 (C-2′), 66.44 (C-4′), 62.18 (C-6), 60.46 (C-6′), 57.12 (C-2), 25.19 (SCH$_2$), 20.43, 20.35, 20.19, 20.15, 20.10, 20.04 (6 C, CH_3COO), 14.94 (CH_3CH_2S).

*Ethyl 2-acetamido-3,6-di-*O*-acetyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-*D*-galactopyranosyl)-2-deoxy-1-thio-β-*D*-glucopyranoside* (**16**).—Treatment of the iodide **16a** without isolation as described earlier gave the crude ethyl thioglycoside **16** which was purified by column chromatography (EtOAc): 0.084 g (45%); mp 114–115 °C; $[\alpha]_D$ −24.5° (*c* 1.0, $CHCl_3$); R_f 0.54 (EtOAc); ^{1}H NMR ($CDCl_3$): δ 5.85 (d, 1 H, $J_{2,NH}$ 9.7 Hz, N–*H*), 5.36 (dd, 1 H, $J_{3',4'}$ 3.3 Hz, $J_{4'5'}$ 0.8 Hz, H-4′), 5.11 (dd, 1 H, $J_{1',2'}$ 7.8 Hz, $J_{2',3'}$ 10.4 Hz, H-2′), 5.09 (dd, 1 H, $J_{2,3}$ 9.5 Hz, $J_{3,4}$ 8.1 Hz, H-3), 4.96 (dd, 1 H, H-3′), 4.51 (d, 1 H, H-1′), 4.52 (dd, 1 H, $J_{5,6a}$ 2.8 Hz, $J_{6a,6b}$ 11.2 Hz, H-6a), 4.36 (dd, 1 H, $J_{1,2}$ 7.5 Hz, H-1), 4.18–4.09 (m, 3 H, H-6b,6′a,6′b), 4.10 (ddd, 1 H, H-2), 3.88 (ddd, 1 H, $J_{5',6'a}$, $J_{5',6'b}$ 6.5 Hz, H-5′), 3.80 (dd, 1 H, $J_{4,5}$ 8.6 Hz, H-4), 3.63 (ddd, 1 H, $J_{5,6b}$ 5.0 Hz, H-5), 3.46 (s, 3 H, CH_3O), 2.16, 2.12, 2.08, 2.06, 2.00, 1.97, 1.96 (7s, 21 H, CH_3COO, CH_3CONH); ^{13}C NMR ($CDCl_3$): δ 170.74, 170.28, 170.18, 170.10, 169.99, 169.86, 169.09 (7 C, CH_3CO), 101.03 (C-1′), 83.87 (C-1), 76.44, 76.38 (C-3,4), 74.56 (C-5), 70.75, 70.45 (C-3′,5′), 68.97 (C-2′), 66.52 (C-4′), 62.26 (C-6), 60 62 (C-6′), 56.13 (CH_3O), 52.45 (C-2), 23.68 (CH_2S), 22.90 (CH_3CON), 20.73, 20.63, 20.42, 20.42, 20.42, 20.30 (6 C, CH_3COO), 14.68 (CH_3CH_2S). Anal. Calcd for $C_{28}H_{41}NO_{16}S$ (679.68): C, 49.48; H, 6.08; N, 2.06. Found: C, 49.15; H, 5.90; N, 1.92.

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