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Synthesis and two-dimensional nuclear magnetic resonance analysis of a tetra- and a hexa-saccharide fragment of the *O*-specific polysaccharide of *Shigella dysenteriae* type 1 †

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Abstract

The synthesis of the tetra- and hexa-saccharide methyl glycosides α-D-Gal*p*-(1 → 3)-α-D-Glc*p*NAc-(1 → 3)-α-L-Rha*p*-(1 → 3)-α-L-Rha*p*-OMe (**1**), and α-L-Rha*p*-(1 → 3)-α-L-Rha*p*-(1 → 2)-α-D-Gal*p*-(1 → 3)-α-D-Glc*p*NAc-(1 → 3)-α-L-Rha*p*-(1 → 3)-α-L-Rha*p*-OMe (**3**) is described, which represent various epitopes of the *O*-specific polysaccharide of *Shigella dysenteriae* type 1. The following monosaccharide intermediates were used: 1,3-di-*O*-acetyl-2-*O*-benzoyl-4-*O*-benzyl-α-L-rhamnopyranose (**6α**), methyl 2,4-di-*O*-benzyl-α-L-rhamnopyranoside (**7**), methyl 2,4-di-*O*-benzoyl-1-thio-α-L-rhamnopyranoside (**8**), 2,3,4-tri-*O*-benzoyl-α-L-rhamnopyranosyl bromide (**9**), methyl 3,4,6-tri-*O*-benzyl-2-*O*-(4-methoxybenzyl)-1-thio-β-D-galactopyranoside (**13**), methyl 2,3,4,6-tetra-*O*-benzyl-1-thio-β-D-galactopyranoside (**16**), and 2-azido-4,6-*O*-benzylidene-3-*O*-bromoacetyl-2-deoxy-β-D-glucopyranosyl chloride (**19**). A detailed analysis of the ^{1}H and ^{13}C NMR spectra of oligosaccharides **1** and **3** confirmed that the hexasaccharide **3** better approaches the conformation of the native polysaccharide, than either **1** or the homologous pentasaccharide **41**.

1. Introduction

The *O*-specific polysaccharides (O-SP) of Gram-negative bacteria constitute the hydrophilic, outer-domain components of lipopolysaccharides (LPS) that are em-

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† For preliminary publications, see refs 1 and 2.

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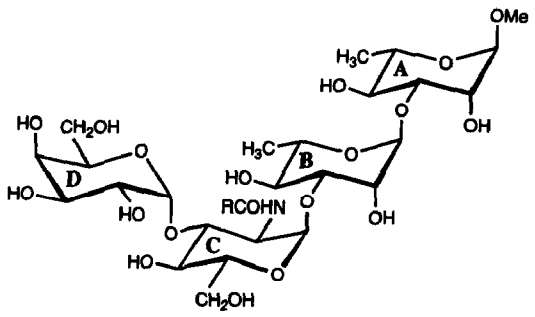
bedded in the phospholipid bilayer on the cell surface [3]. These polysaccharides consist of repeating units of short oligosaccharide fragments. While the inner regions of the LPSs are relatively conserved, the structures of the O-SPs show a large variation. This diversity makes the O-SPs the serologically dominant moiety of the LPSs and, indeed, is the basis for serotyping of bacterial isolates. The *O*-specific polysaccharides are essential for the bacteria to be virulent. On the other hand, there is evidence that antibodies to the O-SP can provide protective immunity to the host. Recently, Robbins and co-workers [4,5] suggested that circulating antibodies to the *O*-specific polysaccharide of *Shigellae* including *S. boydii*, *S. dysenteriae* type 1, *S. flexneri*, and *S. sonnei* may protect the host against shigellosis, and that conjugate vaccines consisting of the O-SP of Shigellae, covalently attached to an immunogenic protein could, indeed, confer protective immunity to humans against shigellosis. As a part of this project, we are currently synthesizing oligosaccharides related to the O-SP of *S. dysenteriae* type 1. The synthetic oligosaccharides may be used to define the structure(s) that mimic the conformational properties of the native O-SP. The knowledge of similarity of the O-SP and a synthetic fragment thereof, as a hapten candidate for inclusion in a conjugate vaccine, is important. Only those oligosaccharides that have a high degree of conformational similarity can be expected to elicit high-avidity antibodies against the native polysaccharide. Further, the synthetic oligosaccharides can be also used as probes to define the molecular specificities of anti-carbohydrate antibodies, and other, carbohydrate-binding proteins. The O-specific polysaccharide of *S. dysenteriae* type 1 is a linear polymer consisting of the iterative tetrasaccharide **A** which contains α-linked D-galactose, 2-acetamido-2-deoxy-D-glucose, and L-rhamnose residues [6,7]. We have described [8] the synthesis of a

$$[3)\text{-}\alpha\text{-L-Rha}p\text{-}(1\rightarrow 2)\text{-}\alpha\text{-D-Gal}p\text{-}(1\rightarrow 3)\text{-}\alpha\text{-D-Glc}p\text{Nac-}(1\rightarrow 3)\text{-}\alpha\text{-L-Rha}p(1\rightarrow]_n$$

A

complete tetrasaccharide repeating unit corresponding to **A**. Also prepared were the related di- [8,9], tri- [8] and penta-saccharide [8] sequences, as their methyl glycosides. A detailed NMR analysis of these fragments showed [8] that the methyl glycoside of the pentasaccharide α-L-Rha*p*-(1 → 3)-α-L-Rha*p*-(1 → 2)-α-D-Gal*p*-(1 → 3)-α-D-Glc*p*NAc-(1 → 3)-α-L-Rha*p* only partially mimics the distribution of the solution conformations of the O-SP. As a prelude to the preparation of extended epitopes of the O-SP we have also reported the synthesis of two multifunctional, fully protected, frame-shifted tetrasaccharide building blocks which can be used both as glycosyl donors and glycosyl acceptors [10,11]. We describe herein the synthesis of an alternative tetrasaccharide and a hexasaccharide fragment of the O-SP. These oligosaccharides have been prepared as their methyl glycosides (**1–3**), that have the natural anomeric configuration at their reducing end termini. We present the complete assignments of the ^{1}H NMR (500 and 600 MHz) and the ^{13}C NMR spectra (101 MHz) for **1** and **3**, and note some of their characteristics in relation to the smaller homologues, and the native O-SP.



1 R=Me
2 R=Et

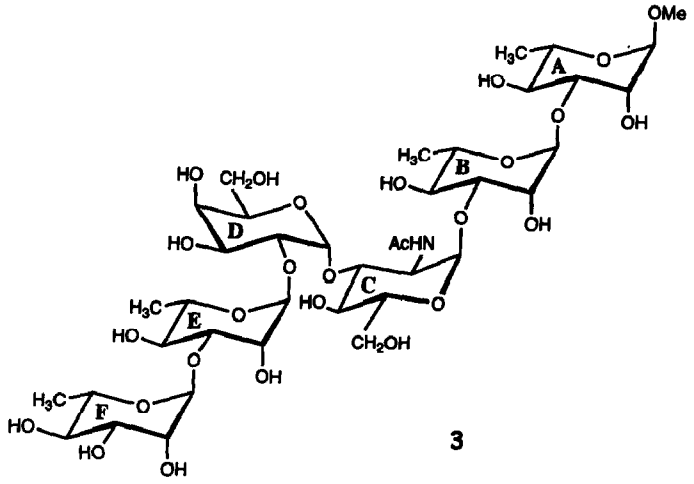
2. Results and discussion

Compounds **1** and **2** were synthesized in a stepwise manner from monosaccharide precursors. The hexasaccharide **3** was prepared in a block synthetic scheme, using a rhamnobiose donor and a tetrasaccharide acceptor derived from α-D-Gal*p*-(1 → 3)-α-D-Glc*p*NAc-(1 → 3)-α-L-Rha*p*-(1 → 3)-α-L-Rha*p*-OMe.

2.1 Synthesis

The monosaccharide intermediates

L-*Rhamnose units.*—Diacetate **6** was selected as the synthetic intermediate for residue B in the target oligosaccharides **1–3**. In compound **6**, the anomeric acetoxy



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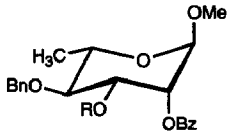
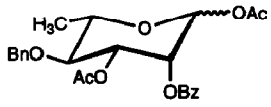


4 R = H
5 R = Ac



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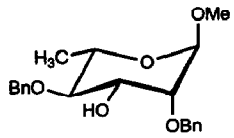

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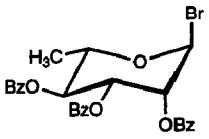

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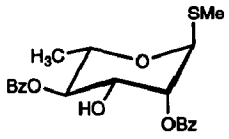
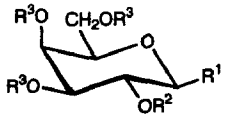


9

Bn = benzyl
Bz = benzoyl

group may serve as the leaving group in Lewis acid-catalyzed glycosylation reactions. Since the acetyl group at O-3 can be chemoselectively removed to expose HO-3 for chain extension, compound **6** can function both as a glycosyl donor and as a glycosyl acceptor. A two-step conversion of the known alcohol [8] **4** by acetylation (Ac_2O–Py) (→ **5**), followed by acetolysis (Ac_2O, H_2SO_4) afforded the rhamnosyl donor **6** as an anomeric mixture ($\alpha:\beta$ ratio ~ 95 : 5 ^1H NMR), in 87% combined yield. Partial resolution of this mixture by chromatography gave the α anomer in the pure state. We note, that the acetolytic step needs careful monitoring to avoid cleavage of the *O*-benzyl group. Other L-rhamnose intermediates used in this work were: methyl 2,4-di-*O*-benzyl-α-L-rhamnopyranoside [12] (**7**) for residue A in **1**–**3**, and 2,3,4-tri-*O*-benzoyl-α-L-rhamnopyranosyl bromide [13] (**8**) for residue F in **3**. These intermediates were prepared as described in their respective references. The bifunctional methyl 2,4-di-*O*-benzoyl-1-thio-α-L-rhamnopyranoside [11,14] (**9**) was selected as the intermediate for residue E in **3**, which can also serve both as a glycosyl donor, and as a glycosyl acceptor. Compound **9** was prepared from methyl 1-thio-α-L-rhamnopyranoside [13,15] in a one-pot protocol, as we described previously, in 76% yield [11]. Our yields [11,14] compare favorably with those (~ 45%, starting from the same precursor) disclosed in recently published multistep protocols [16], that depend heavily on chromatographic purification of the intermediates.

D-*Galactose units.*—Thiogalactoside [8] **13** was selected as the galactose donor for residue D in the hexasaccharide **3**. Previously, we prepared compound **13** by

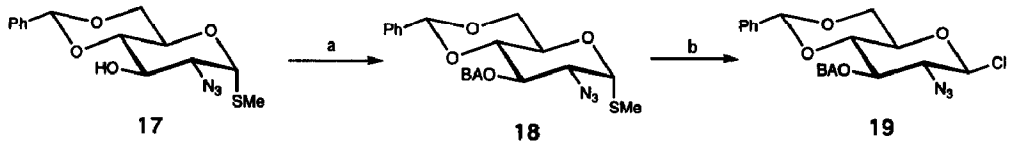


	R^1	R^2	R^3
10	OAc	Ac	Bn
11	SMe	Ac	Bn
12	SMe	H	Bn
13	SMe	MB	Bn
14	SMe	MB	H
15	SMe	H	H
16	SMe	Bn	Bn

Bn = benzyl
MB = 4-methoxybenzyl

O-benzylation of the triol **14**, which was obtained by two different routes [1,10,11]. We also reported the preparation and the synthetic utility of *O*-acylated derivatives [1,10,11] of **14**. In this work, the precursor to **13** was the diacetate [17] **10** which was converted into the crystalline thioglycoside **11** by treatment [18] with (methylthio)trimethylsilane and trimethylsilyl trifluoromethanesulfonate (Me_3-SiOTf) in 82% yield. The high efficiency of the OAc → SMe exchange further demonstrates the utility of this method [11,13,19], which is also applicable to the synthesis of phenyl 1-thioglycosides, using (phenylthio)trimethylsilane [13]. The anomeric configuration in **11** was ascertained from the $^3J_{H\text{-}1,H\text{-}3}$ coupling constant (9.7 Hz). Conventional deacetylation (Zemplén) yielded the alcohol **12** (82%), from which the fully protected thiogalactoside [8] **13** was obtained by alkylation with 4-methoxybenzyl chloride in 85% yield. The fully benzylated galactosyl donor [20] **16** was obtained by conventional benzylation (BnBr, NaH–DMF) of the thiogalactoside [19] **15** in 85% yield.

*2-Amino-2-deoxy-*D*-glucose unit.*—We have reported that a multifunctional 2-azido-2-deoxyglucosyl chloride is the donor of choice for the synthesis [8] of oligosaccharides related to the O-SP of *S. dysenteriae* type 1. In the present study, compound **19** was selected as the key intermediate for the construction of residue C in the target oligosaccharides **1–3**. This intermediate bears a similarity to the other glycosyl donors described above, in that it can function both as a glycosyl donor and as a glycosyl acceptor, after removal of the temporary protecting group from O-3. The bromoacetyl group [21] is ideally suited for this purpose, since it is

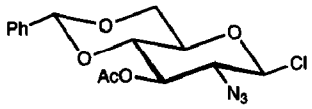


[a]Reagents: (a) $BrCH_2COBr$, C_5H_5N; (b) $Cl_2—CH_2Cl_2$.

BA = bromoacetyl
Ph = phenyl

Scheme 1.

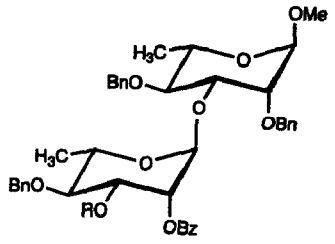
selectively removable in the presence of a variety of acid- and base-sensitive protecting groups. Compound **19** was prepared from the known alcohol [7] **17** by bromoacetylation (→ **18**, 82%) followed by chlorinolysis (90%) (Scheme 1). The β-configuration of the anomeric carbon atoms was inferred from the $^1J_{C\text{-}1,H\text{-}1}$ coupling constant (173 Hz). The related donor **20** was prepared as described [7].



20

Synthesis of oligosaccharides

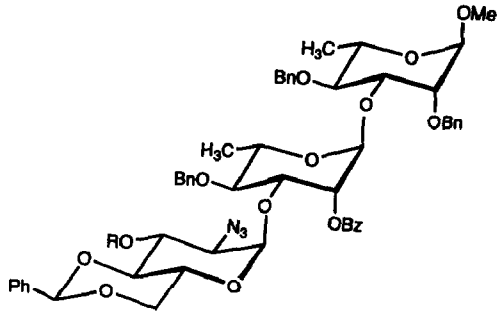
The reaction of the rhamnosyl donor **6** with the alcohol **7** under catalysis [22] by Me_3SiOTf afforded the disaccharide **21** in 73% yield. Next, the *O*-acetyl group was removed to expose HO-3 of residue B for subsequent chain elongation. Surprisingly, we observed little selectivity under mildly basic conditions, which had been previously recommended for the chemoselective removal of an *O*-acetyl group in the presence of an *O*-benzoyl group, e.g., $Mg(OMe)_2$ in MeOH (ref 23), or 1,8-diazabicyclo-[5,4,0]undec-7-ene (ref 24). Our finding with the former reagent concurs with those of Byramova an co-workers [25] who employed Corey's acid-catalyzed, selective deacetylation method [26] (0.005 M HCl in MeOH). We found that anhydrous tetrafluoroboric acid is a superior reagent for such transformations: treatment of a methanolic solution of **21** with HBF_4 in diethyl ether afforded **22** in 86% yield. This alcohol (**22**) was glucosylated with the chloride **19**, under promotion by silver trifluoromethanesulfonate (AgOTf) to give the trisaccharide **23**, which was obtained in crystalline form in 53% yield. The α anomeric configuration for residue C in **23** was indicated by the $^3J_{H\text{-}1,H\text{-}3}$ and $^1J_{C\text{-}1,H\text{-}1}$ coupling constants for this residue (see Experimental). In agreement with our earlier observations on related donors [8] no β-linked trisaccharide could be isolated from the mixture. The stereochemical outcome of this glycosylation reaction appears to be dictated by the moderate nucleophilicity of the acceptor **22**, since under similar conditions, reaction of the closely related *O*-acetylated donor **20** and the highly nucleophilic



21 R = Ac

22 R = H

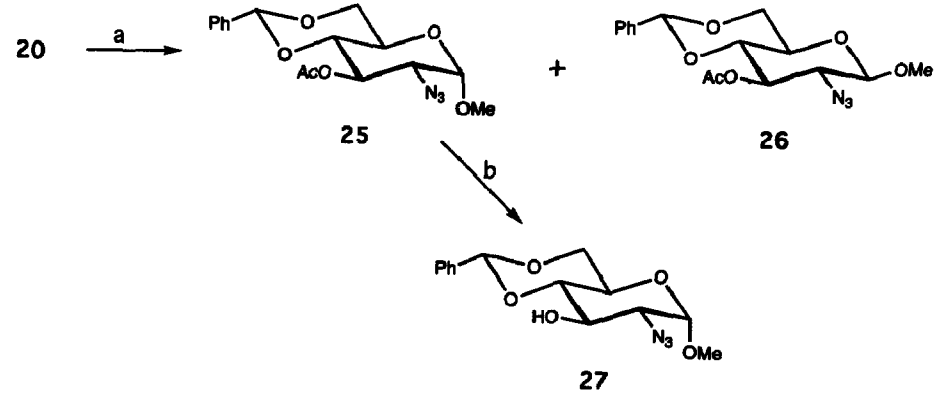
Bn = benzyl
Bz = benzoyl



23 R = BA

24 R = H

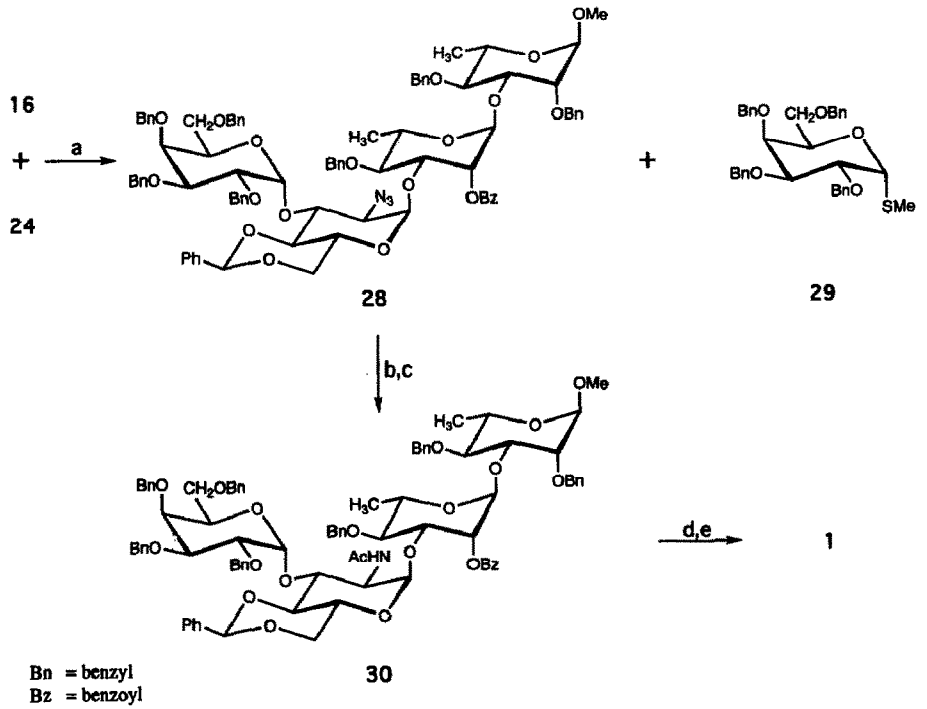
Bn = benzyl
Bz = benzoyl
BA = bromoacetyl
Ph = phenyl



[a]Reagents: (a) CF_3SO_3Ag, MeOH — CH_2Cl_2; (b) NaOMe — MeOH.

Scheme 2.

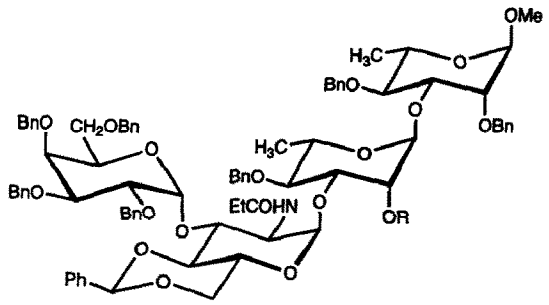
methanol afforded the α- (**25**) and the β-glycoside (26), in a ~ 3:2 ratio (Scheme 2). Removal of the *O*-acyl groups from **23** and **25**, using thiourea [27] and NaOMe, respectively, afforded the glycosyl acceptors **24** and **27** in high yields. Condensation of the galactosyl donor **16** and compound **24** according to Lönn [28] afforded the tetrasaccharide **28** in 88% yield (Scheme 3). This yield is based on the trisaccharide acceptor **24**. The glycosylation reaction was accompanied by anomerization of the donor **16** to the α anomer **29**, which could be isolated in 25% yield (based on **16**). The formation of **29** may be rationalized by the attack of the intermediate galactosyl cation on dimethyl sulfide derived from **16** in the presence of the promoter methyl trifluoromethanesulfonate. However, the exact mechanism of this process is not clear, and a similarity to the exclusive formation of 1-thio-α-D-glucopyranosides from a per-*O*-benzylated glucosyl donor cannot be excluded [29]. Accumulation of **29** in the mixture indicates that its reactivity is lower than that of the corresponding β isomer **16**. This observation is consistent with the findings of Paulsen and co-workers [30,31] on the relative reactivities of the 1,2-*trans* versus the 1,2-*cis* 1-*O*-acetyl glycoses in Lewis acid-catalyzed glycosylation reactions. Reduction of **28** ($N_3 \rightarrow NH_2$) [32], followed by *N*-acetylation afforded the protected tetrasaccharide **30**, which was conventionally deprotected to give **1**. Alterna-



[a]Reagents: (a) CF_3SO_3Me—$(C_2H_5)_2O$; (b) $NiCl_2 \cdot 6\,H_2O$, H_3BO_3, $NaBH_4$—DME, EtOH; (c) Ac_2O—MeOH; (d) NaOMe—MeOH; (e) H_2, Pd-C—EtOH, AcOH.

Scheme 3.

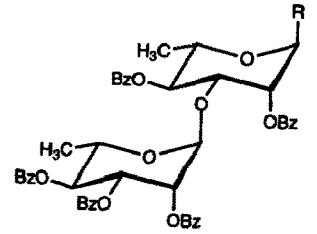
tively, *N*-propionylation of the intermediate amine obtained from **28** gave compound **31**, from which removal of the protecting groups by transesterification (→ **32**) followed by hydrogenolysis gave the tetrasaccharide methyl glycoside **2**. Compound **2** was prepared to probe the importance of the acetamido group in the binding of the O-specific polysaccharide with monoclonal antibodies. Interestingly, the solubility of compound **1** in water is surprisingly low, amounting to only ~ 1% at 0°C.



31 R = Bz
32 R = H

Bn = benzyl
Bz = benzoyl
Ph = phenyl

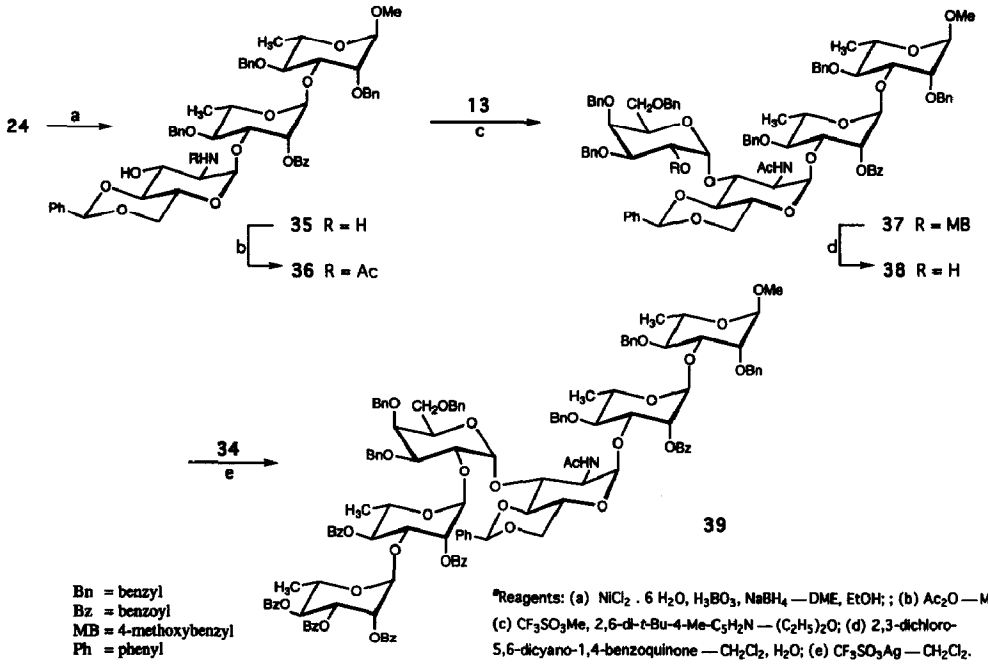
As mentioned earlier, hexasaccharide **3** was synthesized in a convergent, [2 + 4] block scheme. Precursors to the glycobiose block were the rhamnosyl bromide [13] **8** and the thiorhamnoside acceptor [11,14] **9**, which were condensed under by promotion with AgOTf, to afford the disaccharide **33** in 53% yield. TLC analysis of the mixture indicated the formation of several by-products, which account for the moderate yield of **33**. The tendency of thioglycoside acceptors to undergo side-reactions in glycosylation reactions, including the formation of glycals, and the formation of a thioglycoside from the original donor is documented [28,33,34]. It appears that the use of the more resistant [14,33] phenyl thioglycosides would alleviate the difficulties encountered with the methyl thioglycosides. The potential of this approach is currently being explored in our laboratory. Brominolysis of **33** afforded the biose block **34**. The α configuration of the anomeric center of the reducing-end unit was ascertained from the high value of the one-bond, heteronuclear C–H coupling constant (185 Hz).



33 R = SMe
34 R = Br

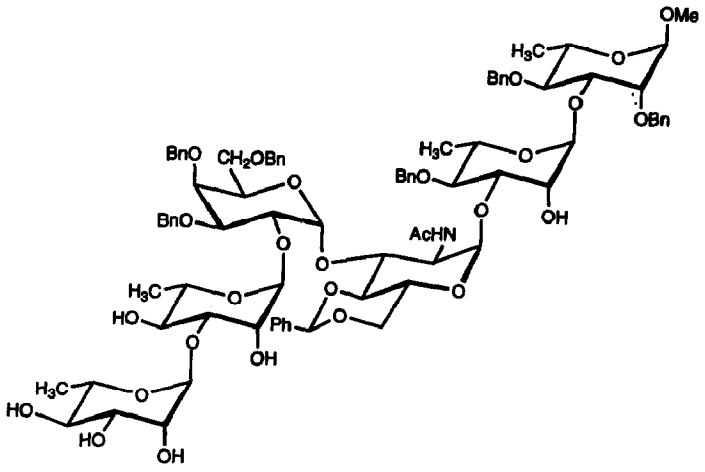
Bz = benzoyl

The synthesis of the glycotetraose block is shown in Scheme 4. First, the triose block **24** was converted to the acetamido derivative **36** by reduction [32] (→ **35**), followed by in situ *N*-acetylation. Next, the trisaccharide acceptor **36** was condensed with the thiogalactoside donor **13** to afford tetrasaccharide **37** in 86% yield.



Scheme 4.

Again, anomerization of the donor was observed. The α interglycosidic linkage for residue D is indicated by the $^{1}J_{C\text{-}1,H\text{-}1}$ heteronuclear coupling constant for the galactose unit of 173 Hz. Removal of the 4-methoxybenzyl group by oxidation [35] with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) afforded the tetraose block **38** in 70% yield. Silver trifluoromethanesulfonate-promoted condensation of the biose (**34**) and the tetraose blocks (**38**) afforded the fully protected hexasaccharide **39** in 38% yield. The structure of **39** was supported by its ^{13}C NMR spectrum which showed the expected seven lines in the anomeric region (six anomeric carbons and the *C*HPh carbon), and by the fast-atom bombardment mass spectrum obtained in the low-resolution mode. The most intense peak in the molecular ion-cluster corresponds to $(^{12}C_{129}{}^{13}CH_{131}NO_{33} + H)^+$, while the monoisotopic molecular ion $(^{12}C_{130}H_{131}NO_{33} + H)^+$ had a somewhat lower intensity. The yield of **39** is in contrast to the high yields achieved during the synthesis of the tetraose block, and raises the possibility that the synthetic approach to higher oligosaccharides will need an alternative combination of the protecting groups and/or alternative points of dissection. Nevertheless, compound **39** could be deprotected in conventional reactions [(*i*) NaOMe–MeOH, → **40**; (*ii*) H_2, Pd–C] to afford the hexasaccharide methyl glycoside **3** in sufficient amounts for NMR measurements and binding studies [36] with a murine monoclonal antibody directed against the O-specific polysaccharide of *S. dysenteriae* type 1.



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2.2 Nuclear magnetic resonance spectroscopy

The ^{1}H and ^{13}C NMR spectra of the tetra- (**1**) and the hexa-saccharide (**3**) were completely assigned, using one- (1D) and two-dimensional (2D) techniques (Tables 1–3). The purpose of this work was to provide further evidence for the proposed structures and to collect data on these oligosaccharides which can, eventually, assist the selection of a fragment that mimics the conformation of the native polysaccharide.

The assignment of the ^{1}H NMR spectrum of **3** relied, to a large extent, on 1D TOCSY experiments [37] performed at 600 MHz. With this technique, most of the individual resonances belonging to the particular spin system of each of the six residues in **3** could unequivocally be identified. The exceptions were the resonances belonging to the H-5 atoms of the rhamnose residues, which are known to be of notoriously low intensity in 1D TOCSY spectra [8] and the H-5, -6, and -6′ signals for the galactose unit. The reason for the latter is the small value of the $^{3}J_{4,5}$ coupling constant, which impedes an efficient transfer of magnetization from H-4 to H-5. The known chemical-shift data [8] of the pentasaccharide glycoside α-L-Rha*p*-(1 → 3)-α-L-Rha*p*-(1 → 2)-α-D-Gal*p*-(1 → 3)-α-D-Glc*p*NAc-(1 → 3)-α-L-Rha*p*-OMe (**41**) permitted the identification of the Gal H-5, -6, and -6′ resonances in the spectrum of **3**. The assignment of the other resonances corresponding to the galactose and the *N*-acetyl-D-glucosamine protons was straightforward. The assignment of the resonance at 4.668 ppm to H-1 of residue A is based on chemical-shift analogy with related compounds [8]. This also identified the other resonances belonging to residue A. The assignment of the remaining three sets of resonances, belonging to rhamnose residues, was aided by the ^{13}C-detected, 2D ^{1}H–^{13}C chemical shift correlation spectrum [38] measured at 101 MHz. Details of this analysis followed guidelines described elsewhere [8]. A combination of the 1D

Table 1
^{1}H NMR chemical shifts [a] for compounds **1** and **3**

H-nucleus [b]	Compound	
	1 [c]	**3** [d]
1_A	4.666	4.668
2_A	4.011	4.014
3_A	3.769	3.771
4_A	3.520	3.527
5_A	3.712	3.714
6_A	1.300 [e]	1.306
1_B	5.060	5.080
2_B	4.216	4.227
3_B	3.916	3.927
4_B	3.545	3.547
5_B	3.845	3.851
6_B	1.313 [e]	1.317
1_C	5.046	5.040
2_C	4.101	4.140
3_C	4.001	4.080
4_C	3.797	3.800
S_C	4.022	4.030
6_C	~3.82	3.822
$6'_C$	~3.81	3.822
1_D	5.431	5.604
2_D	3.818	3.956
3_D	3.773	3.897
4_D	3.992	4.013
5_D	3.889	3.916
6_D	~3.75	3.760
$6'_D$	~3.73	3.786
1_E		5.062
2_E		4.167
3_E		3.881
4_E		3.565
5_E		3.905
6_E		1.312
1_F		5.064
2_F		4.071
3_F		3.853
4_F		3.468
5_F		3.851
6_F		1.317
CH_3O	3.401	3.404
CH_3CO	2.060	2.059

[a] Chemical shifts are quoted in ppm, using acetone (δ_H 2.225) as a secondary internal reference. At 300K, in D_2O. First-order data. [b] For designations A–F, see formulae. [c] At 500 MHz. [d] At 600 MHz. [e] Interchangeable assignments.

Table 2
$^3J_{H,H}$ coupling constants for compounds 1 and 3 [a]

$^3J_{H,H}$ [b]	Compound	
	1	3
1_A–2_A	1.8	1.9
2_A–3_A	3.3	3.2
3_A–4_A	9.6	9.7
4_A–5_A	9.6	9.7
5_A–6_A	6.2	6.2
1_B–2_B	1.9	1.9
2_B–3_B	3.3	3.3
3_B–4_B	9.8	9.7
4_B–5_B	9.6	9.7
5_B–6_B	6.3	6.3
1_C–2_C	3.6	3.6
2_C–3_C	10.6	10.6
3_C–4_C	8.8	8.6
4_C–5_C	10.2	10.2
5_C–6_C	3.3	3.8
5_C–$6'_C$	6.5	7.0
6_C–$6'_C$	ND [c]	ND
1_D–2_D	3.8	3.5
2_D–3_D	10.4	10.1
3_D–4_D	3.2	3.5
4_D–5_D	1.2	1.7
5_D–6_D	ND	5.3
5_D–$6'_D$	ND	5.0
6_D–$6'_D$		11.4
1_E–2_E		1.6
2_E–3_E		3.4
3_E–4_E		9.7
4_E–5_E		9.7
5_E–6_E		6.3
1_F–2_F		1.7
2_F–3_F		3.4
3_F–4_F		9.7
4_F–5_F		9.7
5_F–6_F		6.3

[a] In Hz. [b] For designations A–F, see formulae. [c] ND, not determined.

TOCSY and 2D heteronuclear, ^1H–^{13}C spectra allowed the identification of all but the H-5 resonances of residues B, E, and F, which were identified by a ^1H–^1H COSY experiment [39].

The assignment of the ^{13}C NMR spectrum of **3** could easily be performed by using a ^1H–^{13}C correlation map obtained at 101 MHz. The ^{13}C NMR spectrum of compound **1** was completely assigned by comparison with the spectrum of **3** and the published assignments for the trisaccharide glycoside [8] α-D-Gal*p*-(1 → 3)-α-D-

Table 3
^{13}C NMR chemical shifts [a] for compounds 1 and 3

C-nucleus [b]	Compound [c]	
	1	3
1_A	101.53 (171)	101.53 (173)
2_A	70.55	70.55
3_A	78.79	78.80
4_A	72.14	72.14
5_A	69.31	69.32
6_A	17.45*	17.45**
1_B	102.78 (172)	103.01 (172)
2_B	67.50	67.41
3_B	75.86	75.67
4_B	71.03	71.05
5_B	69.90	69.90*
6_B	17.34*	17.42**
1_C	95.09 (172)	94.88 (171)
2_C	52.64	52.71
3_C	78.00	75.52
4_C	71.21	71.88
5_C	72.43	72.63
6_C	60.79	60.85
1_D	100.06 (172)	98.42 (175)
2_D	69.24	74.52
3_D	70.05	69.73
4_D	69.70	70.20
5_D	71.53	71.61
6_D	61.24	61.50
1_E		102.21 (172)
2_D		70.36
3_E		78.75
4_E		72.06
5_E		70.08
6_E		17.34**
1_F		102.82 (172)
2_F		70.95
3_F		70.87
4_F		72.85
5_F		69.88*
6_F		17.54**
CH_3O	55.51	55.51
CH_3CONH	22.84	22.80
CH_3CONH	174.94	174.86

[a] At 100 MHz, in ppm. At 300 K, in D_2O. [b] For designations A–F, see formulae. [c] Data in parenthesis are one-bond, ^{13}C–^{1}H coupling constants, in Hz. Identical superscripts within a column indicate interchangeable assignments.

Glc*p*NAc-(1 → 3)-α-L-Rha*p*-OMe (**42**) The $^{1}H-^{13}C$ correlation map established the chemical shifts of the directly linked protons which could then be unequivocally identified in the 1D spectrum. The all α stereochemistry of the glycosidic linkages in **1** and **3** was established by measuring the one-bond, $J_{C\text{-}1,H\text{-}1}$ heteronuclear coupling constants, which were 172–173 Hz for the rhamnose residues, and 171–172 Hz for the *N*-acetyl-D-glucosamine residue. The corresponding value for the galactose residue in **3** is unusually high (175 Hz). We have previously observed [8] this high value for the galactose residue of the homologous penta- (**41**), and tetra-saccharide α-L-Rha*p*-(1 → 2)-α-D-Gal*p*-(1 → 3)-α-D-Glc*p*NAc-(1 → 3)-α-L-Rha*p*-OMe (**43**) glycosides. A similarly large coupling constant (175 Hz) was found for the galactose residue in the native polysaccharide [8]. On the other hand, the corresponding value for the trisaccharide glycoside **42** and compound **1**, which have an unglycosylated galactose residue, is only 171–172 Hz. The increased value of the $^{1}J_{C\text{-}1,H\text{-}1}$ coupling constants for the galactose residue suggests that steric compression caused by its vicinal 1,2-substituents increases the *s* character of the C-1 to H-1 bonding orbital in this residue. It is of interest to note that the chemical shift of the C-3 nucleus, i.e., the linkage carbon atom of the Glc*p*NAc residue is also influenced by the Rha*p* residue at O-2 of the galactose unit. In the penta- **41** and tetra-saccharide **43**, and in the hexasaccharide **3**, this nucleus resonates at ~ 75.5 ppm, whereas this resonance occurs at ~ 78 ppm in the trisaccharide **42** and in the tetrasaccharide **1**, which have an unsubstituted galactose residue as the nonreducing end terminus. In the native polysaccharide, the corresponding resonance appears at 75.7 ppm [8]. Based on the assumption that conformational similarity necessitates spectral similarity we believe that the rhamnose residue at O-2 of the galactose unit is necessary for a synthetic fragment to approach the conformation of the native polymer. We note, that similar, unusual ^{13}C NMR chemical shift patterns have been observed earlier for other oligo- and poly-saccharides containing a 1 → 2 linkage [40–43]. In a *sugar A*-(1 → 2)-*sugar B*-(1 → X)-*sugar C* sequence the effect of *sugar A* on the chemical shift of the linkage carbon atom of *sugar C* is ~ 0.6 ppm when the linkage carbon is C-6 (see data in refs 44 and 45). In structures where the linkage carbon of *sugar C* is a secondary carbon, the effect varies from less than 1 ppm as seen in the spectra of (1 → 2)-linked rhamno-oligosaccharides [9,13] to 5 ppm, as observed in a *Salmonella* polysaccharide [43]. This anomaly has been related to changes in the preferred conformer(s) [43].

We compared the chemical shifts of the anomeric protons in oligosaccharides **1** and **3** with the chemical shifts of the respective protons in the O-specific polysaccharide. The criterion for coincidence was set arbitrarily as less than 0.01 ppm difference in the chemical shifts. Interestingly, only three anomeric resonances in **3** were found to coincide with the corresponding resonances in the O-SP (ref 8). These are the resonances corresponding to H-1 of residues C, D, and E. Therefore, further chain elongation is necessary to achieve a high degree of spectral similarity between a synthetic fragment, and the native O-specific polysaccharide of *S. dysenteriae* type 1. Experiments to achieve this goal are currently in progress in our laboratories. As a part of this project, the synthesis and NMR spectroscopic

analysis of an octasaccharide fragment, corresponding to two contiguous repeating units, will be reported in due course.

3. Experimental

General methods.—General experimental conditions are described in ref 8. Optical rotations were measured for $CHCl_3$ solutions, except where indicated otherwise. The NMR data described in the Experimental were obtained on a Gemini 300 (Varian *) spectrometer, operating at 300 MHz for ^1H and at 75 MHz for ^{13}C. The ^{13}C NMR assignments are based on ^1H–^{13}C correlation maps, except that the assignments for compound **2** are based on comparison with the rigorous assignments given for compound **1** in Table 3.

Methyl 3-O-acetyl-2-O-benzoyl-4-O-benzyl-α-L-rhamnopyranoside (**5**).—Acetic anhydride (5 mL) was added to a solution of **4** (refs 8 and 46) (5.0 g, 13.4 mmol) in pyridine (5 mL), at 25°C. After 2 h, the solution was cooled to 0°C. Filtration, followed by washing with H_2O afforded crystalline **5** (5.3 g, 96%); mp 70–71°C; $[\alpha]_D$ +46° (*c* 1.1). NMR ($CDCl_3$): ^1H, δ 8.50–7.25 (aromatic), 5.500 (dd, 1 H, $J_{1,2}$ 1.8, $J_{2,3}$ 3.4 Hz, H-2), 5.406 (dd, 1 H, $J_{3,4}$ 9.7 Hz, H-3), 4.730 (d, 1 H, H-1), 4.715 and 4.655 (2 d, 2 H, CH_2), 3.887 (dq, 1 H, H-5), 3.618 (t, 1 H, H-4), 3.400 (s, 3 H, CH_3O), 1.940 (s, 3 H, CH_3CO), and 1.398 (d, 3 H, $J_{5,6}$ 6.2 Hz, H-6); ^{13}C, δ 169.9 (*C*=O of Ac), 165.5 (*C*=O of Bz), 138.0–127.7 (aromatic), 98.5 (C-1), 78.8 (C-4), 74.9 (CH_2), 71.9 and 70.8 (C-2,3), 67.6 (C-5), 54.9 (CH_3O), 20.9 (CH_3CO), and 18.0 (C-6). CIMS: *m/z* 432 $[(M + NH_4)^+]$. Anal. Calcd for $C_{23}H_{26}O_7$: C, 66.65; H, 6.32. Found: C, 66.69; H, 6.33.

1,3-Di-O-acetyl-2-O-benzoyl-4-O-benzyl-α-(**6α**) *and β-L-rhamnopyranose* (**6β**).—Concentrated H_2SO_4 (0.4 mL) was added dropwise to a stirred solution of **5** (11.1 g, 27 mmol) in Ac_2O (50 mL) at 0°C. After 30 min, solid $NaHCO_3$ (excess) was added. Extractive workup ($CHCl_3$–H_2O), followed by chromatographic purification (8:1 → 6:1 hexane–EtOAc) afforded first **6α** as a syrup (3.6 g, 30%); $[\alpha]_D$ +15° (*c* 1.1). NMR ($CDCl_3$): ^1H, δ 8.10–7.28 (aromatic), 6.127 (d, 1 H, $J_{1,2}$ 2.0 Hz, H-1), 5.515 (dd, 1 H, $J_{2,3}$ 3.4 Hz, H-2), 5.420 (dd, 1 H, $J_{3,4}$ 9.7 Hz, H-3), 4.725 and 4.662 (2 d, 2 H, CH_2), 3.973 (dq, 1 H, H-5), 3.651 (t, 1 H, H-4), 2.169 and 1.967 (2 s, 6 H, 2 CH_3CO), and 1.400 (d, 3 H, $J_{5,6}$ 6.3 Hz, H-6); ^{13}C, δ 170.0 and 168.7 (*C*=O of Ac), 165.3 (*C*=O of Bz), 137.4–127.8 (aromatic), 90.8 ($^1J_{C,H}$ 176 Hz, C-1), 78.4 (C-4), 75.2 (CH_2), 71.8, 70.1, and 69.6 (C-2,3,5), 20.9 and 20.8 (CH_3CO), and 18.0 (C-6). CIMS: *m/z* 460 $[(M + NH_4)^+]$. Anal. Calcd for $C_{24}H_{26}O_8$: C, 65.15; H, 5.92. Found: C, 65.13; H, 5.93.

Subsequent elution afforded a 93:7 mixture (^1H NMR) of **6α** and **6β** (7.2 g, 61%). ^1H NMR data ($CDCl_3$, δ) for **6β**: 5.924 (d, 1 H, $J_{1,2}$ 1.2 Hz, H-1), 5.715 (dd,

* Certain commercial equipment, instruments, or materials are identified in this paper to specify adequately the experimental procedure. Such identification does not imply recommendation by the National Institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for the purpose.

1 H, $J_{2,3}$ 3.2 Hz, H-2), 5.176 (dd, 1 H, $J_{3,4}$ 9.2 Hz, H-3), and 1.455 (d, 3 H, $J_{5,6}$ 5.7 Hz, H-6).

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl-1-thio-β-D-galactopyranoside (**11**).—To a stirred solution of 1,2-di-*O*-acetyl-3,4,6-tri-*O*-benzyl-β-D-galactopyranoside [17] (**10**) (3.0 g, 5.6 mmol), (methylthio)trimethylsilane [18] (5 mL, 35 mmol), and 4A molecular sieves (1 g) was added Me_3SiOTf (100 μL, 0.5 mmol). After 3 h, aq $NaHCO_3$ was added at 0°C. Extractive workup afforded a syrup, which crystallized on standing at 25°C. Trituration in hexane gave **11** (2.4 g, 82%); mp 76–78°C; $[\alpha]_D$ +12° (*c* 0.3). NMR ($CDCl_3$): ^1H, δ 7.38–7.20 (aromatic), 5.446 (t, 1 H, $J_{1,2} = J_{3,4} =$ 9.7 Hz, H-2), 4.951, 4.680, 4.576, 4.540, 4.466, and 4.413 (6 d, 6 H, 3 CH_2 of Bn), 4.238, (d, 1 H, H-1), 4.001 (br d, 1 H, H-4), 3.617 (br s, 3 H, H-5,6,6′), 3.551 (dd, 1 H, $J_{3,4}$ 2.7 Hz, H-3), 2.141 (s, 3 H, CH_3S), and 2.040 (s, 3 H, CH_3CO); ^{13}C, δ 169.8 (C=O), 138.7, 138.0, 137.8, and 128.5–127.5 (aromatic), 83.0 (C-1), 81.3 (C-3), 77.4 (C-4), 74.4, 73.5, and 71.9 (CH_2 of Bn), 72.9 (C-4), 68.8 (C-2), 68.3 (C-6), 20.8 (CH_3CO), and 10.8 (CH_3S). CIMS: *m/z* 540 $[(M + NH_4)^+]$. Anal. Calcd for $C_{30}H_{34}O_6S$: C, 68.94; H, 6.56; S, 6.13. Found: C, 69.01; H, 6.58; S, 6.09.

Methyl 3,4,6-tri-O-benzyl-1-thio-β-D-galactopyranoside (**12**).—A solution of **11** (2.1 g, 4.0 mmol) in MeOH (20 mL) was treated with a catalytic amount of NaOMe for 48 h at 25°C. The solution was treated with Dowex 50 × 2 (H^+) resin, filtered, and concentrated. The residue was triturated with hexane to afford **12** (1.58 g, 82%); mp 69–71°C; $[\alpha]_D$ +3° (*c* 0.5). CIMS: *m/z* 498 $[(M + NH_4)^+]$, 481 $[(M + H)^+]$. Anal. Calcd for $C_{28}H_{32}O_5S$: C, 69.97; H, 6.71; S, 6.67. Found: C, 69.84; H, 6.71; S, 6.60.

Methyl 3,4,6-tri-O-benzyl-2-O-(4-methoxybenzyl)-1-thio-β-D-galactopyranoside (**13**).—To a stirred solution of **12** (10.1 g, 21 mmol) in DMF (50 mL) was added NaH (1.0 g of a 60% suspension in oil, ~25 mmol) at 0°C, followed by 4-methoxybenzyl chloride (3.1 mL, 23 mmol). The mixture was stirred for 3 h. The usual workup, as described in ref 8, afforded crystalline **13** (10.8 g, 85%), which had physical properties identical to those of the authentic preparation [8].

Methyl 2,3,4,6-tetra-O-benzyl-1-thio-β-D-galactopyranoside (**16**).—To a solution of methyl 1-thio-β-D-galactopyranoside [19] (**15**) (1.8 g, 8.6 mmol) in DMF (10 mL) was added NaH (1.4 g of a 60% suspension in oil, ~35 mmol) at 0°C. After 10 min, the mixture was treated with benzyl bromide (6 mL, 50 mmol). Stirring was continued for 3 h at 0°C. The usual workup, as described [8], afforded **16** (4.1 g, 84%), which crystallized upon standing; mp 55–57°C; $[\alpha]_D$ +2° (*c* 1.3); lit. [20] $[\alpha]_D$ +1.6° ($CHCl_3$). NMR ($CDCl_3$): ^1H, δ 4.333 (d, 1 H, $J_{1,2}$ 9.6 Hz, H-1), 3.963 (br d, 1 H, H-4), 3.846 (dd, 1 H, $J_{2,3}$ 9.3 Hz, H-2), and 2.190 (s, 3 H, CH_3S); ^{13}C, δ 138.8, 138.3, 137.9, and 128.7–127.1 (aromatic), 85.6 (C-1), 84.3 (C-3), 77.9 (C-2), 77.2 (C-5), 75.6, 74.4, 73.5, and 72.7 (CH_2 of Bn), 73.7 (C-4), 68.7 (C-6), and 12.6 (CH_3S). CIMS: *m/z* 588 $[(M + NH_4)^+]$. Anal. Calcd for $C_{35}H_{38}O_5S$: C, 73.65; H, 6.71; S, 5.62. Found: C, 73.57; H, 6.76; S, 5.57.

Methyl 2-azido-4,6-O-benzylidene-3-O-bromoacetyl-2-deoxy-1-thio-α-D-glucopyranoside (**18**).—To a stirred solution of methyl 2-azido-4,6-*O*-benzylidene-2-deoxy-1-thio-α-D-glucopyranoside [11] (**17**) (2.17 g, 6.6 mmol) and 2,4,6-trimethylpyridine (4.4 mL, 33 mmol) in CH_2Cl_2 (24 mL) was added bromoacetyl bromide

(2.64 mL, 30 mmol) at 0°C. After 15 min, the solution was allowed to reach 25°C within 15 min. Extractive workup, followed by crystallization (MeOH) afforded **18** as an off-white solid (2.45 g, 82%); mp 129–131°C; $[\alpha]_D$ −100° (*c* 0.5). NMR ($CDCl_3$): ^1H, δ 7.46–7.33 (aromatic), 5.510 (s, 1 H, C*H*Ph), 5.422 (t, 1 H, $J_{2,3} = J_{3,4} = 9.8$ Hz, H-3), 5.369 (d, 1 H, $J_{1,2}$ 5.6 Hz, H-1), 4.356–4.257 (m, 2 H, H-5,6), 4.032 (dd, 1 H, H-2), 3.872 (s, 2 H, CH_2Br), 3.804 (m, 1 H, H-6′), and 2.138 (s, 3 H, CH_3S); ^{13}C, δ 166.1 (*C*=O), 136.7, 129.2, 128.3, and 126.2 (aromatic), 101.6 (*C*HPh), 85.2 (C-1), 79.3 (C-4), 72.2 (C-3), 68.6 (C-6), 63.0 (C-5), 62.3 (C-2), 24.9 (CH_2CO), and 13.0 (CH_3S). FABMS: *m/z* 446 [$(C_{16}H_{18}{}^{81}BrN_3O_5S + H)^+$] and 444 [$(C_{16}H_{18}{}^{79}BrN_3O_5S + H)^+$]. Anal. Calcd for $C_{16}H_{18}BrN_3O_5S$: C, 43.25; H, 4.08; Br, 17.98; S, 7.22. Found: C, 43.18; H, 4.14; Br, 17.93; S, 7.16.

*2-Azido-4,6-O-benzylidene-3-O-bromoacetyl-2-deoxy-β-*D*-glucopyranosyl chloride* (**19**).—To a solution of **18** (2.0 g, 4.5 mmol) in CH_2Cl_2 (40 mL) was added a solution of Cl_2 in CCl_4 (in excess) at 0°C. After 20 min, the reaction was quenched by the addition of cyclohexene. Removal of the volatiles, followed by trituration with hexane afforded amorphous **19** (1.75 g, 90%); $[\alpha]_D$ −96° (*c* 0.8). NMR ($CDCl_3$): ^{13}C, δ 166.1 (*C*=O), 101.4 ($J_{C,H}$ 163 Hz, CHPh), 89.5 ($^1J_{C\text{-}1,H\text{-}1}$ 173 Hz, C-1), 77.6, 73.1, 69.7, 67.8 (C-2,3,4,5), and 67.8 (C-6). CIMS: *m/z* 451 [$(C_{15}H_{15}{}^{81}BrClN_3O_5 + NH_4)^+$], 449 [$(C_{15}H_{15}{}^{79}BrClN_3O_5 + NH_4)^+$], 434 [$(C_{15}H_{15}{}^{81}BrClN_3O_5 + H)^+$], and 432 [$(C_{15}H_{15}{}^{79}BrClN_3O_5 + H)^+$]. Anal. Calcd for $C_{15}H_{15}BrClN_3O_5$: C, 41.64; H, 3.49; N, 9.71. Found: C, 41.62; H, 3.51; N, 9.64.

*Methyl O-(3-O-acetyl-2-O-benzoyl-4-O-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-O-benzyl-α-*L*-rhamnopyranoside* (**21**).—To a stirred mixture of **6α** (1.0 g, 2.3 mmol), compound **7** [12] (2.5 g, 7 mmol), and 4A molecular sieves (3 g) in CH_2Cl_2 (25 mL) was added Me_3SiOTf (300 μL, 1.5 mmol) at 25°C. After 5 h, the mixture was treated with aq $NaHCO_3$. The customary workup, followed by chromatography (20:1 toluene–EtOAc) afforded syrupy **21** (1.2 g, 73%); $[\alpha]_D$ +8° (*c* 1.1). NMR ($CDCl_3$): ^1H, δ 8.08–7.01 (aromatic) 5.650 (dd, 1 H, $H\text{-}2_B$), 5.520 (dd, 1 H, $J_{2,3}$ 3.3 Hz, $H\text{-}3_B$), 5.194 (d, 1 H, $J_{1,2}$ 1.7 Hz, $H\text{-}1_B$), 4.87, 4.69, 4.65, and 4.62 (4 d, 4 H, 2 CH_2 of Bn), 4.78 (s, 2 H, CH_2 of Bn), 4.673 (d, 1 H, $H\text{-}1_A$), 4.088 (dd, 1 H, $H\text{-}3_A$), 3.951 (dq, 1 H, $H\text{-}5_B$), 3.733 (dd, 1 H, $J_{1,2}$ 1.9, $J_{2,3}$ 3.1 Hz, $H\text{-}2_A$), 3.681 (t, 1 H, $H\text{-}4_A$), 3.656 (dq, 1 H, $H\text{-}5_A$), 3.581 (t, 1 H, $J_{3,4} = J_{4,5} = 9.5$ Hz, $H\text{-}4_B$), 3.320 (s, 3 H, CH_3O), 1.951 (s, 3 H, CH_3CO), 1.313 and 1.305 (2 d, 6 H, *J* 6 Hz, $H\text{-}6_A,6_B$): ^{13}C, δ 170.0 (*C*=O of Ac), 165.3 (*C*=O of Bz), 138.2–127.6 (aromatic), 99.2 ($C\text{-}1_B$), 98.6 ($C\text{-}1_A$), 80.8 ($C\text{-}4_A$), 78.8 ($C\text{-}4_B$), 78.0 ($C\text{-}3_A$), 77.6 ($C\text{-}2_A$), 75.4, 74.8, and 72.7 (CH_2), 71.9 ($C\text{-}3_B$), 70.9 ($C\text{-}2_B$), 68.2 ($C\text{-}5_B$), 68.1 ($C\text{-}5_A$), 54.6 (CH_3O), 20.9 (CH_3CO), 18.1 and 17.9 ($C\text{-}6_A,6_B$). FABMS: *m/z* 779 [$(M + K)^+$], 763 [$(M + Na)^+$], 739 [$(M + H - H_2)^+$], and 709 [$(M + H - MeOH)^+$]. Anal. Calcd for $C_{43}H_{48}O_{11}$: C, 69.71; H, 6.53. Found: C, 69.89; H, 6.75.

*Methyl O-(2-O-benzoyl-4-O-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-O-benzyl-α-*L*-rhamnopyranoside* (**22**).—To a solution of **21** (2.7 g, 3.6 mmol) in MeOH (50 mL) was added HBF_4 (6 mL of a 54% solution in diethyl ether) at 25°C. After 24 h, the solution was treated with solid $NaHCO_3$. Extractive workup, followed by chromatography (6:1 hexane–EtOAc) afforded amorphous **22** (2.2 g, 86%); $[\alpha]_D$ −8° (*c* 0.7). NMR ($CDCl_3$): ^1H, δ 8.04–7.12 (aromatic), 5.474 (dd, 1 H, $J_{1,2}$ 1.6,

$J_{2,3}$ 3.4 Hz, H-2_B), 5.205 (d, 1 H, H-1_B), 4.86, 4.84, 4.71, and 4.63 (4 d, 4 H, 2 CH_2 of Bn), 4.73 (s, 2 H, CH_2 of Bn), 4.657 (d, 1 H, H-1_A), 4.240 (dd, 1 H, H-3_B), 4.083 (dd, 1 H, H-3_A), 3.888 (dq, 1 H, H-5_B), 3.712 (dd, 1 H, $J_{1,2}$ 1.8, $J_{2,3}$ 3.1 Hz, H-2_A), 3.60–3.68 (m, 2 H, H-4_A,5_A), 3.441 (t, 1 H, $J_{3,4} = J_{4,5} = 9.4$ Hz, H-4_B), 3.296 (s, 3 H, CH_3O), 1.323, and 1.303 (2 d, 6 H, $J \sim 6$ Hz, H-6_A,6_B). ^{13}C, δ 166.3 (*C*=O), 138.5–127.5 (aromatic), 99.1 (C-1_B), 98.6 (C-1_A), 81.6 (C-4_B), 81.0 (C-4_A), 77.7 (C-2_A), 77.6 (C-3_A), 75.3, 74.9, and 72.7 (*C*H_2), 73.3 (C-2_B), 71.0 (C-3_B), 68.54 and 68.49 (C-5_A,5_B), 54.6 (*C*H_3O), 18.0 and 17.9 (C-6_A,6_B). CIMS: *m/z* 716 [(M + NH_4)$^+$]. Anal. Calcd for $C_{14}H_{18}O_6$: C, 59.57; H, 6.43. Found: C, 59.40; H, 6.50.

Methyl O-*(2-azido-4,6-*O*-benzylidene-3-*O*-bromoacetyl-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*-rhamnopyranoside* (**23**).—To a stirred mixture of **22** (3.3 g, 4.7 mmol), **19** (1.7 g, 3.9 mmol), 2,6-di-*tert*-butyl-4-methylpyridine (0.8 g, 3.9 mmol), and 4A molecular sieves (2 g) in CH_2Cl_2 (40 mL) was added AgOTf (2.4 g), at 0°C. After 1 h, the mixture was processed as usual, followed by chromatographic purification (4:1 hexane–EtOAc) to give crystalline **23** (2.0 g, 53%); mp 153–155°C; $[\alpha]_D$ +63° (*c* 0.6). NMR ($CDCl_3$): ^{1}H, δ 8.10–7.05 (aromatic), 5.784 (dd, 1 H, $J_{1,2}$ 1.9, $J_{2,3}$ 3.0 Hz, H-2_B), 5.593 (t, 1 H, $J_{2,3} = J_{3,4} = 10.0$ Hz, H-3_C), 5.426 (s, 1 H, C*H*Ph), 5.419 (d, 1 H, $J_{1,2}$ 4.1 Hz, H-1_C), 5.265 (d, 1 H, $J_{1,2}$ 1.5 Hz, H-1_B), 4.94, 4.84, 4.66, and 4.64 (4 d, 4 H, 2 CH_2 of Bn), 4.71 (s, 2 H, CH_2 of Bn), 4.664 (d, 1 H, $J_{1,2}$ 1.7 Hz, H-1_A), 4.406 (dd, 1 H, $J_{1,2}$ 3.2, $J_{2,3}$ 9.6 Hz, H-2_C), 3.827 (s, 2 H, CH_2Br), 3.711 (dd, 1 H, $J_{1,2}$ 1.8, $J_{2,3}$ 3.3 Hz, H-2_A), 3.298 (s, 3 H, CH_3O), 3.212 (dd, 1 H, $J_{1,2}$ 3.6, $J_{2,3}$ 10.3 Hz, H-2_C), 1.365, *J* 6.2 Hz, and 1.310, *J* 6.6 Hz (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 166.1 and 165.6 (*C*=O), 138.0–126.5 (aromatic), 101.4 (CHPh), 99.1 (C-1_B), 98.3 (C-1_A), 93.9 ($^1J_{C,H}$ 174 Hz, C-1_C), 81.0, 79.6, and 79.0 (C-4_A,4_B,4_C), 77.4 (C-2_A,3_A), 62.7 and 61.2 (C-2_C,5_C), 54.6 (*C*H_3O), 25.1 (*C*H_2Br), 18.05 and 17.98 (C-6_A,6_B). FABMS: 1094 [($C_{56}H_{60}{}^{81}BrN_3O_{15}$ + H − H_2)$^+$], 1092 [($C_{56}H_{60}{}^{79}BrN_3O_{15}$ + H − H_2)$^+$], 1036 [($C_{56}H_{60}{}^{81}BrN_3O_{15}$ + H − N_2 − MeOH)$^+$], 1034 [($C_{56}H_{60}{}^{79}BrN_3O_{15}$ + H − N_2 − MeOH)$^+$], 988 [($C_{56}H_{60}{}^{81}BrN_3O_{15}$ + H − BnOH)$^+$], and 986 [($C_{56}H_{60}{}^{79}BrN_3O_{15}$ + H − BnOH)$^+$]. Anal. Calcd for $C_{56}H_{60}BrN_3O_{15}$: C, 61.42; H, 5.52; Br, 7.29; N, 3.38. Found: C, 61.21; H, 5.53; Br, 7.37; N, 3.79.

Methyl O-*(2-azido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*-rhamnopyranoside* (**24**).—A solution of **23** (1.95 g, 1.78 mmol) and thiourea (400 mg, 5.2 mmol) in a 1:1 mixture of CH_2Cl_2–MeOH (12 mL) was stirred for 1 h at 25°C. The volatiles were removed under vacuum. The residue was triturated in CH_2Cl_2 (50 mL). The mixture was filtered, the insoluble material washed with CH_2Cl_2, and then discarded. Concentration of the combined CH_2Cl_2 solutions afforded a syrupy residue, which was purified by chromatography, using 4:1 hexane–EtOAc as eluant, to give amorphous **24** (1.6 g, 92%); $[\alpha]_D$ +51° (*c* 0.4). NMR ($CDCl_3$): ^{1}H, δ 8.58–8.36, 7.62–7.13 (aromatic), 5.784 (dd, 1 H, $J_{1,2}$ 2.0, $J_{2,3}$ 3.1 Hz, H-2_B), 5.466 (s, 1 H, C*H*Ph), 5.291 (d, 1 H, $J_{1,2}$ 3.4 Hz, H-1_C), 5.264 (d, 1 H, H-1_B), 4.92, 4.86, 4.64, and 4.62 (4 d, 4 H, 2 CH_2 of Bn), 4.72 (s, 2 H, CH_2 of Bn), 4.660 (d, 1 H, $J_{1,2}$ 1.8 Hz, H-1_A), 4.403 (dd, 1 H, $J_{3,4}$ 9.5 Hz, H-3_B), 3.925 (dq, 1 H, H-5_B), 3.709 (dd, 1 H, $J_{2,3}$ 3.1 Hz, H-2_A), 3.493 (t, 1 H, H-4_B), 3.295 (s, 3 H, CH_3O), 3.195 (dd, 1 H, $J_{2,3}$ 10.0 Hz, H-2_C), 1.327 and 1.308 (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 165.8

(*C*=O), 138.0–126.5 (aromatic), 102.0 (CHPh), 99.2 ($C\text{-}1_B$), 98.4 ($C\text{-}1_A$), 93.7 ($C\text{-}1_C$), 81.6 ($C\text{-}4_C$), 81.0 ($C\text{-}4_A$), 79.7 ($C\text{-}4_B$), 77.5 and 77.4 ($C\text{-}2_A3_A$), 62.7 and 62.4 ($C\text{-}2_C,5_C$), 54.6 (CH_3O), 17.9 and 17.8 ($C\text{-}6_A,6_B$). FABMS: 972 $[(M + H - H_2)^+]$, 946 $[(M + H - N_2)^+]$, and 944 $[(M + H - N_2 - H_2)^+]$. Anal. Calcd for $C_{54}H_{59}N_3O_{14}$: C, 66.69; H, 6.11; N, 4.31. Found: C, 66.67; H, 6.10; N, 4.28.

*Methyl 3-*O*-acetyl-2-azido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranoside* (**25**) *and methyl 3-*O*-acetyl-2-azido-4,6-*O*-benzylidene-2-deoxy-β-*D*-glucopyranoside* (**26**). —To a stirred mixture of 3-*O*-acetyl-2-azido-4,6-*O*-benzylidene-2-deoxy-β-D-glucopyranosyl chloride [8] (**20**) (850 mg, 2.4 mmol), MeOH (200 μL, 5.1 mmol), 2,6-di-*tert*-butyl-4-methylpyridine (0.5 g, 2.4 mmol), and 4A molecular sieves (0.2 g) in CH_2Cl_2 (6 mL) was added AgOTf (0.9 g, 3.5 mmol) at −40°C. The temperature of the mixture was allowed to reach −10°C. More MeOH (300 μL, 7.65 mmol) and AgOTf (0.4 g, 1.6 mmol) were added. Stirring was continued for 1 h between −10 and 0°C. The mixture was treated with ice-cold, aq $NaHCO_3$, then filtered. Extractive workup, followed by chromatography using 4:1 hexane–EtOAc as eluant gave first **26** (260 mg, 31%); mp 118–120°C; $[\alpha]_D$ −88° (*c* 0.4). NMR ($CDCl_3$): ^1H, δ 7.45–7.30 (aromatic), 5.487 (s, 1 H, C*H*Ph), 5.156 (t, 1 H, H-3), 4.392 (d, 1 H, $J_{1,2}$ 8.0 Hz, H-1), 4.357 (dd, 1 H, $J_{5,6'}$ 4.8 Hz, H-6′), 3.789 (t, 1 H, $J_{5,6} = J_{6,6'} = 10.2$ Hz, H-6), 3.613 (t, 1 H, $J_{3,4} = J_{4,5} = 9.4$ Hz, H-4), 3.606 (s, 3 H, CH_3O), 3.480 (ddd, 1 H, H-5), 3.461 (dd, 1 H, $J_{2,3}$ 10.0 Hz, H-2), and 2.129 (s, 3 H, CH_3CO); ^{13}C, δ 169.6 (*C*=O), 136.7, 129.1, 128.2, and 126.1 (aromatic), 103.6 (C-1), 101.5 (*C*HPh), 78.8 (C-4), 71.1 (C-3), 68.4 (C-6), 66.4 (C-5), 64.9 (C-2), 57.6 (*C*H_3O), and 20.8 (*C*H_3CO). Anal. Calcd for $C_{16}H_{19}N_3O_6$: C, 55.01; H, 5.48. Found: C, 55.10; H, 5.46.

Eluted next was a mixture of **25** and **26** (63 mg, 7.5%).

Subsequent elution afforded crystalline **25** (450 mg, 54%); mp 148–149°C; $[\alpha]_D$ +135° (*c* 0.6). NMR ($CDCl_3$): ^1H, δ 7.46–7.33 (aromatic), 5.595 (t, 1 H, H-3), 5.490 (s, 1 H, C*H*Ph), 4.870 (d, 1 H, $J_{1,2}$ 3.5 Hz, H-1), 4.298 (dd, 1 H, $J_{5,6'}$ 4.8 Hz, H-6′), 3.930 (ddd, 1 H, H-5), 3.756 (t, 1 H, $J_{5,6} = J_{6,6'} = 10.2$ Hz, H-6), 3.620 (t, 1 H, $J_{3,4} = J_{4,5} = 9.5$ Hz, H-4), 3.428 (s, 3 H, CH_3O), 3.260 (dd, 1 H, $J_{2,3}$ 10.3 Hz, H-2), and 2.124 (s, 3 H, CH_3CO); ^{13}C, δ 169.7 (*C*=O), 136.9, 129.1, 128.2, and 126.2 (aromatic), 101.7 (*C*HPh), 99.8 (C-1), 79.4 (C-4), 69.0 (C-3), 68.8 (C-6), 62.7 (C-5), 61.8 (C-2), 55.5 (CH_3O), and 20.8 (*C*H_3CO). Anal. Calcd for $C_{16}H_{19}N_3O_6$: C, 55.01; H, 5.48. Found: C, 55.03; H, 5.45.

*Methyl 2-azido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranoside* (**27**).—To a solution of **25** (350 mg, 1 mmol) in MeOH (20 mL) was added a catalytic amount of NaOMe at 25°C. After 1 h, the solution was neutralized (Dowex 50X2, H^+), filtered, and concentrated to afford crystalline **27** (301 mg, 98%); mp 123–125°C; $[\alpha]_D$ +119° (*c* 0.6). NMR ($CDCl_3$): ^{13}C, δ 136.9, 129.4, 128.4, and 126.2 (aromatic), 102.1 (*C*HPh), 99.4 (C-1), 81.8 (C-4), 69.1 (C-3), 68.8 (C-6), 63.3 (C-5), 62.2 (C-2), and 55.5 (*C*H_3O). CIMS: *m*/*z* 325 $[(M + NH_4)^+]$ and 308 $[(M + H)^+]$. Anal. Calcd for $C_{14}H_{17}N_3O_5$: C, 54.71; H, 5.58. Found: C, 52.97; H, 5.71.

Methyl O*-(2,3,4,6-tetra-*O*-benzyl-α-*D*-galactopyranosyl)-(1 → 2)-*O*-(2-azido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*- rhamnopyranoside* (**28**) *and methyl*

2,3,4,6-tetra-O-*benzyl-1-thio-α*-D-*galactopyranoside* (**29**).—To a stirred mixture of **16** (2.0 g, 3.5 mmol), **24** (1.8 g, 1.85 mmol), 2,6-di-*tert*-butyl-4-methylpyridine (0.5 g, 2.5 mmol), and 4A molecular sieves (1.0 g) in diethyl ether (100 mL) was added methyl trifluoromethanesulfonate (500 μL, 4.4 mmol, over a period of 72 h). The usual workup, followed by column chromatographic purifiation (4:1 hexane–EtOAc) afforded first **29** (500 mg, 25%); $[\alpha]_D$ +6° (*c* 0.6). NMR ($CDCl_3$): ^1H, δ 5.390 (d, 1 H, $J_{1,2}$ 5.5 Hz, H-1) and 2.020 (s, 3 H, CH_3S); ^{13}C, δ 138.8, 138.7, 138.2, 138.1, and 128.6-127.1 (aromatic), 84.8 ($^1J_{C\text{-}1,H\text{-}1}$ 165 Hz, C-1), 79.5 (C-3), 76.4, (C-2), 75.2, (C-4), 74.8, 73.4 (2 C), and 72.4 (CH_2 of Bn), 69.7 (C-5), 69.2 (C-6), and 12.2 (CH_3S). CIMS: *m/z* 589 $[(M + NH_4)^+]$. Anal. Calcd for $C_{35}H_{38}O_5S$: C, 73.65; H, 6.71; S, 5.62. Found: C, 73.73; H, 6.70; S, 5.54.

Subsequent elution yielded **16** (160 mg, 8%), followed by a product (520 mg), which was tentatively identified as 2,3,4,6-tetra-*O*-benzyl-D-galactopyranose.

Further elution gave **28** (2.45 g, 88%); $[\alpha]_D$ +66° (*c* 0.4). NMR ($CDCl_3$): ^1H, δ 5.797 (dd, 1 H, H-2_B), 5.615 (d, 1 H, $J_{1,2}$ 3.3 Hz, H-1_D), 5.395 (d, 1 H, $J_{1,2}$ 3.9 Hz, H-1_C), 5.346 (s, 1 H, CHPh), 5.282 (d, 1 H, $J_{1,2}$ 1.8 Hz, H-1_B), 3.280 (s, 3 H, CH_3O), 1.353 and 1.309 (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 165.5 (C=O), 138.8–133.1 and 130.0–126.5 (aromatic), 101.7 ($^1J_{C,H}$ 162 Hz, CHPh), 99.1 $^1J_{C\text{-}1,H\text{-}1}$ 172 Hz, 98.4 $^1J_{C\text{-}1,H\text{-}1}$ 168 Hz, 97.1 $^1J_{C\text{-}1,H\text{-}1}$ 173 Hz (C-1_A,1_B,1_D), 93.7 (C-1_C), 82.7 (C-3_D), 80.9, 79.6, and 78.2 (C-4_A,4_B,4_C), 77.5 and 77.4 (C-2_A3_A), 76.0, 75.2, 74.8, 73.0, 72.9, and 72.6 (CH_2 of Bn), 71.8 and 68.6 (C-6_C,6_D), 62.0 and 61.4 (C-2_C,5_C), 54.5 (CH_3O), 18.0 and 17.9 (C-6_A,6_B). FABMS: 1558 $[(M + Bn - N_2)^+]$, 1495 $[(M + H - H_2)^+]$, and 1468 $[(M + H - N_2)^+]$. Anal. Calcd for $C_{88}H_{93}N_3O_{19}$: C, 70.61; H, 6.26; N, 2.80. Found: C, 70.55; H, 6.50; N, 2.73.

Methyl O-*(2,3,4,6-tetra*-O-*benzyl-α*-D-*galactopyranosyl)-(1 → 2)*-O-*(2-acetamido-4,6*-O-*benzylidene-2-deoxy-α*-D-*glucopyranosyl)-(1 → 3)*-O-*(2*-O-*benzoyl-4-α*-L-*rhamnopyranosyl)-(1 → 3)-2,4-di*-O-*benzyl-α*-L-*rhamnopyranoside* (**30**).—To a stirred solution of **28** (1 g, 0.67 mmol) in 1,2-dimethoxyethane (1.5 mL) was added a solution of $NiCl_2 . 6H_2O$ (2 g, 8.4 mmol) and H_3BO_3 (1.2 g, 19 mmol) in EtOH (50 mL). To this solution was added, under stirring, a solution of $NaBH_4$ (600 mg, 16 mmol) in EtOH (30 mL), during a period of 1 h, at 25°C. Subsequently, the mixture was treated with Ac_2O (6 mL). Extractive workup, followed by chromatography (2:1 hexane–EtOAc) afforded amorphous **30** (680 mg, 67%); $[\alpha]_D$ +57° (*c* 0.2). NMR ($CDCl_3$): ^1H, δ 8.05–8.02 and 7.59–6.90 (aromatic), 6.055 (d, 1 H, $J_{NH\text{-}H\text{-}2}$ 7.4 Hz, NH), 5.667 (dd, 1 H, H-2_B), 5.505 (d, 1 H, $J_{1,2}$ 3.8 Hz, H-1_D), 5.273 (s, 1 H, CHPh), 5.204 (d, 1 H, H-1_B), 5.166 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1_C), 4.450 (ddd, 1 H, H-2_C), 4.350 (dd, 1 H, H-3_B), 3.910 (dd, 1 H, H-2_D), 3.280 (s, 3 H, CH_3O), 3.105 (dd, 1 H, H-3_D), 1.343 and 1.281 (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 169.2 (C=O of Ac), 165.2 (C=O of Bz), 139.0–126.5 (aromatic), 102.0 ($^1J_{C\text{-}H}$ 162 Hz, CHPh), 99.5 $^1J_{C\text{-}1,H\text{-}1}$ 173 Hz, 99.0 $^1J_{C\text{-}1,H\text{-}1}$ 168 Hz, and 97.6 $^1J_{C\text{-}1,H\text{-}1}$ 173 Hz, (C-1_A,1_B,1_D), 95.0 (C-1_C), 82.7 (C-3_D), 81.0, 80.1 and 78.6 (C-4_A,4_B,4_C), 77.3 (C-2_A3_A), 75.9, 75.2, 74.3, 73.8, 73.5, 72.8, and 71.2 (CH_2 of Bn), 70.1 and 68.7 (C-6_B,6_C), 62.4 (C-5_C), 54.6 (CH_3O), 51.4 (C-2_C), 22.4 (CH_3CO), 18.0 and 17.8 (C-6_A,6_B). FABMS: 1603 $[(M + Bn)^+]$ and 1512 $[(M + H)^+]$. Anal. Calcd for $C_{90}H_{97}NO_{20}$: C, 71.46; H, 6.46; N, 0.93. Found: C, 71.53; H, 6.43; N, 0.98.

Methyl O-α-D-*galactopyranosyl-(1 → 2)*-O-*(2-acetamido-2-deoxy-α-D-glucopyranosyl)-(1 → 3)*-O-α-L-*rhamnopyranosyl-(1 → 3)*-α-L-*rhamnopyranoside* (**1**).—A solution of **30** (600 mg, 0.4 mmol) in MeOH (20 mL) was treated with a catalytic amount of NaOMe for 48 h at 25°C. The usual workup, as described for compound **12**, followed by column chromatographic purification using 1:1 hexane–EtOAc as eluant, gave an amorphous solid (450 mg) which was hydrogenolyzed in 1:1 EtOH–AcOH (30 mL) over 5% Pd–C at 345 kPa and 25°C for 48 h. Removal of the catalyst by filtration, and the volatiles under vacuum, afforded amorphous **1** (185 mg, 68% combined yield), which was purified by chromatography on a Biogel P-2 column using 0.02 M pyridinium acetate as eluant: $[\alpha]_D$ +54° (*c* 0.2, H_2O). For NMR data, see Tables 1–3. FABMS: 690 $[(M+H)^+]$. Anal. Calcd for $C_{27}H_{49}NO_{19}$. $2H_2O$: C, 44.69; H, 7.08; N, 1.93. Found: C, 44.10; H, 7.16; N, 1.92.

Methyl O-*(2,3,4,6-tetra*-O-*benzyl-α-D-galactopyranosyl)-(1 → 2)*-O-*(4,6*-O-*benzylidene-2-deoxy-2-propionamido-α-D-glucopyranosyl)-(1 → 3)*-O-*(2*-O-*benzoyl-4*-O-*benzyl-α-L-rhamnopyranosyl)-(1 → 3)-2,4-di*-O-*benzyl-α-L-rhamnopyranoside* (**31**).—Transformation of compound **28**, as described for the preparation of compound **30** except that Ac_2O was replaced by propionic anhydride, afforded amorphous **31** (41%); $[\alpha]_D$ +44° (*c* 0.4). NMR ($CDCl_3$): ^{13}C, δ 173.1 [*C*(=O)C_2H_5], 165.0 (*C*=O of Bz), 138.8–126.5 (aromatic), 101.6 (*C*HPh), 98.8, 98.5, and 96.8 (C-1_A,1_B,1_D), 95.1 (C-1_C), 82.8 (C-3_D), 81.0, 80.1, and 78.4 (C-4_A,4_B,4_C), 77.4 (C-2_A3_A), 75.9, 75.3, 74.4, 73.7, 73.4, 72.8, and 71.2 (*C*H_2 of Bn), 69.8 and 68.7 (C-6_B,6_C), 62.7 (C-5_C), 54.6 (*C*H_3O), 51.4 (C-2_C), 28.8 (*C*H_2CH_3), 18.2 and 18.0 (C-6_A,6_B), and 9.3 (CH_2*C*H_3). FABMS: 1526 $[(M+H)^+]$. Anal. Calcd for $C_{91}H_{99}NO_{20}$: C, 71.58; H, 6.53; N, 0.92. Found: C, 71.00; H, 6.72; N, 0.90.

Methyl O-*(2,3,4,6-tetra*-O-*benzyl-α-D-galactopyranosyl)-(1 → 2)*-O-*(4,6*-O-*benzylidene-2-deoxy-2-propionamido-α-D-glucopyranosyl)-(1 → 3)*-O-*(4*-O-*benzyl-α-L-rhamnopyranosyl)-(1 → 3)-2,4-di*-O-*benzyl-α-L-rhamnopyranoside* (**32**).—A solution of **31** (350 mg, 0.23 mmol) in MeOH (10 mL) was treated with a catalytic amount of NaOMe for 24 h at 25°C. The usual workup gave a syrup, which was chromatographed, using 2:1 hexane–EtOAc as eluant, to give **32** (220 mg, 68%); $[\alpha]_D$ +44° (*c* 0.4). NMR ($CDCl_3$): ^1H, δ 7.40–6.94 (aromatic), 6.36 (d, 1 H, N*H*), 5.58 (d, 1 H, H-1_D), 5.33 (s, 1 H, C*H*Ph), 5.07 (d, 1 H, H-1_C), 5.04 (br s, 1 H, H-1_B), 3.29 (s, 3 H, CH_3O), 2.16 (q, 2 H, CH_2CH$_3$), 1.05 (t, 3 H, CH$_2$CH_3), 1.32 and 1.25 (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 174.0 (*C*=O), 138.7–126.0 (aromatic), 101.8 (*C*HPh), 101.1, 98.4, and 96.9 (C-1_A,1_B,1_D), 93.3 (C-1_C), 82.7 (C-3_D), 81.0, 80.1, and 78.6 (C-4_A,4_B,4_C), 77.4 and 77.3 (C-2_A3_A), 75.7, 75.3, 74.3, 73.9, 73.8, 72.5, and 71.3 (*C*H_2 of Bn), 71.0 and 68.8 (C-6_B,6_C), 62.7 (C-5_C), 54.6 (*C*H_3O), 51.4 (C-2_C), 29.1 (*C*H_2CH_3), 18.0 and 17.89 (C-6_A,6_B), and 9.7 (CH_2*C*H_3). FABMS: 1422 $[(M+H)^+]$. Anal. Calcd for $C_{84}H_{95}NO_{19}$: C, 70.91; H, 6.73; N, 0.98. Found: C, 70.99; H, 7.25; N, 0.87.

Methyl O-α-D-*galactopyranosyl-(1 → 2)*-O-*(2-deoxy-2-propionamido-α-D-glucopyranosyl)-(1 → 3)*-O-α-L-*rhamnopyranosyl-(1 → 3)*-α-L-*rhamnopyranoside* (**2**).—Hydrogenolysis of **32**, as described for the preparation of **1**, afforded **2** as an amorphous solid (81%); $[\alpha]_D$ +46° (*c* 0.4, H_2O). NMR (D_2O): ^1H, δ 5.485 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1_D), 5.058 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1_B), 5.035 (d, 1 H, $J_{1,2}$ 3.7 Hz,

H-1_C), 4.665 (d, 1 H, $J_{1,2}$ 1.7 Hz, H-1_A), 4.216 (dd, 1 H, H-2_B), 4.125 (dd, 1 H, $J_{1,2}$ 3.7, $J_{2,3}$ 10.8 Hz, H-2_C), 3.549 (t, 1 H, H-4_B), 3.518 (t, 1 H, H-4_A), 3.400 (s, 3 H, CH_3O), 1.313 (d, 1 H, $J_{5,6}$ 6.2 Hz, H-6_B), 1.300 (d, 1 H, $J_{5,6}$ 6.3 Hz, H-6_A), and 1.109 (t, 1 H, J 7.7 Hz, CH_3CH_2); ^{13}C, δ 102.89 (C-1_B), 101.66 (C-1_A), 99.75 (C-1_D), 95.33 (C-1_C), 78.85 (C-3_A), 77.23 (C-3_C), 75.91 (C-3_B), 72.51 (C-5_C), 72.21 (C-4_A), 71.58 (C-5_D), 71.34 (C-4_C), 71.08 (C-4_B), 70.60 (C-2_A), 70.07 (C-3_D), 70.01 (C-5_B), 69.80 (C-4_D), 69.38 (C-5_A), 69.33 (C-2_D), 67.65 (C-2_B), 61.38 (C-6_D), 60.75 (C-6_C), 55.55 (CH_3O), 52.52 (C-2_C), 29.90 (CH_2CH_3), 17.41 and 17.31 (C-6_A,6_B), and 10.14 (CH_3CH_2). FABMS: 726 [$(M + Na)^+$] and 704 [$(M + H)^+$]. Anal. Calcd for $C_{28}H_{49}NO_{19}$: C, 47.79; H, 7.02; N, 1.99. Found: C, 47.00; H, 7.05; N, 2.13.

Methyl O-*(2,3,4-tri-*O*-benzoyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzoyl-1-thio-α-*L*-rhamnopyranoside* (**33**).—To a stirred mixture of methyl 2,4-di-*O*-benzoyl-1-thio-α-L-rhamnopyranoside [11,14] (**8**; 2.8 g, 7 mmol), 2,3,4-tri-*O*-benzoyl-α-L-rhamnopyranosyl bromide [13] (**9**; 3.2 g, 6 mmol), and 4A molecular sieves (3 g) in CH_2Cl_2 (40 mL) was added AgOTf (2.8 g, 12.7 mmol) at −10°C. After 30 min the mixture was processed as usual (ref 8), followed by chromatographic purification (4:1 hexane–EtOAc), to give amorphous **33** (3.2 g, 53%); $[\alpha]_D$ +137° (*c* 0.6). NMR ($CDCl_3$): ^1H, δ 8.27–7.17 (aromatic), 5.645 (t, 1 H, $J_{3,4} = J_{4,5} = 9.7$ Hz, H-4_A), 5.637. (dd, 1 H, H- 2_A), 5.608 (dd, 1 H, $J_{2,3}$ 3.3, $J_{3,4}$ 9.9 Hz, H-3_B), 5.498 (t, 1 H, H-4_B), 5.397 (d, 1 H, H-1_A), 5.300 (dd, 1 H, H-2_B), 5.220 (d, 1 H, $J_{1,2}$ 1.7 Hz, H-1_B), 4.452 (dd, 1 H, H-3_A), 4.398 (dq, 1 H, H-5_A), 4.129 (dq, 1 H, H-5_B), 2.230 (s, 3 H, CH_3S), 1.388 (s, 3 H, $J_{5,6}$ 6.3 Hz, H-6_A), and 1.160 (s, 3 H, $J_{5,6}$ 6.0 Hz, H-6_B); ^{13}C, δ 166.2, 165.9, 165.7, 165.1, and 164.9 (*C*=O), 133.8–128.4 (aromatic), 99.3 (C-1_B), 83.3 (C-1_A), 76.7 (C-3_A), 73.7 and 73.2 (C-2_A,4_A), 71.4 (C-4_B), 70.7 (C-2_B), 69.3 (C-3_B), 67.51 and 67.45 (C-5_A,5_B), 17.6 (C-6_A), 17.2 (C-6_B), and 13.9 (CH_3S). CIMS: *m/z* 878 [$(M + NH_4)^+$]. Anal. Calcd for $C_{48}H_{44}O_{13}S$: C, 66.96; H, 5.15; S, 3.72 Found: C, 66.92; H, 5.19; S, 3.76.

O-*(2,3,4-Tri-*O*-benzoyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzoyl-α-*L*-rhamnopyranosyl bromide* (**34**).—To a stirred solution of **33** (1.0 g, 1.2 mmol) in CH_2Cl_2 (40 mL) was added bromine (60 μL, 1.2 mmol) at 0°C. After 10 min, Bu_4NBr (excess) was added. Stirring was continued for an additional 4 h. The usual workup, followed by column chromatographic purification (4:1 hexane–EtOAc) afforded **34** (0.85 g) as an amorphous solid. NMR ($CDCl_3$): ^1H, δ 8.23–7.19 (aromatic), 6.597 (br s, 1 H, H-1_A), 5.735 (dd, 1 H, H-2_A), 5.703 (t, 1 H, $J_{3,4} = J_{4,5} = 9.9$ Hz, H-4_A), 5.578 (dd, 1 H, $J_{2,3}$ 3.3, $J_{3,4}$ 9.9 Hz, H-3_B), 5.501 (t, 1 H, H-4_B), 5.307 (dd, 1 H, H-2_B), 5.263 (d, 1 H, H-1_B), 4.912 (dd, 1 H, $J_{2,3}$ 3.4, $J_{3,4}$ 10.0 Hz, H-3_A), 4.301 and 4.095 (2 dq. 2 H, H-5_A,5_B), 1.416 and 1.170 (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 166.0, 165.9, 165.6, 165.1, and 164.9 (*C*=O), 134.0–128.0 (aromatic), 99.5 (C-1_B), 84.7 ($^1J_{C\text{-}1,H\text{-}1}$ 185 Hz, C-1_A), 75.0 (C-2_A,3_A), 72.2 (C-4_A), 71.7 and 67.7 (C-5_A,5_B), 71.3 (C-4_B), 70.5 (C-2_B), 69.2 (C-3_B), 17.24, and 17.16 (C-6_A,6_B).

Methyl O-*(2-amino-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*-rhamnopyranoside* (**35**).—A solution of the trisaccharide **24** (1.3 g, 1.3 mmol) in 1,2-dimethoxyethane (2 mL) was first treated with a solution of $NiCl_2 \cdot 6H_2O$ and H_3BO_3 in EtOH, then with a solution of $NaBH_4$ in EtOH, as described for the

preparation of compound **30**. Extractive workup, followed by chromatography, using 2:1 EtOAc–hexane as eluant, afforded crystalline **35** (1.0 g, 79%); mp 84–86°C; $[\alpha]_D$ +36° (*c* 0.8). NMR ($CDCl_3$): ^1H, δ 8.07–8.03, 7.69–7.11 (aromatic), 6.000 (d, 1 H, $J_{NH\text{-}H\text{-}2}$ 7.8 Hz, N*H*), 5.574 (dd, 1 H, H-2_B), 5.476 (s, 1 H, C*H*Ph), 5.217 (d, 1 H, $J_{1,2}$ 1.7 Hz, H-1_B), 5.040 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1_C), 4.90, 4.80, 4.67, and 4.59 (4 d, 4 H, *J* 12 Hz, 2 CH_2 of Bn), 4.72 (s, 2 H, CH_2 of Bn), 4.662 (d, 1 H, $J_{1,2}$ 1.7 Hz, H-1_A), 4.400 (dd, 1 H, $J_{2,3}$ 3.9, $J_{3,4}$ 9.9 Hz, H-3_B), 4.127 (ddd, 1 H, H-2_C), 3.704 (dd, 1 H, $J_{2,3}$ 3.1 Hz, H-2_A), 3.301 (s, 3 H, CH_3O), 1.350 and 1.316 (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 166.0 (*C*=O), 138.0–126.8 (aromatic), 101.9 (*C*HPh), 99.5 (C-1_B), 98.5 (C-1_A), 94.6 (C-1_C), 82.0, 81.0, and 79.7 (C-4_A,4_B,4_C), 77.6 (C-3_A), 77.4 (C-2_A), 75.2 (C-3_B), 69.3 (C-2_B), 68.6 (C-6_C), 62.7 (C-5_C), 54.6 (CH_3O), 54.4 (C-2_C), 18.0 and 17.9 (C-6_A,6_B). FABMS: 948 $[(M + H)^+]$. Anal. Calcd for $C_{54}H_{61}NO_{14}$: C, 68.41; H, 6.48, N, 1.48. Found: C, 68.73; H, 6.80; N, 1.43.

Methyl O-*(2-acetamido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*-rhamnopyranoside* (**36**).—To a stirred solution of **35** (900 mg, 0.95 mmol) in MeOH (20 mL) was added Ac_2O (1.5 mL, 16 mmol) at 0°C. After 10 min, the volatiles were removed under vacuum. Chromatographic purification of the residue, using 2:1 EtOAc–hexane as eluant, afforded amorphous **36** (900 mg, 86%); $[\alpha]_D$ +21° (*c* 0.4). FABMS: 990 $[(M + H)^+]$. Anal. Calcd for $C_{56}H_{63}NO_{15}$: C, 67.93; H, 6.41; N, 1.42. Found: C, 68.13; H, 6.57; N, 1.39.

Methyl O-*[3,4,6-tri-*O*-benzyl-2-*O*-(4-methoxybenzyl)-α-*D*-galactopyranosyl]-(1 → 3)-*O*-(2-acetamido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*-rhamnopyranoside* (**37**).—To a stirred solution of **13** (450 mg, 0.75 mmol), **36** (360 mg, 0.36 mmol), and 2,6-di-*tert*-butyl-4-methylpyridine (250 mg, 1.2 mmol) in diethyl ether (10 mL) was added methyl trifluoromethanesulfonate (50 μL, 0.44 mmol), at 25°C. After 8 h, the mixture was processed as usual, and subjected to chromatographic purification (3:1 → 2:1 hexane–EtOAc) to afford amorphous **37** (480 mg, 86%); $[\alpha]_D$ +44° (*c* 0.3). NMR ($CDCl_3$): ^{13}C, δ 101.7 ($^1J_{C,H}$ 166 Hz, CHPh), 98.9 $^1J_{C\text{-}1,H\text{-}1}$ 174 Hz and 98.4 $^1J_{C\text{-}1,H\text{-}1}$ 169 Hz (C-1_A,1_B), 97.1 ($^1J_{C\text{-}1,H\text{-}1}$ 173 Hz, C-1_D), and 94.5 ($^1J_{C\text{-}1,H\text{-}1}$ 173 Hz, C-1_C). FABMS: 1632 $[(M + Bn)^+]$, 1580 $[(M + K)^+]$, 1564 $[(M + Na)^+]$, and 1542 $[(M + H)^+]$.

Methyl O-*(3,4,6-tri-*O*-benzyl-α-*D*-galactopyranosyl)-(1 → 3)-*O*-(2-acetamido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*-rhamnopyranoside* (**38**).—To a stirred mixture of **37** (410 mg, 0.26 mmol), CH_2Cl_2 (15 mL), and H_2O (2 mL) was added DDQ (80 mg, 0.35 mmol) at 25°C. After 1 h, more DDQ (60 mg, 0.26) was added, and stirring was continued for a further period of 3 h. Extractive workup (aq $NaHCO_3$), followed by chromatography (3:2 hexane–EtOAc) afforded amorphous **38** (265 mg, 70%); $[\alpha]_D$ +32° (c 0.3). NMR ($CDCl_3$): ^1H, δ 8.05–7.03 (aromatic), 5.967 (d, 1 H, N*H*), 5.616 (dd, 1 H, H-2_B), 5.486 (s, 1 H, C*H*Ph), 5.273 (d, 1 H, $J_{1,2}$ 4.1 Hz, H-1_D), 5.204 (br s, 1 H, H-1_B), 5.090 (d, 1 H, H-1_C), 3.293 (s, 3 H, CH_3O), 1.523 (s 3 H, CH_3CO), 1.355 and 1.300 (2 d, 6 H, H-6_A,6_B); ^{13}C, δ 170.3 (*C*=O of Ac), 165.4 (*C*=O of Bz), 138.6–126.1 (aromatic), 101.1 (CHPh), 100.2, 99.0, and 98.5 (C-1_A,1_B,1_D), 95.6 (C-1_C), 82.1 (C-3_D), 81.0, 79.9, and 79.8

($C\text{-}4_A,4_B,4_C$), 77.8 ($C\text{-}2_A3_A$), 75.9, 75.3, 74.5, 73.3, 73.1, and 72.7 (CH_2 of Bn), 69.9 and 68.5 ($C\text{-}6_B,6_C$), 54.6 (CH_3O), 51.4 ($C\text{-}2_C$), 22.5 (CH_3CO), 18.1 and 17.8 ($C\text{-}6_A,6_B$). FABMS: 1422 $[(M + H)^+]$.

Methyl O-*(2,3,4-tri-*O*-benzoyl-α-*L*-rhamnopyranosyl)-(1 → 3)-*O*-(2,4-di-*O*-benzoyl-α-*L*-rhamnopyranosyl)-(1 → 2)-*O*-(3,4,6-tri-*O*-benzyl-α-*D*-galactopyranosyl)-(1 → 3)-*O*-(2-acetamido-4,6-*O*-benzylidene-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-(2-*O*-benzoyl-4-*O*-benzyl-α-*L*-rhamnopyranosyl)-(1 → 3)-2,4-di-*O*-benzyl-α-*L*-rhamnopyranoside* (**39**).—To a stirred mixture of **34** (340 mg, 0.38 mmol), **38** (200 mg, 0.14 mmol), 2,6-di-*tert*-butyl-4-methylpyridine (100 mg, 0.49 mmol), and 4A molecular sieves (0.2 g) in CH_2Cl_2 (80 mL) was added AgOTf (160 mg, 0.72 mmol) at −50°C. After 20 min, aq $NaHCO_3$ was added. The mixture was filtered, and the solids were washed with $CHCl_3$. Concentration of the organic phase afforded a syrup, which was chromatographed (2:1 hexane–EtOAc) to give amorphous **39** (120 mg, 38%); $[\alpha]_D$ +62° (*c* 0.3). NMR ($CDCl_3$): ^{13}C, δ 100.8 (*C*HPh), 99.3, 99.2, 98.5, and 98.4 ($C\text{-}1_A,1_B,1_E,1_F$), 97.6 ($C\text{-}1_D$), 93.1 ($C\text{-}1_C$), and 54.6 (CH_3O). FABMS: 2235 $[(^{12}C_{129}{}^{13}CH_{131}NO_{33} + H)^+]$ and 2234 $[(^{12}C_{130}H_{131}NO_{33} + H)^+]$. Anal. Calcd for $C_{130}H_{131}NO_{33}$: C, 69.85; H, 5.91; N, 0.63. Found: C, 69.18; H, 6.10; N, 0.74.

Methyl O-α-*L*-rhamnopyranosyl-(1 → 3)-*O*-α-*L*-rhamnopyranosyl-(1 → 2)-*O*-α-*D*-galactopyranosyl-(1 → 3)-*O*-(2-acetamido-2-deoxy-α-*D*-glucopyranosyl)-(1 → 3)-*O*-α-*L*-rhamnopyranosyl-(1 → 3)-α-*L*-rhamnopyranoside* (**3**).—A solution of compound **39** (110 mg) in MeOH was treated with NaOMe, as described for the preparation of compound **12**. The mixture was chromatographed, using 20:1 EtOAc–MeOH as eluant, to give intermediate **40** {35 mg, 44%; $[\alpha]_D$ +90° (c 0.3). NMR ($CDCl_3$): ^1H, δ 5.632 (br s, 1 H, $H\text{-}1_{Rha}$), 5.650 (d, 1 H, $J_{1,2}$ 3.8 Hz, $H\text{-}1_D$), 5.301 (s, 1 H, *H*CPh), 5.210 (br s, 1 H, $H\text{-}1_{Rha}$), 5.127 (br s, 1 H, $H\text{-}1_{Rha}$), 5.008 (br s, 1 H, $H\text{-}1_{Rha}$), 4.942 (d, 1 H, $J_{1,2}$ 3.3 Hz, $H\text{-}1_C$), and 3.260 (s, 3 H, CH_3O); ^{13}C, δ 171.0 (*C*=O), 138.3–137.4 and 129.0–126.5 (aromatic), 101.4 (2 *C*HPh and $C\text{-}1_{Rha}$), 100.6 (2 C, 2 $C\text{-}1_{Rha}$), 98.5 ($C\text{-}1_{Rha}$), 97.0 ($C\text{-}1_{Gal}$), 93.8 ($C\text{-}1_{GlcN}$), 75.6, 75.2, 74.3, 73.7, 73.0, and 72.6 (6 CH_2 of Bn), 70.5 and 68.4 ($C\text{-}6_C,6_D$), 54.7 (CH_3O), 51.9 ($C\text{-}2_C$), 23.2 (CH_3CO), 18.0 (2 C), 17.9, and 17.4 ($C\text{-}6_A,6_B,6_E,6_F$). FABMS: 1610 $[(M + H)^+]$, 1464 $[(M - C_6H_{11}O_4 + H_2)^+]$, and 1318 $[(M - C_{12}H_{21}O_8 + H_2)^+]$}. Compound **40** was hydrogenolyzed as described for compound **1**, to give the hexasaccharide **3** (16 mg, 76%); $[\alpha]_D$ +60° (*c* 0.2, H_2O). For NMR data, see Tables 1–3. FABMS: 982 $[(M + H)^+]$, 834 $[(M - C_6H_{11}O_4 + H_2)^+]$, and 688 $[(M - C_{12}H_{21}O_8 + H_2)^+]$.

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References

[1] V. Pozsgay, C.P.J. Glaudemans, J.B. Robbins, and R. Schneerson, *Bioorg. Med. Chem. Lett.*, 2 (1992) 255–260.

[2] B. Coxon, V. Pozsgay, C.P.J. Glaudemans, J.B. Robbins, and R. Schneerson, *Abstracts*, 206th ACS Meeting, August 22–27, 1993, Chicago, IL, CARB 32.

[3] S.M. Hammond, P.A. Lambert, and A.N. Rycroft, *The Bacterial Cell Surface*, Croom Helm and Kapitan Szabo, London, 1984.

[4] J.B. Robbins, C. Chu, and R. Schneerson, *Clin. Inf. Dis.*, 15 (1992) 346–362.

[5] J.B. Robbins, C. Chu, D.C. Watson, S. Szu, E.M. Daniels, C.U. Lowe, and R. Schneerson, *Rev. Inf. Dis.*, 13 (Suppl) 4 (1991) S362-S365.

[6] B.A. Dmitriev, Yu.A. Knirel, N.K. Kochetkov, and I.L. Hofman, *Eur. J. Biochem.*, 66 (1976) 559–566.

[7] S. Sturm, B. Jann, K. Jann, P. Fortnagel, and K.N. Timmis, *Microb. Pathog.*, 1 (1986) 307–324.

[8] V. Pozsgay, B. Coxon, and H. Yeh, *Bioorg. Med. Chem.*, 1 (1993) 237–257, and references therein.

[9] V. Pozsgay, J.-R. Brisson, and H.J. Jennings, *Can. J. Chem.*, 65 (1987) 2764–2769.

[10] V. Pozsgay, C.P.J. Glaudemans, J.B. Robbins, and R. Schneerson, *Carbohydr. Res.*, 244 (1993) 259–273.

[11] V. Pozsgay, C.P.J. Glaudemans, J.B. Robbins, and R. Schneerson, *Tetrahedron*, 48 (1992) 10249–10264.

[12] V. Pozsgay, *Carbohydr. Res.*, 69 (1979) 284–286.

[13] V. Pozsgay and H.J. Jennings, *J. Org. Chem.*, 53 (1988) 4042–4052.

[14] V. Pozsgay, *Carbohydr. Res.*, 235 (1992) 295–302.

[15] A. Lipták, L. Szabó, and J. Harangi, *J. Carbohydr. Chem.*, 7 (1988) 687–699.

[16] P. Kovac, *Carbohydr. Res.*, 245 (1993) 219–231.

[17] V. Pozsgay and H.J. Jennings, *Synthesis*, (1990) 724–726.

[18] V. Pozsgay and H.J. Jennings, *Tetrahedron Lett.*, 28 (1987) 1375–1376.

[19] V. Pozsgay and H.J. Jennings, *Carbohydr. Res.*, 179 (1988) 61–75.

[20] K. Koike, M. Sugimoto, S. Sato, Y. Ito, Y. Nakahara, and T. Ogawa, *Carbohydr. Res.*, 163 (1987) 189–208.

[21] C.A.A. van Boeckel and T. Beetz, *Tetrahedron Lett.*, 24 (1983) 3775–3778.

[22] T. Ogawa, K. Beppu, and S. Nakabayashi, *Carbohydr. Res.*, 93 (1981) c6–c9.

[23] S. Josephson and D.R. Bundle, *J. Chem. Soc., Perkin Trans. 1*, (1980) 297–301.

[24] L.H.B. Baptistella, J.F. dos Santos, K.C. Ballabio, and A.J. Marsaioli, *Synthesis*, (1989) 436–438.

[25] E.J. Corey, D.A. Clark, G. Goto, A. Marfat, C. Mioskowski, B. Samuelsson, and C. Hammarström, *J. Am. Chem. Soc.*, 102 (1980) 1436–1439.

[26] N.E. Byramova, M.V. Ovchinnikov, L.V. Backinowsky, and N.K. Kochetkov, *Carbohydr. Res.*, 124 (1983) c8–c11.

[27] M.J. Bertolini and C.P.J. Glaudemans, *Carbohydr. Res.*, 15 (1970) 263–270.

[28] (a) H. Lönn, Ph.D. Thesis, University of Stockholm, Sweden, 1984; (b) H. Lönn, *Carbohydr. Res.*, 139 (1985) 105–113.

[29] R.R. Schmidt and M. Strumpp, *Justus Liebigs Ann. Chem.*, (1983) 1249–1256.

[30] H. Paulsen, T. Hasenkamp, and M. Paal, *Carbohydr. Res.*, 144 (1985) 45–55.

[31] H. Paulsen and M. Paal, *Carbohydr. Res.*, 135 (1984) 53–69.

[32] H. Paulsen and V. Sinwell, *Chem. Ber.*, 111 (1978) 869–878.

[33] V. Pozsgay, in T. Suami, A. Hasegawa, and H. Ogura, (Eds), *Carbohydrates, Synthetic Methods and Applications in Medicinal Chemistry*, Kodansha/VCH, 1992, pp 188–227.

[34] A.M.P. van Steijn, J.P. Kamerling, and J.F.G. Vliegenthart, *Carbohydr. Res.*, 211 (1991) 261–277.

[35] Y. Oikawa, T. Yoshioko, and O. Yonemitsu, *Tetrahedron Lett.*, 23 (1982) 885–888.

[36] V. Pavliak, E.M. Nashed, V. Pozsgay, P. Kovac, A. Karpas, C. Chu, R. Schneerson, J.B. Robbins, and C.P.J. Glaudemans, *J. Biol. Chem.*, 268 (1993) 25797–25802.

[37] A. Bax and D.G. Davis, *J. Magn. Reson.*, 65 (1985) 355–360.

[38] A. Bax, *J. Magn. Reson.*, 53 (1983) 517–520.

[39] W.P. Aue, E. Bartholdi, and R.R. Ernst, *J. Chem. Phys.*, 64 (1976) 2229–2246.

[40] P.-E. Jansson, L. Kenne, and G. Widmalm, *Carbohydr. Res.*, 188 (1989) 169–191.
[41] A. Adeyeye, P.-E. Jansson, L. Kenne, and G. Widmalm, *J. Chem. Soc. Perkin Trans. 2*, (1991) 963–973.
[42] N.K. Kochetkov, E.V. Vinogradov, Y.A. Knirel, A.S. Shaskov, and G.M. Lipkind, *Bioorg. Khim.*, 18 (1992) 116–125.
[43] A.S. Shaskov, E.V. Vinogradov, Y.A. Knirel, N.E. Nifant'ev, N.K. Kochetkov, J. Dabrowszki, E.V. Kholodkova, and E.S. Stanislavsky, *Carbohydr. Res.*, 241 (1993) 177–188.
[44] V. Pozsgay, P. Nanasi, and A. Neszmelyi, *Carbohydr. Res.*, 75 (1979) 310–313.
[45] T. Usui, N. Yamaoka, K. Matsuda, K. Tuzimura, H. Sugiyama, and S. Seto, *J. Chem. Soc. Perkin Trans. 1*, (1973) 2425–2432.
[46] H.-P. Wessel and D.R. Bundle, *J. Chem. Soc. Perkin Trans. 1*, (1985) 2251–2260.