Carbohydrate Research, 219 (1991) 51–69
Elsevier Science Publishers B.V., Amsterdam

Synthesis and characterization of 6-*O*-β-lactosyl-α,β-D-mannopyranoses and 2,6-di-*O*-β-lactosyl-α,β-D-mannopyranoses*

Lucjan J. J. Hronowski, Walter A. Szarek†, George W. Hay, Edward R. Ison, Anita Krebs,
Department of Chemistry, Queen's University, Kingston, Ontario K7L 3N6 (Canada)
and William T. Depew
Department of Medicine, Queen's University, Kingston, Ontario K7L 3N6 (Canada)

(Received August 16th, 1990; accepted October 15th, 1990)

ABSTRACT

The reaction of 2,3,6,2',3',4',6'-hepta-*O*-acetyl-α-lactosyl bromide (**4**) and benzyl 3,4-di-*O*-benzyl-α-D-mannopyranoside (**3**) in the presence of mercury(II) cyanide in benzene–nitromethane produced benzyl 3,4-di-*O*-benzyl-2,6-bis-*O*-(2,3,6,2',3',4',6'-hepta-*O*-acetyl-β-lactosyl)-α-D-mannopyranoside (**5**) and benzyl 3,4-di-*O*-benzyl-6-*O*-(2,3,6,2',3',4',6'-hepta-*O*-acetyl-β-lactosyl)-α-D-mannopyranoside (**6**), as part of a complex mixture. Column chromatography, followed by acetylation of the fraction containing **5** and **6**, gave a sample of **5** and benzyl 2-*O*-acetyl-3,4-di-*O*-benzyl-6-*O*-(2,3,6,2',3',4',6'-hepta-*O*-acetyl-β-lactosyl)-α-D-mannopyranoside (**7**) in ~35% and 17% yields (based on **4**), respectively. Deprotection of **5** and **7** afforded the target compounds, namely 2,6-di-*O*-β-lactosyl-α,β-D-mannopyranoses and 6-*O*-β-lactosyl-α,β-D-mannopyranoses, respectively. If the coupling of **4** with **3** were performed in the presence of silver trifluoromethanesulfonate and 2,4,6-trimethylpyridine, only a mixture of 3,6,2',3',4',6'-hexa-*O*-acetyl-α-lactose-1,2-{[3,6,2',3',4',6'-hexa-*O*-acetyl-α-lactose 1,2-(benzyl 3,4-di-*O*-benzyl-α-D-mannopyranosid-6-yl orthoacetyl)-2-yl] orthoacetate} and 3,6,2',3',4',6'-hexa-*O*-acetyl-α-lactose 1,2-(benzyl 3,4-di-*O*-benzyl-α-D-mannopyranosid-6-yl orthoacetate) was obtained. The orthoacetates were characterized by n.m.r. spectroscopy. The two target materials are useful in the assessment of the binding properties of galactose-terminated ligands to the asialoglycoprotein receptor of normal rabbit and human hepatocytes.

INTRODUCTION

D-Mannose is a very common constituent of glycans which are conjugated to the peptide chains of glycoproteins[1–3]. This monosaccharide has been implicated as the site of glycosidic linkages between the glycan and the peptide moieties in certain *O*-glycoproteins[1], and as both a chain constituent[4] and a branch point[1,4–13] in numerous glycosylically *N*-linked oligo-mannosylicglycoproteins[1–3,6,8,11]. These data suggested that oligosaccharides having D-mannose as the terminal, reducing unit, and having D-galactopyranose or lactose units as ligands attached to the mannopyranose residue,

* Synthesis and Binding of D-Galactose-terminated Ligands to Human and Rabbit Asialoglycoprotein Receptor. Part IV.

† Author for correspondence.

0008-6215/91/$ 03.50

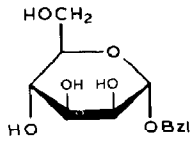
might assume conformations[14] similar to those of natural determinants and may be useful candidate molecules in our investigations of the binding of D-galactopyranose-terminated ligands[15–17] to the asialoglycoprotein receptor of normal, human, and rabbit hepatocytes. This article reports the synthesis and characterization of 6-*O*-β-lactosyl-α,β-D-mannopyranoses (**11**) and 2,6-di-*O*-β-lactosyl-α,β-D-mannopyranoses (**9**).

An *N*-acetyllactosamine analog of **9**, namely 2,6-di-*O*-[β-D-galactopyranosyl-(1→4)-*O*-(2-acetamido-2-deoxy-β-D-glucopyranosyl)]-D-mannose[5], and its *p*-(trifluoroacetamido)phenyl glycoside[18], have been prepared by Arnarp and co-workers. A tris(sialyl) derivative of the former pentasaccharide forms one segment of the glycosyl portion of the bovine blood coagulation factor IX[9]. As well, an *N*-acetyllactosamine analog of **11**, namely *O*-β-D-galactopyranosyl-(1→4)-*O*-(2-acetamido-2-deoxy-β-D-glucopyranosyl)-(1→6)-D-mannose, has been synthesized[19,20]. Although **9** has been previously prepared [21], no details of the method were published, and this paper constitutes the first complete description of the synthesis of **9** and **11**.

It is noteworthy that during the course of synthesizing **9** and **11**, following standard methodologies[5,21], only complex 1,2-orthoesters of peracetylated lactose were initially obtained. Of course, the formation of 1,2-orthoesters during Koenigs-Knorr-type glycosidation is very well known[17,22–26], and conditions have been defined which give high yields of 1,2-orthoesters[24,27–29] with no detectable glycoside formation[27,28]. Equally well known is the use of 1,2-orthoesters for glycoside formation[25,30–33] with high stereoselectivity[25,31] (see ref. 34). For the characterization of the complex orthoesters encountered in the present study, and those earlier reported[17], model 1,2-orthoesters of lactose were prepared[22–24,29] from hepta-*O*-acetyl-α-lactosyl bromide (**4**) (ref. 15). These model compounds were identified by high-resolution, proton nuclear magnetic resonance (^{1}H-n.m.r.) spectroscopy[35–37], and by the ease with which they underwent hydrolysis[31,32] in solutions of weak acids. The nature of the products of hydrolysis of orthoesters and the stereoselectivity of the hydrolysis of the intermediate dioxolenium ions have been the subjects of extensive discussion[38–40].

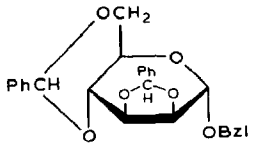
RESULTS AND DISCUSSION

Benzyl 3,4-di-*O*-benzyl-α-D-mannopyranoside (**3**) was prepared from D-mannose, which was first converted into benzyl α-D-mannopyranoside (**1**) and then into the 2,3:4,6-di-*O*-benzylidene derivative (**2**), in the manner described by Shaban *et al.*[41] Hydrogenolysis of **2**, using lithium aluminum hydride–aluminum chloride[42,43], gave **3** (ref. 5). Compound **3** was coupled with **4** (ref. 15) (see Scheme 1) in the presence of mercury(II) cyanide[23] in benzene–nitromethane to produce benzyl 3,4-di-*O*-benzyl-2,6-bis-*O*-2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-β-lactosyl)-α-D-mannopyranoside (**5**) and benzyl 3,4-di-*O*-benzyl-6-*O*-(2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-β-lactosyl)-α-D-mannopyranoside (**6**) as part of a complex mixture. Column chromatography, using 2:3 (v/v) toluene–ethyl acetate, separated this mixture into three fractions having R_F 0.55, 0.44, and 0.23. In our experience, the components having R_F 0.55 and 0.23 are the typical side-reaction and decomposition products of **4** in the Helferich[23] coupling procedure.

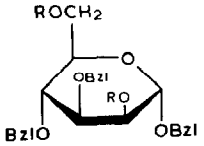


1

Bzl = CH_2Ph

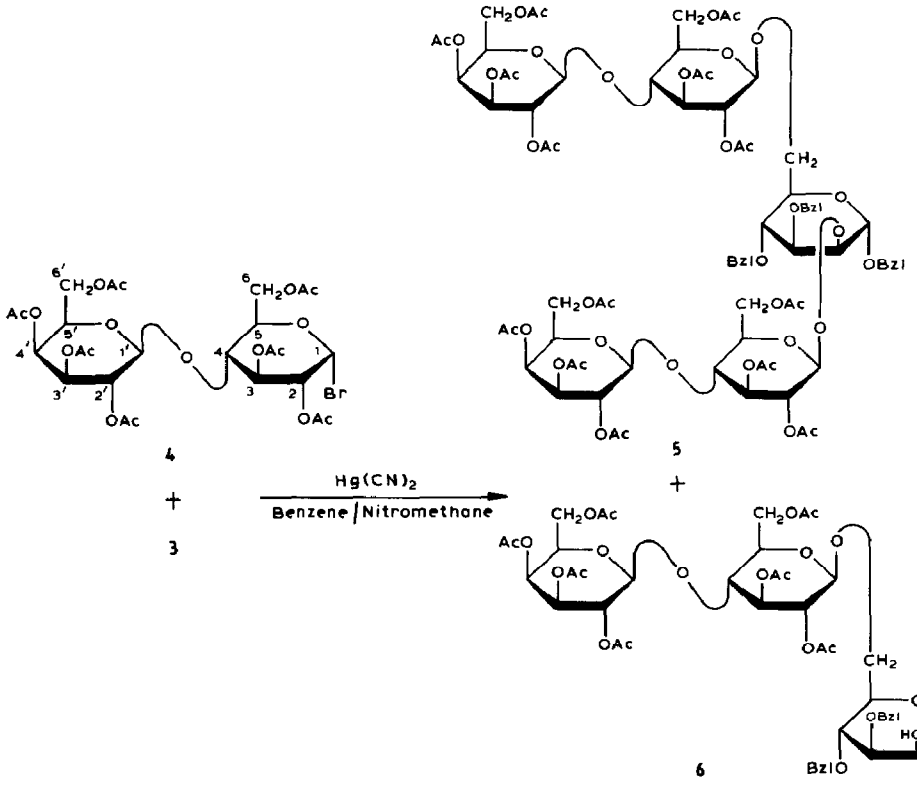


2



3 R = H

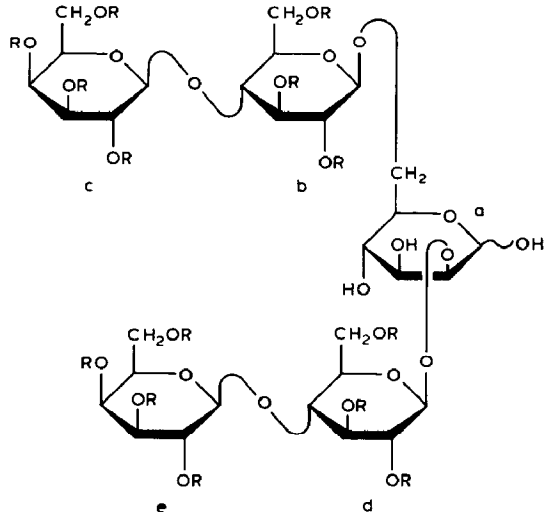
3a R = Ac



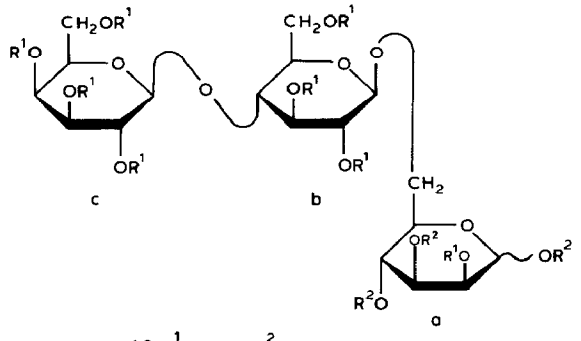
Scheme 1

The fraction having R_F 0.55 afforded a ^{1}H-n.m.r. spectrum similar to those of the 1,2-orthoesters of peracetylated lactose (see Scheme 3). The fraction having R_F 0.23 gave a ^{1}H-n.m.r. spectrum indistinguishable from that of a mixture of 2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-α- (**18**) and β-lactose (**19**) and thus was indicated to be the hydrolysis product of **4**. In association with unidentified impurities, **5** and **6** migrated conjointly (R_F 0.44) on column chromatography. However, when this fraction was treated with acetic anhydride in pyridine, esterification of all of the free hydroxyl groups was achieved, and column chromatography, using 1:1 (v/v) toluene–ethyl acetate, afforded benzyl 2-*O*-acetyl-3,4-di-*O*-benzyl-6-*O*-(2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-β-lactosyl)-α-D-mannopyranoside (**7**) and impure **5**.

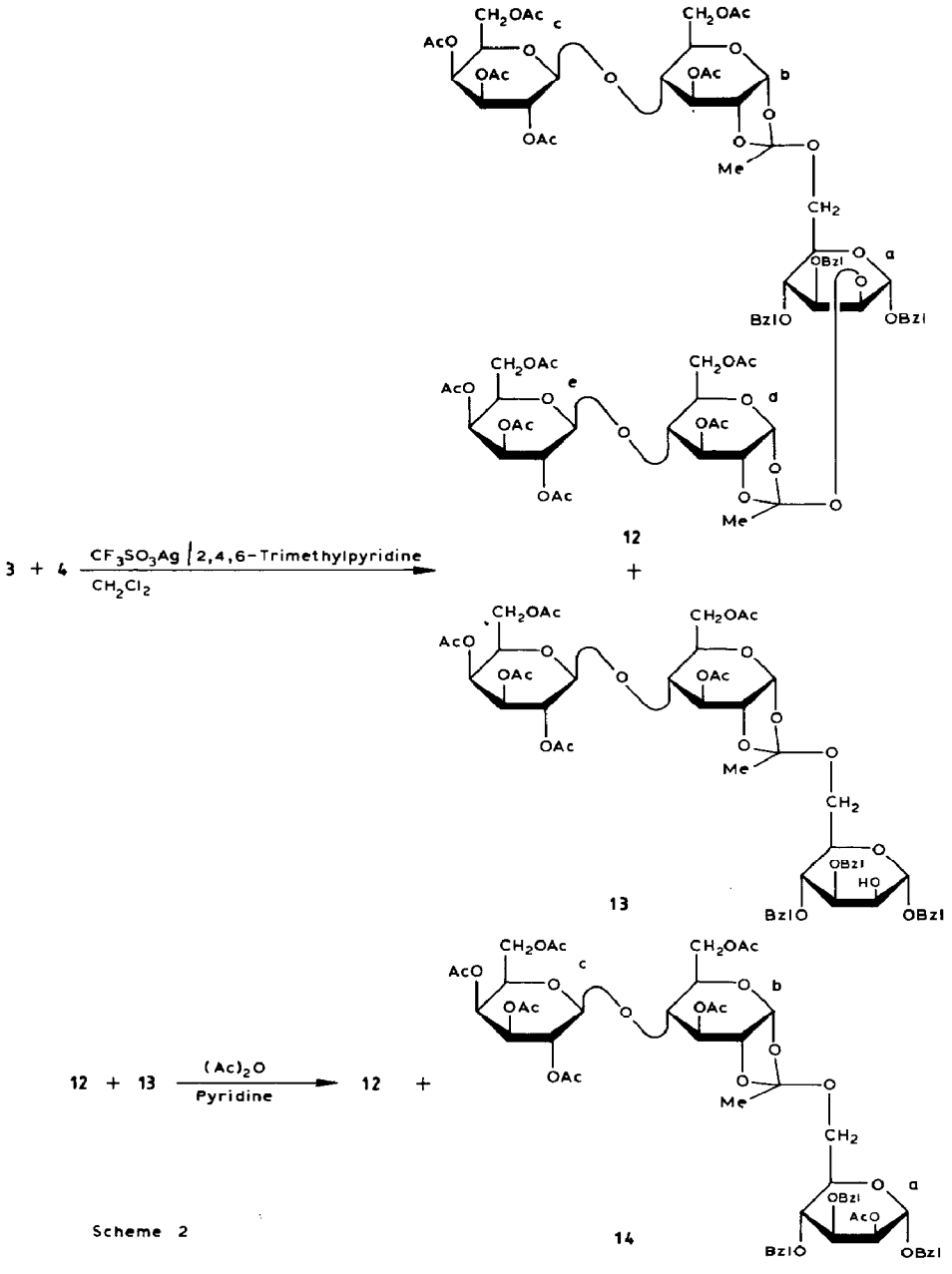
The ^{1}H-n.m.r. signals of the protons of **7** and those of the other products described in this article were assigned on the basis of two-dimensional, Fourier-transform, proton chemical-shift correlation spectroscopy (COSY)[36,37] experiments.



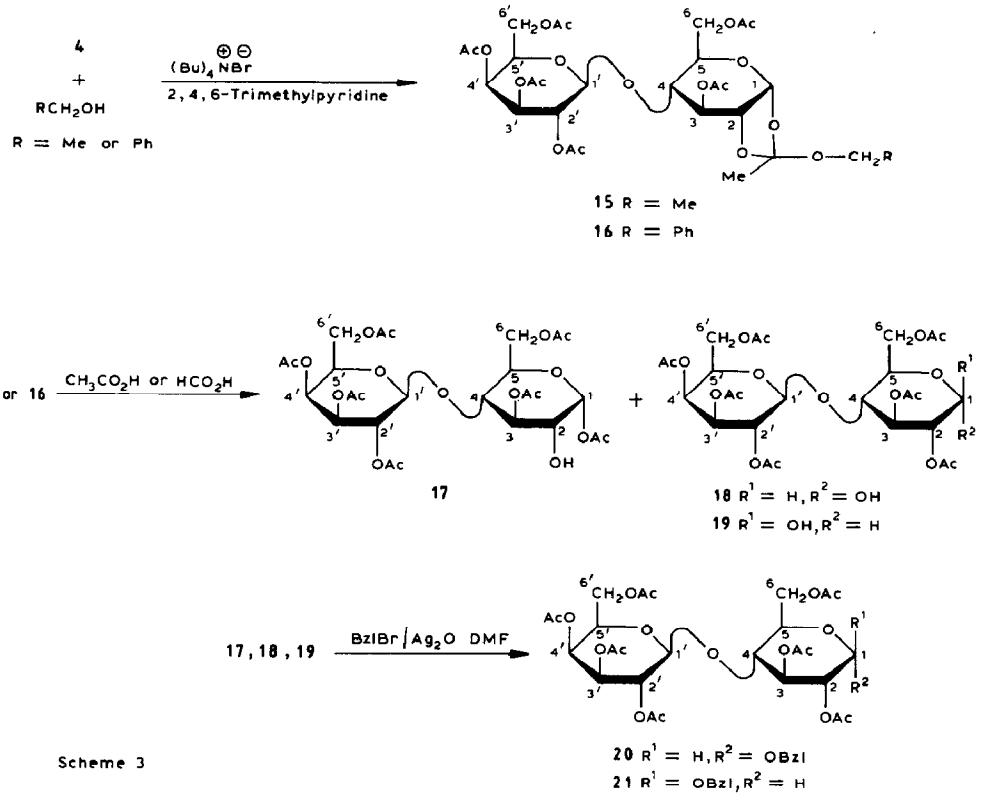
8 R = Ac
9 R = H



10 R^1 = Ac, R^2 = H
11 R^1 = R^2 = H


CH2OAc
AcO
OAc
OAc
OAc
Me
CH2
OBzl
BzlO
OBzl
a
b
c
d
e
12
3 + 4
CF3SO3Ag / 2,4,6-Trimethylpyridine
CH2Cl2
+
HO
13
12 + 13
(Ac)2O
Pyridine
12 +
14

Scheme 2



Scheme 3

The chemical shift of the H-1b resonance and the value of the coupling constant are δ 4.50 and 8.0 Hz, respectively, and infer that the glycosidic linkage has the β-D-configuration[15,16].

The linkage of the lactosyl group to the C-6 position of mannose was determined on the basis of the chemical shifts of the resonances of the protons on the mannosyl residue in compound **7**. Comparison of the values of these chemical shifts with those of the chemical shifts of the resonances of the corresponding protons of benzyl 3,4-di-*O*-benzyl-α-D-mannopyranoside (**3**) and its fully acetylated derivative (**3a**), which are summarized in Table I, shows relatively small variations for all of the protons except for those at C-2 and C-6. Acetylation of **3** to **3a** caused a downfield shift of the H-2 signal of ~1.3 p.p.m. An almost identical shift of the signal of H-2 in the mannosyl residue was observed in the spectrum of **7**. In contrast, acetylation caused a downfield shift of the H-6 signals of ~0.5 p.p.m. in the spectrum of **3a**, whereas the corresponding shift was not observed in the case of **7**. Instead, the resonances of the H-6 protons in **7** occur at positions which are similar to those observed for the resonances of the H-6 protons in **3**.

The impure sample of **5**, obtained by us from the coupling[23] of **4** and **3** (see Scheme 1) was *O*-debenzylated by catalytic transfer hydrogenation[44] using 10% palladium-on-carbon in methanol containing 10% formic acid. The product mixture was resolved by column chromatography to give 2,6-di-*O*-(2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-β-lactosyl)-α,

TABLE 1

^{1}H-N.m.r. data[a] of the D-mannosyl residues in **3**[b], **3a**[b], and **7**[b]

Proton	*Chemical shifts (δ) and coupling constants (Hz)*[c]		
	3	**3a**	**7**
H-1 ($J_{1,2}$)	4.97 (1.9)	4.90 (1.5)	4.88 (1.7)
H-2 ($J_{2,3}$)	4.07 (3.0)	5.41 (3.2)	5.39 (3.3)
H-3 ($J_{3,4}$)	3.95 (9.3)	4.04 (9.1)	4.02 (9.1)
H-4 ($J_{4,5}$)	3.89 (9.3)	3.75 (10.0)	3.67–3.73
H-5	3.72	3.89	3.67–3.73
H-6 ($J_{6,5}$)	3.79 (3.9)	4.27 (2.0)	3.81–3.86
H-6 ($J_{6,5}$)	3.83 (2.8)	4.35 (5.1)	4.06–4.16

[a] For a solution in $CDCl_3$. [b] More complete ^{1}H-n.m.r. data for **3**, **3a**, and **7** are given in the Experimental Section. [c] *In parentheses.*

β-D-mannoses (**8**) in 17% yield. *O*-Deacetylation[45] of **8** afforded **9** in 97% yield. The deprotection of **9** by a similar series of reactions gave finally 6-*O*-(2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-β-lactosyl)-2-*O*-acetyl-α,β-D-mannopyranoses (**10**) in 41% yield and then **11** in 96% yield.

The chemical shifts of the protons of **8** and **10** were assigned with the aid of COSY[34,35] experiments. The H-1 protons of **8** and **10** and the H-1 protons of **8** resonate in the δ 4.51–4.62 region, and the values of the coupling constants are in the range 7.8–7.9 Hz. These values indicate that the glycosidic bonds of these constituents have the β-D-configuration[15,16].

Lee *et al.*[21] reported the synthesis of **9** but provided no experimental details. Subsequently, it was learned[46] that an impure sample of **5** had been prepared by coupling **4** with **3** in the presence of silver trifluoromethanesulfonate and 2,4,6-trimethylpyridine[47,48]. In our hands the attempted preparation of **5** by the latter method afforded only a mixture of the 1,2-orthoesters **12** and **13** (see Scheme 2), and the desired lactoside could not be detected in the product mixture. Treatment of the mixture of **12** and **13** with acetic anhydride in pyridine gave a new mixture containing **12** and **14**. Column chromatography readily separated these two components from one another, but each was contaminated with small amounts of impurities. The crude yields of **12** and **14** were 48 and 19%, respectively.

The interpretation of ^{1}H-n.m.r. spectral data associated with some of the side products of these reactions, including the complex 1,2-orthoesters (see refs. 22–26) described herein and previously[17], required the synthesis of several model compounds of known structure (see Scheme 3). The 1,2-orthoesters, 3,6,2′,3′,4′,6′-hexa-*O*-acetyl-1,2-*O*-(ethyl orthoacetyl)-α-lactose (**15**) and 3,6,2′,3′,4′,6′-hexa-*O*-acetyl-1,2-*O*-(benzyl orthoacetyl)-α-lactose (**16**), were prepared from **4** by reaction with ethanol and benzyl alcohol, respectively. The reaction conditions were similar to those described[24] for the preparation of 3,4,6-tri-*O*-acetyl-1,2-*O*-(alkyl orthoacetyl)-α-D-glucoses from 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide and involved the addition of the alcohol to a suspension of **4** and tetrabutylammonium bromide[29] in 2,4,6-trimethylpyridine[27].

Compounds **15** and **16** were each obtained in a yield >80% after column chromatography. High-resolution ^{1}H-n.m.r. spectroscopy indicated that each of **15** and **16** was a single diastereomer. In their study of tri-*O*-acetyl-1,2-*O*-orthoesters of α-D-glucopyranose, Lemieux and Morgan[24] reported that two diastereomeric orthoesters were produced in each case, and they reasoned, on the basis of ^{1}H-n.m.r. spectral data[24] and energy considerations[49], that the major isomer was that in which the alkoxyl group on the dioxolane ring was *trans* to the pyranose ring (*i.e.*, of the *exo* configuration). The close correlation between the coupling constants of the protons of the D-glucopyranosyl residues of **15** and **16** and those of the (presumed) *exo* isomer of 3,4,6-tri-*O*-acetyl-1,2-*O*-(ethyl orthoacetyl)-α-D-glucopyranose[24] (see Table III) infers that **15** and **16** also possess the *exo* configuration at the orthoester function. Table II summarizes the

TABLE II

^{1}H-N.m.r. data[a] of the D-glucosyl residues in **12**[b], **14**[b], and a model compound[c].

Proton	*Chemical shifts (δ) and coupling constants (Hz)*[d]			
	12 (ring b)	**12** (ring d)	**14**	[c]
H-1 ($J_{1,2}$)	5.66 (5.2)	5.58 (5.1)	5.65 (5.3)	5.60 (5.1)
H-2 ($J_{2,3}$)	4.40 (2.7)	4.36 (2.7)	4.36 (2.7)	4.37 (1.8)
H-3 ($J_{3,4}$)	5.55 (1.1)	5.46 (1.1)	5.52 (1.4)	5.49
H-4 ($J_{4,5}$)	3.65 (9.5)	3.57 (9.6)	3.64 (9.6)	3.50–3.97
H-5	3.87	3.77	3.87	3.50–3.97
H-6 ($J_{6,5}$)	4.12 (5.6)	4.06 (5.7)	4.12 (5.5)	4.05–4.17
H-6 ($J_{6,5}$)	4.25 (2.3)	4.21 (2.4)	4.26 (2.4)	4.24 (1.6)
Me	1.71	1.64	1.73	1.70

[a] For the solution in $CDCl_3$. [b] More complete ^{1}H-n.m.r. data for **12** and **14** are given in the Experimental Section. [c] The H-X″ protons of 1,2-*O*-[1,3-bis-*O*-(2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-β-lactosyl)glycer-2-yl orthoacetyl]-3,6,2′,3′,4′,6′-hexa-*O*-acetyl-α-lactose, which is compound **18** in ref. 17. [d] In parentheses.

TABLE III

^{1}H-N.m.r. data[a] of the D-glucosyl residues in **15**[b], **16**[b], and a model compound[c]

Proton	*Chemical shifts (δ) and coupling constants (Hz)*[d]		
	15	**16**	[c]
H-1 ($J_{1,2}$)	5.66 (5.0)	5.63 (5.2)	5.72 (5.0)
H-2 ($J_{2,3}$)	4.31 (2.6)	4.32 (2.7)	(2.8)
H-3 ($J_{3,4}$)	5.54 (1.0)	5.56 (1.2)	5.19 (2.8)
H-4 ($J_{4,5}$)	3.66 (9.5)	3.64 (9.8)	5.09 (9.0)
H-5	3.86	3.87	
H-6 ($J_{6,5}$)	4.10–4.17 (5.7)	4.07–4.18 (5.6)	
H-6 ($J_{6,5}$)	4.25 (2.1)	4.26 (2.4)	
Me	1.72	1.80	

[a] For a solution in $CDCl_3$. [b] More complete ^{1}H-n.m.r. data for **15** and **16** are given in the Experimental Section. [c] 3,4,6-Tri-*O*-acetyl-1,2-*O*-(ethyl orthoacetyl)-α-D-glucopyranose[24]. [d] In parentheses.

chemical shifts and coupling constants for the protons of ring b in **12** and **14** and of ring d in **12**. Note that these values correspond very closely with those of the corresponding protons of the model compounds, **15** and **16** (see Table III). These similarities, and the bulky nature of the alcohol group in the present series of 1,2-orthoesters of peracetylated lactose, particularly in structures **12** and **14**, make it probable[29,32,49] that they, too, have the alcohol group in the *exo* orientation.

The data of Tables II and III reveal that the resonances of the protons of the D-glucopyranosyl residues of **12** and **14–16** exhibit a characteristic set of chemical-shift values. These values are readily distinguishable from those of the corresponding sites of lactosyl derivatives (see Table IV and ref. 16) and are insensitive to changes in the constituent groups of the 1,2-orthoesters. Thus, the ^{1}H-n.m.r. spectra provide a convenient way to identify such structural features in complex compounds, such as those cited in Scheme 2 and Table II. In the case of the pentasaccharide **12**, confirmatory evidence for the occurrence of orthoacetyl units was obtained by ^{13}C-n.m.r. spectroscopy. The spectrum in $CDCl_3$ showed the presence of two signals at δ 121.65 and 121.42, attributable to the resonances of the C-1 atoms of the ethylidene fragments. These signals are in the region in which such atoms have been observed to resonate (see ref. 26).

The hydrolysis of **15** using 88% (v/v) formic acid, or of **16**, using 95% (v/v) aqueous acetic acid, gave an approximately equimolar mixture of 1,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-α-lactose (**17**) and a ~1:2 mole-ratio mixture of **19** and **18**, respectively. A similar mixture of **17**, **18**, and **19** had been obtained[50] by the hydrolysis of hepta-*O*-acetyl-β-lactosyl chloride in acetone or in *N*,*N*-dimethylformamide (DMF). The mixture of **17**, **18**, and **19** was treated with benzyl bromide and silver(I) oxide in DMF to produce benzyl 2,3,6,2′,3′,4′,6′-hepta-*O*-acetyl-α-lactoside (**20**) and the corresponding β-anomer (**21**) in yields of 39 and 23%, respectively. Analysis of the reaction products, using thin-layer chromatography (t.l.c.) and ^{1}H-n.m.r. spectroscopy, failed to detect the presence of a 2-*O*-benzyl derivative. This result infers that the 1-*O*-acyl group of **17**

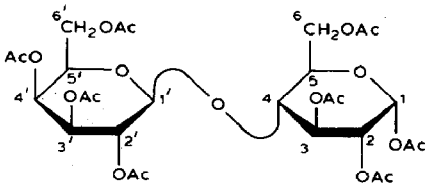
TABLE IV[a]

^{1}H-N.m.r. data[a] of the D-glucosyl residues in **17–22**[b]

Proton	Chemical shifts (δ) and coupling constants (Hz)[c]					
	17	**18**	**19**	**20**	**21**	**22**
H-1	6.17	5.38	4.73	5.03	4.51	6.26
($J_{1,2}$)	(3.7)	(3.4)	(7.9)	(3.7)	(7.8)	(3.7)
H-2	3.73	4.83	4.80	4.80	4.97	5.01
H-3	5.26	5.53	5.24	5.53	5.16	5.47
H-4	3.75	3.77	3.79	3.75	3.82	3.82
H-5	3.92	4.05–4.21	3.65	3.94	3.58	4.02
H-6	4.12	4.05–4.21	4.05–4.21	4.11	4.11	4.13
H-6	4.38	4.47–4.53	4.47–4.53	4.38	4.52	4.46

[a] For a solution in $CDCl_3$. [b] More complete ^{1}H-n.m.r. data for **17–22** are given in the Experimental Section. [c] In parentheses.

migrated to the C-2 position during the reaction. Similar conditions were used by Croon and Lindberg[51] to prepare 4-*O*-benzyl-D-glucopyranose from methyl 2,3,4-tri-*O*-acetyl-β-D-glucopyranoside by exploiting the facile migration of the acetyl group from the C-4 to the C-6 position. Compound **21** also was prepared by the reaction[23] of **4** with benzyl alcohol. Compound **17** was separated from **18** and **19** by column chromatography. The mixture of **18** and **19** was obtained as well from **20** by *O*-debenzylation. These products were investigated by ^{1}H-n.m.r. spectroscopy. Table IV lists the values of the coupling constants $J_{1,2}$, and the chemical shifts of the resonances of the protons of the D-glucosyl residues of **17–21**, as well as those of 1,2,3,6,2′,3′,4′,6′-octa-*O*-acetyl-α-lactose (**22**). The data for the protons of the D-galactopyranosyl residues of these compounds have not



22

been shown because they differ by less than ±0.01 p.p.m. from those given for peracetylated lactosyl glycerides which were fully described in an earlier publication[16] in this series. For the compounds cited in Table IV, the $J_{1,2}$ values of the α-lactosides are in the range 3.4–3.7 Hz, whereas those of the β-lactosides are in the range 7.8–7.9 Hz. Moreover, the chemical shifts of the resonances of the H-1 protons of **18** and **20** are 0.5–0.6 p.p.m. downfield from those of **19** and **21**, respectively (see Table IV). This feature is consistent with the results[16] from other α,β-pairs of lactosyl glycosides.

Thus, the target compounds **9** and **11** have been synthesized by reaction sequences in which the key intermediates and principal side-reaction products have been fully charaterized.

EXPERIMENTAL

General methods. — Melting points were determined on a Fisher–Johns apparatus and are uncorrected. Optical rotations were measured with a Perkin–Elmer model 141 or 241 automatic polarimeter for solutions in a 0.1-dm cell. ^{1}H-n.m.r. spectra were recorded with a Bruker CXP-200 (200 MHz) or AM-400 (400 MHz) spectrometer, with tetramethylsilane (Me_4Si) as the internal standard, for solutions in $CDCl_3$, unless otherwise stated. The ^{13}C-n.m.r. spectrum was recorded on the Bruker AM-400 spectrometer at 100.6 MHz, with $CDCl_3$ as the solvent and internal standard (77.00 p.p.m.). Chemical shifts (δ) of all of the signals are given in p.p.m. downfield the signal of Me_4Si. In recording these data two conventions have been used to identify the protons. For the disaccharide derivatives cited, the D-galactopyranosyl ring has been assigned primed numbers, and the aglycon has not been numbered. For the tri- and penta-saccharides cited, the rings have been assigned letters. Thin-layer chromatography (t.l.c.) was

performed on glass plates precoated with E. Merck Silica Gel-60 F254 as the adsorbent (layer thickness, 0.25 mm). The following solvent systems (v/v) were used: (*A*) 1:1, and (*B*) 2:3 toluene–ethyl acetate; (*C*) 9:9:1, (*D*) 8:8:1, (*E*) 4:4:1, and (*F*) 3:3:1 toluene–ethyl acetate–2-propanol. The developed plates were air-dried and sprayed with a solution of cerium(IV) sulfate (1%) and molybdic acid (1.5%) in 10% aqueous sulfuric acid, and heated at 150°. Column chromatography was performed using E. Merck Silica Gel-60 (70–230 mesh, cat. No. 7734) as the solid phase. Solvents were evaporated under reduced pressure at ~40°.

Benzyl-α-D-mannopyranoside (**1**) — Compound **1** was prepared in the manner described by Shaban *et al.*[41] and had m.p. 130–133°, lit.[41] m.p. 132–133°; $[\alpha]_D^{25}$ +75.5° (*c* 1.35, water), lit.[41] $[\alpha]_D^{26}$ +73.5° (*c* 1.5, water); ^{1}H-n.m.r. (400 MHz, Me_2SO-d_6): δ 3.38–3.71 (m, 6 H, H-2,3,4,5,6,6), 4.43 (d, 1 H, J_{gem} 12.1 Hz, C*H*$_2$Ph), 4.49 (t, 1 H, ^3J 5.9 Hz, CH_2OH), 4.56 (d, 1 H, ^3J 6.0 Hz, OH), 4.67 (d, 1 H, J_{gem} 12.1 Hz, C*H*$_2$Ph), 4.69 (m, 1 H, H-1), 4.73 (d, 1 H, ^3J 5.9 Hz, OH), 4.74 (d, 1 H, ^3J 4.6 Hz, OH), and 7.28–7.43 (m, 5 H, Ph).

Benzyl 2,3:4,6-di-O-benzylidene-α-D-mannopyranoside (**2**). — Compound **2** was prepared by the method of Shaban *et al.*[41] and had m.p. 173–176°, lit.[41] m.p. 174–176°; ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 3.8–3.94 (m, 3 H), 4.20 (d, 1 H, *J* 5.4 Hz), 4.30 (dd, 1 H, *J* 9.8, *J* 3.9 Hz), 4.42 (d, 1 H, J_{gem} 11.7 Hz, C*H*$_2$Ph), 4.68 (dd, 1 H, *J* 5.5, *J* 7.6 Hz), 4.73 (d, 1 H, J_{gem} 11.7 Hz, C*H*$_2$Ph), 5.22 (s, 1 H), 5.65 (s, 1 H), 6.29 (s, 1 H), and 7.29–7.56 (m, 15 H, 3 Ph).

Benzyl 3,4-di-O-benzyl-α-D-mannopyranoside (**3**) *and benzyl 2,6-di-O-acetyl-3,4-di-O-benzyl-α-D-mannopyranoside* (**3a**). — Compound **3** was prepared by the method of Arnarp *et al.*[5]; $[\alpha]_D^{27}$ +55.3° (*c* 1.14, chloroform), lit.[5] $[\alpha]_D^{21}$ +55° (*c* 1, chloroform); ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 2.19 (br s, 1 H, OH), 2.70 (br s, 1 H, OH), 3.72 (dt, 1 H, $J_{5,4}$ 9.3, ^3J 3.3 Hz, H-5), 3.79 (m, 1 H, J_{gem} 11.9, $J_{6,5}$ 3.9 Hz, H-6), 3.83 (m, 1 H, J_{gem} 11.9, $J_{6,5}$ 2.8 Hz, H-6), 3.89 (t, 1 H, ^3J 9.3 Hz, H-4), 3.95 (dd, 1 H, $J_{3,4}$ 9.3, $J_{3,2}$ 3.0 Hz, H-3), 4.07 (m, 1 H, $J_{2,3}$ 3.0, $J_{2,1}$ 1.9 Hz, H-2), 4.47 (d, 1 H, J_{gem} 11.7 Hz, C*H*$_2$Ph), 4.67 (d, 1 H, J_{gem} 10.9 Hz, C*H*$_2$Ph), 4.68 (d, 1 H, J_{gem} 11.7 Hz, C*H*$_2$Ph), 4.70 (s, 2 H, C*H*$_2$Ph), 4.88 (d, 1 H, J_{gem} 10.9 Hz, C*H*$_2$Ph), 4.97 (d, 1 H, $J_{1,2}$ 1.9 Hz, H-1), and 7.1–7.4 (m, 15 H, 3 Ph). The protons having signals at δ 2.19 and 2.70 were exchangeable with D_2O.

Compound **3** was treated with acetic anhydride in pyridine to give **3a**; ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 2.08 (s, 3 H, OAc), 2.14 (s, 3 H, OAc), 3.75 (t, 1 H, ^3J 9.7 Hz, H-4), 3.89 (ddd, 1 H, $J_{5,4}$ 10.0, $J_{5,6}$ 5.1, $J_{5,6}$ 2.0 Hz, H-5), 4.04 (dd, 1 H, $J_{3,4}$ 9.1, $J_{3,2}$ 3.2 Hz, H-3), 4.27 (dd, 1 H, J_{gem} 11.7, $J_{6,5}$ 2.0 Hz, H-6), 4.35 (dd, 1 H, J_{gem} 11.7, $J_{6,5}$ 5.1 Hz, H-6), 4.49 (d, 1 H, J_{gem} 11.8 Hz, C*H*$_2$Ph), 4.52 (d, 1 H, J_{gem} 10.4 Hz, C*H*$_2$Ph), 4.54 (d, 1 H, J_{gem} 10.6 Hz, C*H*$_2$Ph), 4.68 (d, 1 H, J_{gem} 11.8 Hz, C*H*$_2$Ph), 4.70 (d, 1 H, J_{gem} 11.3 Hz, C*H*$_2$Ph), 4.89 (d, 1 H, J_{gem} 10.6 Hz, C*H*$_2$Ph), 4.90 (d, 1 H, $J_{1,2}$ 1.5 Hz, H-1), 5.41 (dd, 1 H, $J_{2,3}$ 3.2, $J_{2,1}$ 1.5 Hz, H-2), and 7.1–7.4 (m, 15 H, 3 Ph).

Benzyl 2,6-bis-O-(2,3,6,2′,3′,4′,6′-hepta-O-acetyl-β-lactosyl)-3,4-di-O-benzyl-α-D-mannopyranoside (**5**) *and benzyl 6-O-(2,3,6,2′,3′,4′,6′-hepta-O-acetyl-β-lactosyl)-2-O-acetyl-3,4-di-O-benzyl-α-D-mannopyranoside* (**7**). — A mixture of **4** (ref. 15) (3.82 g, 5.46 mmol), **3** (0.82 g, 1.82 mmol), and mercury(II) cyanide (1.56 g, 6.18 mmol) in 1:1 (v/v)

benzene–nitromethane (40 mL)[23] was stirred for 19 h at 40°. Compound **4** (1.29 g, 1.84 mmol) and mercury(II) cyanide (0.51 g, 2.02 mmol) were added, and stirring was continued for 27 h at 40°. The reaction mixture was diluted with toluene (30 mL) and washed sequentially with sat. aq. sodium hydrogencarbonate (2 × 30 mL) and water (30 mL). The organic phase was dried ($CaCl_2$), concentrated, and the residual mixture was resolved by column chromatography to give three main components having R_F 0.55, 0.44, and 0.23 (solvent *B*). The component having R_F 0.44 (1.54 g) consisted of a mixture of **5**, **6**, and other minor impurities. This mixture was treated with acetic anhydride (10 mL) in pyridine (30 mL) at room temperature, concentrated, and the residual mixture was resolved by column chromatography to give two components having R_F 0.59 and 0.34 (solvent *A*). The component having R_F 0.59 was chromatographically homogeneous **7** (0.308 g, 15%), which was obtained as a colorless, glassy solid: $[\alpha]_D^{22}$ +8° (*c* 0.65, chloroform); ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.97 (s, 3 H, OAc), 1.98 (s, 3 H, OAc), 2.04 (s, 3 H, OAc), 2.05 (s, 3 H, OAc), 2.06 (s, 3 H, OAc), 2.09 (s, 3 H, OAc), 2.14 (s, 3 H, OAc), 2.16 (s, 3 H, OAc), 3.57 (ddd, 1 H, $J_{5b,4b}$ 9.5, $J_{5b,6b}$ 4.4, $J_{5b,6b}$ 2.2 Hz, H-5b), 3.67–3.73 (m, 2 H, H-4a,5a), 3.81 (t, 1 H, ^3J 9.5 Hz, H-4b), 3.81–3.86 (m, 1 H, H-6a), 3.87 (br t, 1 H, ^3J 6.7 Hz, H-5c), 4.02 (dd, 1 H, $J_{3a,4a}$ 9.1, $J_{3a,2a}$ 3.3 Hz, H-3a), 4.07 (dd, 1 H, J_{gem} 11.8, $J_{6b,5b}$ 4.4 Hz, H-6b), 4.06–4.16 (m, 3 H, H-6a,6c,6c), 4.47 (d, 1 H, J_{gem} 12.1 Hz, CH_2Ph), 4.48 (d, 1 H, $J_{1c,2c}$ 7.9 Hz, H-1c), 4.50 (d, 1 H, $J_{1b,2b}$ 8.0 Hz, H-1b), 4.506 (d, 1 H, J_{gem} 12.4 Hz, CH_2Ph), 4.512 (d, 1 H, J_{gem} 11.4 Hz, CH_2Ph), 4.52 (dd, 1 H, J_{gem} 11.8, $J_{6b,5b}$ 2.2 Hz, H-6b), 4.67 (d, 1 H, J_{gem} 12.2 Hz, CH_2Ph), 4.69 (d, 1 H, J_{gem} 10.8 Hz, CH_2Ph), 4.88 (d, 1 H, $J_{1a,2a}$ 1.7 Hz, H-1a), 4.91 (d, 1 H, J_{gem} 11.0 Hz, CH_2Ph), 4.96 (dd, 1 H, $J_{3c,2c}$ 10.5, $J_{3c,4c}$ 3.5 Hz, H-3c), 5.03 (dd, 1 H, $J_{2b,3b}$ 9.6, $J_{2b,1b}$ 8.0 Hz, H-2b), 5.11 (dd, 1 H, $J_{2c,3c}$ 10.5, $J_{2c,1c}$ 7.9 Hz, H-2c), 5.20 (t, 1 H, J 9.3 Hz, H-3b), 5.35 (br d, 1 H, ^3J 3.4 Hz, H-4c), 5.39 (dd, 1 H, $J_{2a,3a}$ 3.3, $J_{2a,1a}$ 1.7 Hz, H-2a), and 7.25–7.40 (m, 15 H, 3 Ph). The component having R_F 0.34 consisted of impure **5** (0.999 g, 35% crude yield), which was shown by ^{1}H-n.m.r. spectroscopy to be contaminated by minor impurities.

2,6-Bis-O-*(2,3,6,2',3',4',6'-hepta*-O-*acetyl-β-lactosyl)-α,β*-D-*mannopyranoses* (**8**) — A suspension of 10% (w/w) palladium-on-carbon (2.2 g) in methanol (10 mL) (Caution! Fire hazard.) was added to a solution of impure **5** (0.78 g, 0.46 mmol, theoretical) in methanol (100 mL) containing 10% (v/v) formic acid[44], and stirred for 10.5 h at room temperature. A second portion of catalyst (1.9 g) suspended in methanol (10 mL) was added, followed by the addition of methanol (20 mL) containing 10% (v/v) formic acid, and stirring was continued for 22 h. The mixture was filtered, the residue washed with methanol (100 mL), and the combined filtrate and wash solution were evaporated to dryness. The residue was resolved by column chromatography to give **8** (0.110 g, 17%) as a colorless, glassy solid, R_F 0.38 (solvent *E*); ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.97 (s, 6 H, 2 OAc), 2.03–2.07 (m, 24 H, 8 OAc), 2.14 (s, 3 H, OAc), 2.15 (s, 3 H, OAc), 2.16 (s, 6 H, 2 OAc), 3.3–5.15 (m, 7 H, mannosyl Hs) 3.61 (ddd, 1 H, ^3J 9.8, ^3J 3.3, ^3J 2.0 Hz, H-5b or H-5d), 3.67 (ddd, 1 H, ^3J 9.9, ^3J 5.6, ^3J 1.9 Hz, H-5b or H-5d), 3.783 (t, 1 H, ^3J 9.7 Hz, H-4b or H-4d), 3.807 (t, 1 H, ^3J 9.7 Hz, H-4b or H-4d), 3.89 (br t, 2 H, ^3J 6.6 Hz, H-5c,5e), 3.98–4.19 (m, 6 H, H-6b,6c,6c,6d,6e,6e), 4.50 (d, 1 H, ^3J 8.1 Hz, H-1c or H-1e), 4.51 (d, 1 H, ^3J 7.9 Hz, H-1b or H-1d), 4.54 (d, 1 H, ^3J 8.0 Hz, H-1c or

H-1e), 4.53–4.58 (m, 1 H, H-6b or H-6d), 4.59 (d, 1 H, ^3J 7.8 Hz, H-1b or H-1d), 4.71 (dd, 1 H, J_{gem} 12.3, ^3J 1.7 Hz, H-6b or H-6d), 4.861 (dd, 1 H, ^3J 9.2, ^3J 8.0 Hz, H-2b or H-2d), 4.896 (dd, 1 H, ^3J 9.5, ^3J 8.1 Hz, H-2b or H-2d), 4.971 (dd, 1 H, ^3J 10.5, ^3J 3.1 Hz, H-3c or H-3e), 4.978 (dd, 1 H, ^3J 10.4, ^3J 2.9 Hz, H-3c or H-3e), 5.09–5.14 (m, 2 H, H-2c,2e), 5.188 (t, 1 H, ^3J 9.3 Hz, H-3b or H-3d), 5.191 (t, 1 H, ^3J 9.5 Hz, H-3b or H-3d), and 5.35 (m, 2 H, H-4c,4e).

Anal. Calc. for $C_{58}H_{80}O_{40}$: C, 49.15; H, 5.69. Found: C, 49.12; H, 5.72.

2,6-Di-O-β-lactosyl-α,β-D-mannopyranoses (**9**). — To a solution of **8** (0.088 g, 0.062 mmol) in absolute methanol (15 mL) was added 0.1M sodium methoxide in methanol (5 mL), and the solution was stirred at room temperature for 0.5 h. A second aliquot of 0.1M sodium methoxide in methanol (2.0 mL) was added, and stirring was continued for 2.5 h. The reaction solution was treated with Amberlite IR-120 (H^+) resin (5 mL) for 20 min. The resin was removed by filtration and washed with methanol (25 mL). The combined filtrate and wash solution was concentrated, and the residue was dried under vacuum to give **9** (50.5 mg, 97%) as a glassy solid.

2-O-Acetyl-6-O-(2,3,6,2',3',4',6'-hepta-O-acetyl-β-lactosyl)-α,β-D-mannopyranoses (**10**). — A suspension of 10% (w/w) palladium-on-carbon (1.7 g) in methanol (40 mL) (Caution! Fire hazard.) containing 10% (v/v) formic acid[44] was added to a solution of **7** (0.272 g, 0.245 mmol) in methanol (25 mL), and the mixture was stirred for 27 h at room temperature. The product mixture was obtained in the manner described above for the preparation of **8** and was resolved by column chromatography to afford **10** (85 mg, 41%) as a white solid: R_F 0.38 (solvent *F*); ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.98 (s, 3 H, OAc), 2.051 (s, 3 H, OAc), 2.055 (s, 6 H, 2 OAc), 2.07 (s, 3 H, OAc), 2.14 (s, 3 H, OAc), 2.15 (s, 3 H, OAc), 2.16 (s, 3 H, OAc), 2.42 (br d, 1 H, ^3J 5.2 Hz, OH-3a), 2.72 (br d, 1 H, ^3J 3.3 Hz, OH-4a), 3.60–3.66 (m, 2 H, H-4a,5b), 3.71 (d, 1 H, ^3J 3.6 Hz, OH-1a), 3.81 (t, 1 H, ^3J 9.5 Hz, H-4b), 3.83 (dd, 1 H, J_{gem} 11.2, $J_{6a,5a}$ 6.0 Hz, H-6a), 3.89 (br t, 1 H, ^3J 6.8 Hz, H-5c), 3.97–4.10 (m, 5 H, H-3a,5a,6a,6b,6c), 4.15 (dd, 1 H, J_{gem} 11.1, $J_{6c,5c}$ 6.3 Hz, H-6c), 4.52 (d, 1 H, $J_{1c,2c}$ 8.1 Hz, H-1c), 4.62 (d, 1 H, $J_{1b,2b}$ 7.8 Hz, H-1b), 4.65 (dd, 1 H, J_{gem} 12.4, $J_{6b,5b}$ 2.1 Hz, H-6b), 4.91 (dd, 1 H, $J_{2b,3b}$ 9.3, $J_{2b,1b}$ 7.8 Hz, H-2b), 4.97 (dd, 1 H, $J_{3c,2c}$ 10.3, $J_{3c,4c}$ 3.3 Hz, H-3c), 5.11 (m, 1 H, H-2a), 5.11 (dd, 1 H, $J_{2c,3c}$ 10.3, $J_{2c,1c}$ 8.1 Hz, H-2c), 5.21 (t, 1 H, ^3J 9.3 Hz, H-3a), 5.22 (dd, 1 H, $J_{1a,2a}$ 1.2, ^3J 3.6 Hz, H-1a), and 5.35 (br d, 1 H, ^3J 3.3 Hz, H-4c).

Anal. Calc. for $C_{34}H_{48}O_{24}$: C, 48.57; H, 5.75. Found: C, 48.50; H, 5.80.

6-O-β-Lactosyl-α,β-D-mannopyranoses (**11**). — *O*-Deacetylation of **10** (0.0675 g, 0.080 mmol), in the manner described for the preparation of **9**, gave **11** (39 mg, 96%) as a light-yellow, glassy solid; ^{1}H-n.m.r. (400 MHz, Me_2SO-d_6): δ 3.00–4.28 (multiplets, 20 H, CH_2 and CH), 4.44–5.12 (multiplets, 10 H, 10 OH), 4.85 (br d, 1 H, ^3J 4.4 Hz, H-1a), 6.26 (d, ^3J 6.6 Hz, OH-1a), and 6.35 (d, ^3J 4.4 Hz, OH-1a). The signals at δ 6.26 and 6.35, and those in the range δ 4.44–5.12, except for the H-1a signal, were extinguished in the presence of D_2O. The ratio of the area-integrals of the signals at δ 6.26 and 6.35 was 1:4.

3,6,2',3',4',6'-Hexa-O-acetyl-α-lactose 1,2-[(3,6,2',3',4',6'-hexa-O-acetyl-α-lactose 1,2-(benzyl 3,4-di-O-benzyl-α-D-mannopyranosid-6-yl orthoacetyl)-2-yl) orthoacetate] (**12**) *and 3,6,2',3',4',6'-hexa-O-acetyl-α-lactose 1,2-(benzyl 2-O-acetyl-3,4-di-O-*

benzyl-α-D-mannopyranosid-6-yl orthoacetate) (**14**). — A solution of **4** (5.29 g, 7.56 mmol) in dichloromethane (15 mL) was added, dropwise, during 15 min, to a mixture of **3** (0.85 g, 1.9 mmol), 2,4,6-trimethylpyridine (1.06 g, 8.75 mmol), and silver(I) trifluoromethanesulfonate (1.91 g, 7.55 mmol) in dichloromethane (15 mL) which had been cooled to −40°. The cooling bath was removed, and the mixture was stirred at room temperature overnight. Pyridine (2 mL) was added, the mixture was filtered, and the residue was washed with dichloromethane (40 mL). The combined filtrate and wash solution was evaporated to dryness, and the residual mixture was separated by column chromatography into three fractions having R_F 0.56, 0.44, and 0.29 (solvent *B*). Examination of the fractions having R_F 0.56 and 0.29, using ^{1}H-n.m.r. spectroscopy (60 MHz), indicated that no aromatic protons were present, and the fractions were discarded. The fraction having R_F 0.44 was resolved by column chromatography (solvent *A*) into two components having R_F 0.20 and 0.26, corresponding to **12** and 3,6,2',3',4',6'-hexa-*O*-acetyl-α-lactose 1,2-(benzyl 3,4-di-*O*-benzyl-α-D-mannopyranosid-6-yl orthoacetate) (**13**), respectively. The difference in R_F values was insufficient for preparative separation of **12** and **13** using solvent *A*. The mixture of **12** and **13** was, therefore, treated with acetic anhydride (10 mL) in pyridine (30 mL) in the manner described above for the preparation of **5** and **7**. This reaction afforded a mixture of **12** and **14**, having R_F 0.23 and 0.49 (solvent *A*), respectively, which was partially resolved by column chromatography. ^{1}H-N.m.r. spectroscopy of **12** and **14** indicated the presence of small amounts of impurities after column chromatography. Compound **12** (1.518 g, 48%): ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.64 (s, 3 H, Me), 1.71 (s, 3 H, Me), 1.98 (s, 6 H, 2 OAc), 2.027 (s, 3 H, OAc), 2.037 (s, 3 H, OAc), 2.056 (s, 3 H, OAc), 2.069 (s, 3 H, OAc), 2.096 (s, 3 H, OAc), 2.103 (s, 3 H, OAc), 2.110 (s, 3 H, OAc), 2.119 (s, 3 H, OAc), 2.16 (s, 3 H, OAc), 2.18 (s, 3 H, OAc), 3.57 (m, 1 H, $J_{4d,5d}$ 9.6 Hz, H-4d), 3.65 (m, 1 H, $J_{4b,5b}$ 9.5 Hz, H-4b), 3.65–3.74 (m, 3 H, H-5a,6a,6a), 3.767 (ddd, 1 H, $J_{5d,4d}$ 9.6, $J_{5d,6d}$ 5.7, $J_{5d,6d}$ 2.4 Hz, H-5d), 3.778 (t, 1 H, *J* 9.6 Hz, H-4a), 3.87 (ddd, 1 H, $J_{5b,4b}$ 9.5, $J_{5b,6b}$ 5.6, $J_{5b,6b}$ 2.3 Hz, H-5b), 3.93 (dd, 1 H, $J_{3a,4a}$ 9.6, $J_{3a,2a}$ 3.1 Hz, H-3a), 3.93–3.98 (m, 2 H, H-5c,5e), 4.061 (dd, 1 H, J_{gem} 12.2, $J_{6d,5d}$ 5.7 Hz, H-6d), 4.064 (dd, 1 H, $J_{2a,3a}$ 3.1, $J_{2a,1a}$ 2.0 Hz, H-2a), 4.117 (dd, 1 H, J_{gem} 12.1, $J_{6b,5b}$ 5.6 Hz, H-6b), 4.10–4.18 (m, 4 H, H-6c,6c,6e,6e), 4.21 (dd, 1 H, J_{gem} 12.2, $J_{6d,5d}$ 2.4 Hz, H-6d), 4.25 (dd, 1 H, J_{gem} 12.1, $J_{6b,5b}$ 2.3 Hz, H-6b), 4.364 (ddd, 1 H, $J_{2d,1d}$ 5.1, $J_{2d,3d}$ 2.7, $^4J_{2d,4d}$ 1.0 Hz, H-2d), 4.397 (ddd, 1 H, $J_{2b,1b}$ 5.2, $J_{2b,3b}$ 2.7, $^4J_{2b,4b}$ 1.1 Hz, H-2b), 4.46 (d, 1 H, J_{gem} 11.7 Hz, coupled to H having signal at δ 4.69, CH_2Ph), 4.594 (d, 1 H, $J_{1e,2e}$ 8.0 Hz, H-1e), 4.600 (d, 1 H, J_{gem} 10.8 Hz, coupled to H at δ 4.879, CH_2Ph), 4.65 (d, 1 H, $J_{1c,2c}$ 8.0 Hz, H-1c), 4.69 (d, 2 H, J_{gem} 12.0 Hz, CH_2Ph), 4.73 (d, 1 H, J_{gem} 11.6 Hz, coupled to H at δ 4.69, CH_2Ph), 4.84 (d, 1 H, $J_{1a,2a}$ 2.0 Hz, H-1a), 4.879 (d, 1 H, J_{gem} 10.8 Hz, CH_2Ph), 5.002 (dd, 1 H, $J_{3e,2e}$ 10.4, $J_{3e,4e}$ 3.4 Hz, H-3e), 5.017 (dd, 1 H, $J_{3c,2c}$ 10.4, $J_{3c,4c}$ 3.5 Hz, H-3c), 5.157 (dd, 1 H, $J_{2e,3e}$ 10.4, $J_{2e,1e}$ 8.0 Hz, H-2e), 5.190 (dd, 1 H, $J_{2c,3c}$ 10.4, $J_{2c,1c}$ 8.0 Hz, H-2c), 5.379 (dd, 1 H, ^3J 3.5, ^3J 0.9 Hz, H-4c or H-4e), 5.389 (dd, 1 H, ^3J 3.5, ^3J 1.2 Hz, H-4c or H-4e), 5.46 (dd, 1 H, $J_{3d,2d}$ 2.7, $J_{3d,4d}$ 1.1 Hz, H-3d), 5.55 (dd, 1 H, $J_{3b,2b}$ 2.7, $J_{3b,4b}$ 1.1 Hz, H-3b), 5.58 (d, 1 H, $J_{1d,2d}$ 5.1 Hz, H-1d), 5.66 (d, 1 H, $J_{1b,2b}$ 5.2 Hz, H-1b), and 7.14–7.40 (m, 15 H, 3 Ph).

Compound **14** (0.396 g, 19%): ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.73 (s, 3 H, Me), 1.98 (s, 3 H, Me), 2.03 (s, 3H, OAc), 2.058 (s, 3 H, OAc), 2.066 (s, 3 H, OAc), 2.121 (s, 3 H, OAc), 2.128 (s, 3 H, OAc), 2.16 (s, 3 H, OAc), 3.64 (m, 1 H, $J_{4b,5b}$ 9.6 Hz, H-4b), 3.67–3.84 (m, 4 H, H-4a,5a,6a,6a), 3.87 (ddd, 1 H, $J_{5b,4b}$ 9.6, $J_{5b,6b}$ 5.5, $J_{5b,6b}$ 2.4 Hz, H-5b), 3.94 (t of d, 1 H, $J_{5c,6c}$ 6.7, $J_{5c,4c}$ 0.9 Hz, H-5c), 4.01 (dd, 1 H, $J_{3a,4a}$ 8.8, $J_{3a,2a}$ 3.4 Hz, H-3a), 4.12 (dd, 1 H, J_{gem} 12.0, $J_{6b,5b}$ 5.5 Hz, H-6b), 4.1–4.2 (m, 2 H, H-6c,6c), 4.26 (dd, 1 H, J_{gem} 12.0, $J_{6b,5b}$ 2.4 Hz, H-6b), 4.36 (ddd, 1 H, $J_{2b,1b}$ 5.3, $J_{2b,3b}$ 2.7, $^4J_{2b,4b}$ 1.0 Hz, H-2b), 4.46 (d, 1 H, J_{gem} 11.9 Hz, coupled to H at δ 4.67, CH_2Ph), 4.52 (d, 1 H, J_{gem} 11.1 Hz, coupled to H at δ 4.69, CH_2Ph), 4.58 (d, 1 H, J_{gem} 11.0 Hz, coupled to H at δ4.91, CH_2Ph), 4.61 (d, 1 H, $J_{1c,2c}$ 8.0 Hz, H-1c), 4.67 (d, 1 H, J_{gem} 11.9 Hz, CH_2Ph), 4.69 (d, 1 H, J_{gem} 11.1 Hz, CH_2Ph), 4.86 (d, 1 H, $J_{1a,2a}$ 1.8 Hz, H-1a), 4.91 (d, 1 H, J_{gem} 11.0 Hz, CH_2Ph), 5.01 (dd, 1 H, $J_{3c,2c}$ 10.6, $J_{3c,4c}$ 3.5 Hz, H-3c), 5.19 (dd, 1 H, $J_{2c,3c}$ 10.6, $J_{2c,1c}$ 8.0 Hz, H-2c), 5.383 (dd, 1 H, $J_{4c,3c}$ 3.5, $J_{4c,5c}$ 0.9 Hz, H-4c), 5.397 (dd, 1 H, $J_{2a,3a}$ 3.4, $J_{2a,1a}$ 1.8 Hz, H-2a), 5.52 (dd, 1 H, $J_{3b,2b}$ 2.7, $J_{3b,4b}$ 1.4 Hz, H-3b), 5.65 (d, 1 H, $J_{1b,2b}$ 5.3 Hz, H-1b), and 7.16–7.40 (m, 15 H, 3 Ph).

3,6,2′,3′,4′,6′-Hexa-O-*acetyl-1,2*-O-*(ethyl orthoacetyl)*-α-*lactose* (**15**). — Absolute ethanol (2.4 mL, 41 mmol) was added to a suspension of **4** (23.2 g, 33.2 mmol) and tetrabutylammonium bromide (3.506 g, 10.9 mmol) in 2,4,6-trimethylpyridine (130 mL), and the mixture was heated for 10 h at 50°, with manual shaking during the initial 15 min. The reaction product mixture was filtered, and the residue was washed with dichloromethane (50 mL). The combined filtrate and wash solution was evaporated, and the residual mixture was resolved by column chromatography to give **15** (17.9 g, 81%) as a colorless, glassy solid: R_F 0.41 (solvent *A*); ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.18 (t, 3 H, ^3J 7.1 Hz, CH_3CH$_2$), 1.72 (s, 3 H, Me), 1.98 (s, 3 H, OAc), 2.04 (s, 3 H, OAc), 2.07 (s, 3 H, OAc), 2.12 (s, 6 H, 2 OAc), 2.17 (s, 3 H, OAc), 3.55 (q, 2 H, ^3J 7.1 Hz, CH$_3$CH_2), 3.66 (m, 1 H, $J_{4,5}$ 9.5 Hz, H-4), 3.86 (ddd, 1 H, $J_{5,4}$ 9.5, $J_{5,6}$ 5.7, $J_{5,6}$ 2.1 Hz, H-5), 3.95 (m, 1 H, $J_{5',6'}$ 6.7, $J_{5',4'}$ 1.0 Hz, H-5′), 4.10–4.17 (m, 3 H, H-6,6′,6′), 4.25 (dd, 1 H, J_{gem} 12.0, $J_{6,5}$ 2.1 Hz, H-6), 4.31 (ddd, 1 H, $J_{2,1}$ 5.0, $J_{2,3}$ 2.6, $^4J_{2,4}$ 1.0 Hz, H-2), 4.62 (d, 1 H, $J_{1',2'}$ 8.0 Hz, H-1′), 5.01 (dd, 1 H, $J_{3',2'}$ 10.3, $J_{3',4'}$ 3.4 Hz, H-3′), 5.19 (dd, 1 H, $J_{2',3'}$ 10.3, $J_{2',1'}$ 8.0 Hz, H-2′), 5.38 (m, 1 H, $J_{4',3'}$ 3.4, $J_{4',5'}$ 1.0 Hz, H-4′), 5.54 (dd, 1 H, $J_{3,2}$ 2.6, $J_{3,4}$ 1.0 Hz, H-3), and 5.66 (d, 1 H, $J_{1,2}$ 5.0 Hz, H-1).

3,6,2′,3′,4′,6′-Hexa-O-*acetyl-1,2*-O-*(benzyl orthoacetyl)*-α-*lactose* (**16**). — Benzyl alcohol (2.8 g, 26 mmol) was added to a suspension of **4** (14.3 g, 20.4 mmol) and tetrabutylammonium bromide (2.25 g, 7.0 mmol) in 2,4,6-trimethylpyridine (80 mL). The mixture was treated in the manner described above for the preparation of **15**. Column chromatography of the product mixture gave **16** (11.79 g, 80%) as a colorless, glassy solid: R_F 0.48 (solvent *A*); $[\alpha]_D^{24}$ −0.4° (*c* 2.15, chloroform); ^{1}H-n.m.r. (200 MHz, $CDCl_3$): δ 1.80 (s, 3 H, Me), 1.98 (s, 3 H, OAc), 2.04 (s, 3 H, OAc), 2.07 (s, 3 H, OAc), 2.105 (s, 3 H, OAc), 2.12 (s, 3 H, OAc), 2.18 (s, 3 H, OAc), 3.64 (m, 1 H, H-4), 3.87 (ddd, 1 H, $J_{5,4}$ 9.8, $J_{5,6}$ 5.6, $J_{5,6}$ 2.4 Hz, H-5), 3.94 (m, 1 H, H-5′), 4.07–4.18 (m, 3 H, H-6,6′,6′), 4.26 (dd, 1 H, J_{gem} 12.2, $J_{6,5}$ 2.4 Hz, H-6), 4.32 (ddd, 1 H, $J_{2,1}$ 5.2, $J_{2,3}$ 2.7, $^4J_{2,4}$ 1.0 Hz, H-2), 4.57 (s, 2 H, CH_2Ph), 4.62 (d, 1 H, $J_{1',2'}$ 8.0 Hz, H-1′), 5.01 (dd, 1 H, $J_{3',2'}$ 10.4, $J_{3',4'}$ 3.4 Hz, H-3′), 5.20 (dd, 1 H, $J_{2',3'}$ 10.4, $J_{2',1'}$ 8.0 Hz, H-2′), 5.39 (dd, 1 H, $J_{4',3'}$ 3.4, $J_{4',5'}$ 0.8 Hz, H-4′), 5.56 (dd, 1 H, $J_{3,2}$ 2.7, $J_{3,4}$ 1.2 Hz, H-3), 5.63 (d, 1 H, $J_{1,2}$ 5.2 Hz, H-1), and 7.25–7.43 (m, 5 H, Ph).

Anal. Calc. for $C_{33}H_{42}O_{18}$: C, 54.54; H, 5.83. Found: C, 54.61; H, 5.66.

1,3,6,2',3',4',6'-Hepta-O-*acetyl-α-lactose* (**17**) *and 2,3,6,2',3',4',6'-hepta*-O-*acetyl-α-* (**18**) *and β-lactose* (**19**). — A solution of **15** (2.11 g, 3.17 mmol) in 88% (v/v) formic acid (15 mL) was kept at room temperature for 15 min and evaporated to dryness to give a glassy solid, which was shown by t.l.c. (solvent *C*) to consist of two components having R_F 0.34 and 0.41, corresponding to the R_F values of **17** and a mixture of **18** and **19**, respectively. ^{1}H-N.m.r. spectroscopy indicated that **17** and the mixture of **18** and **19** were present in appproximately equimolar amounts. The separation of **17** from **18** and **19** by column chromatography afforded each fraction as a glassy solid. ^{1}H-N.m.r. spectroscopy indicated that **18** and **19** were present in the mixture in an approximate mass ratio of 2:1, respectively. The spectrum of the mixture of **18** and **19** could be correlated closely with those of **18** and **19**, which were prepared by *O*-debenzylation of **20** (see below).

Compound **17**: ^{1}H-n.m.r. (200 MHz, $CDCl_3$): δ 1.97 (s, 3 H, OAc), 2.060 (s, 3 H, OAc), 2.065 (s, 3 H, OAc), 2.11 (s, 3 H, OAc), 2.15 (s, 3 H, OAc), 2.16 (s, 3 H, OAc), 2.20 (s, 3 H, OAc), 3.73 (m, 1 H, H-2), 3.75 (m, 1 H, H-4), 3.87 (m, 1 H, H-5'), 3.92 (ddd, 1 H, $J_{5,4}$ 10.4, $J_{5,6}$ 4.5, $J_{5,6}$ 2.0 Hz, H-5), 4.07 (dd, 1 H, J_{gem} 11.0, $J_{6',5'}$ 7.2 Hz, H-6'), 4.12 (dd, 1 H, J_{gem} 12.3, $J_{6,5}$ 4.5 Hz, H-6), 4.19 (dd, 1 H, J_{gem} 11.0, $J_{6',5'}$ 6.1 Hz, H-6'), 4.38 (dd, 1 H, J_{gem} 12.3, $J_{6,5}$ 2.0 Hz, H-6), 4.51 (d, 1 H, $J_{1',2'}$ 7.8 Hz, H-1'), 4.96 (dd, 1 H, $J_{3',2'}$ 10.4, $J_{3',4'}$ 3.4 Hz, H-3'), 5.14 (dd, 1 H, $J_{2',3'}$ 10.4, $J_{2',1'}$ 7.8 Hz, H-2'), 5.26 (dd, 1 H, ^3J 10.0, ^3J 9.2 Hz, H-3), 5.37 (dd, 1 H, $J_{4',3'}$ 3.4, $J_{4',5'}$ 0.9 Hz, H-4'), and 6.17 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1).

When stored at room tempereature, the composition of the above-cited mixture of **17**, **18**, and **19** changes so that, after 2.5 months, it consists of ~90% **18** and **19**, as shown by t.l.c. and by ^{1}H-n.m.r. spectroscopy. Hydrolysis of **16**, using 95% acetic acid, also provides **17**, and **18** and **19**, in an ~1:1 ratio, based on t.l.c. data.

Preparation of benzyl 2,3,6,2',3',4',6'-hepta-O-*acetyl-α-lactoside* (**20**) *and benzyl 2,3,6,2',3',4',6'-hepta*-O-*acetyl-β-lactoside* (**21**) *from a mixture of* **17** *and* **18** *and* **19**. — An ~1:1 mixture (10.15 g, 16.0 mmol, theoretical) of **17** and **18** and **19**, was dissolved in *N*,*N*-dimethylformamide (DMF) (100 mL) and reduced in volume to 80 mL by high-vacuum distillation of the solvent at room temperature. Benzyl bromide (11.1 g, 65 mmol) was added, and the solution was cooled in an ice-water bath. Silver(I) oxide (10.0 g, 43.2 mmol) was added in small portions, and the mixture was stirred at the bath temperature for 1.5 h and at room temperature for 6 h. The mixture was filtered, and the residue was washed sequentially with DMF (50 mL) and dichloromethane (50 mL). To the combined filtrate and wash solution was added 0.2M potassium cyanide (500 mL), and the mixture was stirred for 10 min. The aqueous phase was separated and extracted with dichloromethane (3 × 50 mL).The combined organic phases were washed with water (50 mL) and evaporated to dryness. The residual mixture was found by t.l.c. to contain two major components having R_F 0.42 and 0.48 (solvent *A*), as well as trace amounts of substances having larger R_F values, and a third major component which migrated near the solvent front (R_F ~ 1). The mixture was resolved by column chromatography to give **20** (4.55 g, 39%) as a solid foam: R_F 0.42; $[\alpha]_D^{25}$ +78° (*c* 2.30, chloroform); ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.97 (s, 3 H, OAc), 2.02 (s, 3 H, OAc),

2.040 (s, 3 H, OAc), 2.048 (s, 3 H, OAc), 2.056 (s, 3 H, OAc), 2.14 (s, 3 H, OAc), 2.16 (s, 3 H, OAc), 3.75 (m, 1 H, $J_{4,5}$ 10.0, $J_{4,3}$ 9.2 Hz, H-4), 3.85 (m, 1 H, H-5'), 3.94 (ddd, 1 H, $J_{5,4}$ 10.0, $J_{5,6}$ 4.3, $J_{5,6}$ 2.0 Hz, H-5), 4.07 (dd, 1 H, J_{gem} 11.0, $J_{6',5'}$ 7.3 Hz, H-6'), 4.11 (dd, 1 H, J_{gem} 11.9, $J_{6,5}$ 4.3 Hz, H-6), 4.13 (dd, 1 H, J_{gem} 11.0, $J_{6',5'}$ 6.3 Hz, H-6'), 4.38 (dd, 1 H, J_{gem} 11.9, $J_{6,5}$ 2.0 Hz, H-6), 4.47 (d, 1 H, $J_{1',2'}$ 7.9 Hz, H-1'), 4.53 (d, 1 H, J_{gem} 12.4 Hz, CH_2Ph), 4.72 (d, 1 H, J_{gem} 12.4 Hz, CH_2Ph), 4.80 (dd, 1 H, $J_{2,3}$ 10.2, $J_{2,1}$ 3.7 Hz, H-2), 4.94 (dd, 1 H, $J_{3',2'}$ 10.3, $J_{3',4'}$ 3.4 Hz, H-3'), 5.03 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1) 5.12 (dd, 1 H, $J_{2',3'}$ 10.3, $J_{2',1'}$ 7.9 Hz, H-2'), 5.35 (dd, 1 H, $J_{4',3'}$ 3.4, $J_{4',5'}$ 0.7 Hz, H-4'), 5.53 (dd, 1 H, $J_{3,2}$ 10.2, $J_{3,4}$ 9.2 Hz, H-3), and 7.29–7.43 (m, 5 H, Ph).

Compound **21** (2.70 g, 23%) was obtained as a crystalline solid from ethanol: m.p. 144–146°; R_F 0.48; $[\alpha]_D^{23}$ −36° (*c* 2.10, chloroform); ^{1}H-n.m.r. (400 MHz; $CDCl_3$): δ 1.96 (s, 3 H, OAc), 2.01 (s, 3 H, OAc), 2.039 (s, 3 H, OAc), 2.046 (s, 3 H, OAc), 2.053 (s, 3 H, OAc), 2.143 (s, 3 H, OAc), 2.147 (s, 3 H, OAc), 3.58 (ddd, 1 H, $J_{5,4}$ 9.7, $J_{5,6}$ 4.9, $J_{5,6}$ 2.0 Hz, H-5), 3.82 (m, 1 H, $J_{4,5}$ 9.7, $J_{4,3}$ 9.2 Hz, H-4), 3.87 (m, 1 H, H-5'), 4.08 (dd, 1 H, J_{gem} 11.1, $J_{6',5'}$ 7.3 Hz, H-6'), 4.11 (dd, 1 H, J_{gem} 11.9, $J_{6,5}$ 4.9 Hz, H-6), 4.13 (dd, 1 H, J_{gem} 11.1, $J_{6',5'}$ 6.5 Hz, H-6'), 4.48 (d, 1 H, $J_{1',2'}$ 7.9 Hz, H-1'), 4.51 (d, 1 H, $J_{1,2}$ 7.8 Hz, H-1), 4.52 (dd, 1 H, J_{gem} 11.9, $J_{6,5}$ 2.0 Hz, H-6), 4.60 (d, 1 H, J_{gem} 12.3 Hz, CH_2Ph), 4.86 (d, 1 H, J_{gem} 12.3 Hz, CH_2Ph), 4.95 (dd, 1 H, $J_{3',2'}$ 10.4, $J_{3',4'}$ 3.7 Hz, H-3'), 4.97 (dd, 1 H, $J_{2,3}$ 9.4, $J_{2,1}$ 7.8 Hz, H-2), 5.11 (dd, 1 H, $J_{2',3'}$ 10.4, $J_{2',1'}$ 7.9 Hz, H-2'), 5.16 (t, 1 H, ^3J 9.2 Hz, H-3), 5.35 (dd, 1 H, $J_{4',3'}$ 3.7, $J_{4',5'}$ 0.9 Hz, H-4'), and 7.24–7.41 (m, 5 H, Ph).

Preparation of **21** *from* **4**. — A mixture of **4** (1.93 g, 2.76 mmol), benzyl alcohol (0.407 g, 3.76 mmol), and mercury(II) cyanide (1.074 g, 4.25 mmol) in 1:1 (v/v) benzene–nitromethane (10 mL)[23] was stirred for 4 h at 40°, diluted with toluene (20 mL), and washed sequentially with a sat. aq. solution of sodium hydrogencarbonate (2 × 20 mL) and water (20 mL). The organic phase was evaporated to dryness, and the residual mixture was resolved by column chromatography (solvent *A*) to give **21** (0.857 g, 43%) which, after recrystallization from ethanol, had physical properties indistinguishable from those of the sample of **21** prepared from the mixture of **17** and **18** and **19**.

Anal. Calc. for $C_{33}H_{42}O_{18}$: C, 54.54; H, 5.83. Found: C, 54.62; H, 5.90.

O-*Debenzylation of* **20**. — A suspension of 10% (w/w) palladium-on-carbon (2.0 g) in methanol (15 mL) (Caution! Fire hazard.) was added to a solution of **20** (2.037 g, 2.80 mmol) in methanol (80 mL) containing 10% (v/v) formic acid, and the mixture was shaken (60 c.p.m.) under hydrogen (60 p.s.i.g.) for 26 h at room temperature. An additional 1-g portion of catalyst slurried in methanol (10 mL) (Caution! Extremely dangerous fire hazard at this point.) was added at 3, 7, and 20 h of reaction time. The mixture was filtered, and the residue was washed with methanol (80 mL). The combined filtrate and wash solution was evaporated to dryness. Examination of the residue by t.l.c. indicated the presence of two fractions having R_F 0.44 and 0.59 (solvent *D*). The more mobile fraction was shown by ^{1}H-n.m.r. spectroscopy to be **20** (0.140 g, 6.6%). The fraction having R_F 0.44 was found by ^{1}H-n.m.r. spectroscopy to consist of **18** and **19** (1.109 g, 62%) in a ratio of ~2:1, respectively.

Compound **18**: ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.97 (s, 3 H, OAc), 2.05 (s, 3 H, OAc), 2.060 (s, 3 H, OAc), 2.064 (s, 3 H, OAc), 2.08 (s, 3H, OAc), 2.136 (s, 3 H, OAc),

2.16 (s, 3 H, OAc), 3.29 (br d, 1 H, ^3J 3.4 Hz, OH), 3.77 (t, 1 H, ^3J 9.5 Hz, H-4), 3.88 (m, 1 H, H-5'), 4.05–4.21 (m, 4 H, H-5,6,6',6'), 4.47–4.53 (m, 2 H, H-1',6), 4.83 (dd, 1 H, $J_{2,3}$ 10.2, $J_{2,1}$ 3.4 Hz, H-2), 4.966 (dd, 1 H, $J_{3',2'}$ 10.4, $J_{3',4'}$ 3.3 Hz, H-3'), 5.12 (dd, 1 H, $J_{2',3'}$ 10.4, $J_{2',1'}$ 8.0 Hz, H-2'), 5.36 (br d, 1 H, $J_{4',3'}$ 3.3, Hz, H-4'), 5.38 (t, 1 H, ^3J 3.4 Hz, H-1), and 5.53 (dd, 1 H, $J_{3,2}$ 10.2, $J_{3,4}$ 9.5 Hz, H-3).

Compound **19**: ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.97 (s, 3 H, OAc), 2.05 (s, 3 H, OAc), 2.060 (s, 3 H, OAc), 2.064 (s, 3 H, OAc), 2.08 (s, 3 H, OAc), 2.133 (s, 3 H, OAc), 2.16 (s, 3 H, OAc), 3.65 (ddd, 1 H, $J_{5,4}$ 10.1, $J_{5,6}$ 4.9, $J_{5,6}$ 1.8 Hz, H-5), 3.67 (d, 1 H, ^3J 7.9 Hz, OH), 3.79 (m, 1 H, H-4), 3.88 (m, 1 H, H-5'), 4.05–4.21 (m, 3 H, H-6,6',6'), 4.47–4.53 (m, 2 H, H-1',6), 4.73 (t, 1 H, ^3J 7.9 Hz, H-1), 4.80 (m, 1 H, H-2), 4.961 (dd, 1 H, $J_{3',2'}$ 10.3, $J_{3',4'}$ 3.3 Hz, H-3'), 5.11 (dd, 1 H, $J_{2',3'}$ 10.3, $J_{2',1'}$ 7.8 Hz, H-2'), 5.24 (t, 1 H, ^3J 9.3 Hz, H-3), and 5.36 (br d, 1 H, $J_{4',3'}$ 3.3 Hz, H-4').

1,2,3,6,2',3',4',6'-Octa-O-acetyl-α-lactose (**22**). — The anomeric mixture of octa-*O*-acetyllactoses, which was prepared by the isomerization of crystalline octa-*O*-acetyl-β-lactose[15,52] in the presence of zinc(II) chloride[52], was resolved by column chromatography (solvent *A*) to give **22**: $[\alpha]_D^{22}$ +51° (*c* 1.08, chloroform), lit.[52] $[\alpha]_D^{20}$ +53° (chloroform); ^{1}H-n.m.r. (400 MHz, $CDCl_3$): δ 1.97 (s, 3 H, OAc), 2.02 (s, 3 H, OAc), 2.066 (s, 3 H, OAc), 2.071 (s, 3 H, OAc), 2.075 (s, 3 H, OAc), 2.14 (s, 3 H, OAc), 2.17 (s, 3 H, OAc), 2.19 (s, 3 H, OAc), 3.82 (t, 1 H, ^3J 9.7 Hz, H-4), 3.89 (br t, 1 H, ^3J 6.8 Hz, H-5'), 4.02 (ddd, 1 H, $J_{5,4}$ 10.1, $J_{5,6}$ 3.6, $J_{5,6}$ 1.9 Hz, H-5), 4.10 (dd, 1 H, J_{gem} 11.0, $J_{6',5'}$ 7.2 Hz, H-6'), 4.13 (dd, 1 H, J_{gem} 12.0, $J_{6,5}$ 3.6 Hz, H-6), 4.17 (dd, 1 H, J_{gem} 11.0, $J_{6',5'}$ 6.1 Hz, H-6'), 4.46 (dd, 1 H, J_{gem} 12.0, $J_{6,5}$ 1.9 Hz, H-6), 4.49 (d, 1 H, $J_{1',2'}$ 7.9 Hz, H-1'), 4.96 (dd, 1 H, $J_{3',2'}$ 10.4, $J_{3',4'}$ 3.3 Hz, H-3'), 5.01 (dd, 1 H, $J_{2,3}$ 10.2, $J_{2,1}$ 3.7 Hz, H-2), 5.13 (dd, 1 H, $J_{2',3'}$ 10.4, $J_{2',1'}$ 7.9 Hz, H-2'), 5.36 (dd, 1 H, $J_{4',3'}$ 3.3, $J_{4',5'}$ 0.8 Hz, H-4'), 5.47 (dd, 1 H, $J_{3,2}$ 10.2, $J_{3,4}$ 9.0 Hz, H-3), and 6.26 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1).

ACKNOWLEDGMENTS

The authors thank the Natural Sciences and Engineering Research Council Canada for partial support of the research in the form of a grant (to W.A.S.).

REFERENCES

1 J. Montreuil, *Adv. Carbohydr. Chem. Biochem.*, 37 (1980) 157–223, and references cited therein.
2 T. Ogawa, K. Katano, K. Sasajima, and M. Matsui, *Tetrahedron*, 37 (1981) 2779–2786.
3 T. Ogawa and K. Sasajima, *Tetrahedron*, 37 (1981) 2787–2792.
4 T. Ogawa and H. Yamamoto, *Carbohydr. Res.*, 137 (1985) 79–88.
5 J. Arnarp, M. Haraldsson, and J. Lönngren, *Carbohydr. Res.*, 97 (1981) 307–313.
6 J. Conchie, A. J. Hay, and J. A. Lomax, *Carbohydr. Res.*, 112 (1983) 281–295.
7 R. Bayard, J.-P. Kerckaert, G. Strecker, L. Dorland, H. van Halbeek, and J. F. G. Vliegenthart, *Eur. J. Biochem.*, 137 (1983) 319–323.
8 M. Lowe and B. Nilsson, *J. Biol. Chem.*, 258 (1983) 1885–1887.
9 T. Mizuochi, T. Taniguchi, K. Fujikawa, K. Titani, and A. Kobata, *J. Biol. Chem.*, 258 (1983) 6020–6024.
10 P.-K- Tsai, J. Frevert, and C. E. Ballou, *J. Biol. Chem.*, 259 (1984) 3805–3811.
11 M. Fukuda, A. Dell, J. E. Oates, and M. N. Fukuda, *J. Biol. Chem.*, 259 (1984) 8260–8273.
12 T. Ogawa and T. Nukada, *Carbohydr. Res.*, 136 (1985) 135–152.

13 P. de Waard, J. P. Kamerling, H. van Halbeek, J. F. G. Vliegenthart, and J. J. S. Broertjes, *Eur. J. Biochem.*, 168 (1987) 679–685.
14 J. Montreuil, *Biol. Cell*, 51 (1984) 115–131.
15 L. J. J. Hronowski, W. A. Szarek, G. W. Hay, A. Krebs, and W. T. Depew, *Carbohydr. Res.*, 190 (1989) 203–218.
16 L. J. J. Hronowski, W. A. Szarek, G. W. Hay, A. Krebs, and W. T. Depew, *Carbohydr. Res.*, 193 (1989) 91–103.
17 L. J. J. Hronowski, W. A. Szarek, G. W. Hay, A. Krebs, and W. T. Depew, *Carbohydr. Res.*, 219 (1991) 33–49.
18 J. Arnarp, H. Baumann, H. Lönn, J. Lönngren, H. Nyman, and H. Ottosson, *Acta Chem. Scand.*, B37 (1983) 329–334.
19 J. Alais and A. Veyrières, *Carbohydr. Res.*, 92 (1981) 310–313.
20 J. Arnarp, J. Lönngren, and H. Ottosson, *Carbohydr. Res.*, 98 (1981) 154–156.
21 Y. C. Lee, R. R. Townsend, M. R. Hardy, J. Lönngren, J. Arnarp, M. Haraldsson, and H. Lönn, *J Biol. Chem.*, 258 (1983) 199–202.
22 B. Helferich, A. Doppstadt, and G. A. Gottschlich, *Naturwissenschaften*, 40 (1953) 441–442.
23 B. Helferich and K. Weis, *Chem. Ber.*, 89 (1956) 314–321.
24 R. U. Lemieux and A. R. Morgan, *Can. J. Chem.*, 43 (1965) 2199–2204, and references cited therein.
25 K. Igarashi, *Adv. Carbohydr. Chem. Biochem.*, 34 (1977) 243–283.
26 V. Magnus, D. Vikić-Topić, S. Iskrić, and S. Kveder, *Carbohydr. Res.*, 114 (1983) 209–224.
27 J. Banoub and D. R. Bundle, *Can. J. Chem.*, 57 (1979) 2091–2097.
28 D. S. K. Tsui and P. A. J. Gorin, *Carbohydr. Res.*, 144 (1985) 137–147.
29 J. Banoub, P. Boullanger, M. Potier, and G. Descotes, *Tetrahedron Lett.*, 27 (1986) 4145–4148.
30 A. S. Perlin, *Can. J. Chem.*, 41 (1963) 555–561.
31 N. K. Kochetkov, A. Ya. Khorlin, and A. F. Bochkov, *Tetrahedron Lett.*, (1964) 289–293; *Tetrahedron*, 23 (1967) 693–707.
32 N. K. Kochetkov, A. F. Bochkov, T. A. Sokolovskaya, and V. J. Snyatkova, *Carbohydr. Res.*, 16 (1971) 17–27.
33 L. V. Backinowsky, S. A. Nepogod'ev, A. S. Shashkov, and N. K. Kochetkov, *Carbohydr. Res.*, 138 (1985) 41–54.
34 A. F. Bochkov, V. I. Betanely, and N. K. Kochetkov, *Carbohydr. Res.*, 30 (1973) 418–419; P. J. Garegg and I. Kvarnström, *Acta Chem. Scand.*, B30 (1976) 655–658.
35 L. D. Hall, *Adv. Carbohydr. Chem. Biochem.*, 29 (1974) 11–40; P. A. J. Gorin, *ibid.*, (1981) 13–104; A. S. Perlin and B. Casu, in G. O. Aspinall (Ed.), *The Polysaccharides*, Vol. 1, Academic Press, New York, 1982, pp. 135–172, and references cited therein.
36 A. Bax, R. Freeman, and G. Morris, *J. Magn. Reson.*, 42 (1981) 164–168; R. Benn and H. Günther, *Angew. Chem. Int. Ed. Engl.*, 22 (1983) 350–380; S. L. Patt, *J. Carbohydr. Chem.*, 3 (1984) 493–511.
37 A. Bax, W. Egan, and P. Kováč. *J. Carbohydr. Chem.*, 3 (1984) 593–611.
38 J. F. King and A. D. Allbutt, *Can. J. Chem.*, 48 (1970) 1754–1769.
39 W. E. Dick, Jr., *Carbohydr. Res.*, 21 (1972) 255–268.
40 R. U. Lemieux and H. Driguez, *J. Am. Chem. Soc.*, 97 (1975) 4069–4075, and references cited therein.
41 M. A. E. Shaban, I. E. Ary, D. A. Jeanloz, and R. W. Jeanloz, *Carbohydr. Res.*, 45 (1975) 105–114.
42 A. Lipták, I. Jodál, and P. Nánási, *Carbohydr. Res.*, 44 (1975) 1–11.
43 A. Lipták, P. Fügedi, and P. Nánási, *Carbohydr. Res.*, 51 (1976) c19–c21.
44 V. S. Rao and A. S. Perlin, *Carbohydr. Res.*, 83 (1980) 175–177.
45 A. Thompson and M. L. Wolfrom, *Methods Carbohydr. Chem.*, 2 (1963) 215–220, and references cited therein.
46 M. Haraldsson, (1984), personal communication.
47 R. U. Lemieux, T. Takeda, and B. Y. Chung, in H. S. El Khadem (Ed.), *Synthetic Methods for Carbohydrates, ACS Monogr.*, Washington D.C., 1976, pp. 90–115.
48 D. R. Bundle and S. Josephson, *J. Chem. Soc., Perkin Trans. 1*, (1979) 2736–2739.
49 R. U. Lemieux and J. D. T. Cipera, *Can. J. Chem.*, 34 (1956) 906–910.
50 W. E. Dick and D. Weisleder, *Carbohydr. Res.*, 46 (1976) 173–182.
51 I. Croon and B. Lindberg, *Acta Chem. Scand.*, 13 (1959) 593–594.
52 C. S. Hudson and J. M. Johnson, *J. Am. Chem. Soc.*, 37 (1915) 1270–1275.