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SYNTHETIC RECEPTOR ANALOGUES: PREPARATION OF THE 3-*O*-METHYL, 3-*C*-METHYL, AND 3-DEOXY DERIVATIVES OF METHYL 4-*O*-α-D-GALACTOPYRANOSYL-β-D-GALACTOPYRANOSIDE (METHYL β-D-GALABIOSIDE)

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ABSTRACT

Methyl β-D-galactopyranoside was transformed into methyl 2-*O*-benzyl- (**5**, 24%) and 2-*O*-benzyloxymethyl-4,6-*O*-benzylidene-β-D-galactopyranoside (**8**, 60%) in two and four steps respectively. Compounds **5** and **8** were then transformed into the corresponding 3-*O*-methyl, 3-*C*-methyl, and 3-deoxy derivatives variously by *O*-methylation, Wittig olefination/stereospecific hydrogenation, and xanthate reduction. Regioselective reductive opening of the 4,6-*O*-benzylidene rings gave galactoside derivatives with HO-4 unsubstituted. Bromide-ion catalysed α-D-galactosidation and hydrogenolysis of the benzyl protecting-groups then gave the desired β-D-galabioside analogues.

INTRODUCTION

Glycolipids of the globo-series[1] have been suggested to function as receptors towards various pathogens such as *E. coli*[2a,b] and *Shigella dysenteriae* toxin[2c], both *in vivo* and *in vitro*. The main receptor activity resides in the β-D-galabioside (4-*O*-α-D-galactopyranosyl-β-D-galactopyranoside) portion of the glycolipids[2c,3]. These glycolipids are also significant in such disorders as Burkitt lymphoma[2d] and Fabry's disease[2e]. Several syntheses of galabiose derivatives have been reported[4], and also a route suitable for large-scale preparation of galabiose[5]. Addition of such derivatives to incubates effectively hinders the adhesion of pathogens to glycolipid-bearing host cells[3].

The crystal structure[6] of galabiose revealed an intramolecular hydrogen-bond between HO-3 and the ring oxygen O-5′, which should augment the conformational stability of the molecule. Similar hydrogen-bonds have been found in crystals of lactose[7a], *N*-acetyl-lactosamine[7b], and mannobiose[7c]. Replacement of HO-3 in methyl *N*-acetyl-β-lactosaminide by hydrogen gave an analogue with increased

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affinity for a monoclonal antibody that had been raised against the parent sugar[8a]. This and other results have focused attention on hydrophobic surfaces as being responsible for the attractive forces between carbohydrates and proteins[8], whereas the importance of intermolecular hydrogen-bonds was clearly demonstrated in the crystal structure (1.7-Å resolution) of a 1:1 complex between an L-arabinose-binding protein and the sugar[9].

In order to investigate the importance of the HO-3 · · · · O-5′ hydrogen bond for the conformation of galabiose and to obtain derivatives with varied hydrophobic surfaces[8] for receptor interaction studies, we have synthesised derivatives of methyl β-D-galabioside in which HO-3 is replaced by MeO (**32**), CH_3 (**38**), and H (**41**).

The route chosen involved transformations at position 3 of methyl β-D-galactopyranoside (**1**), followed by bromide-ion catalysed α-D-galactosidation, rather than manipulation of the parent disaccharide. Four derivatives (**5**, **8**, **10**, and **11**) of **1** with HO-3 unsubstituted were prepared, and *O*-methylation, Wittig olefination/stereospecific hydrogenation, and xanthate reduction[10] were then applied. Regioselective cleavage of 4,6-*O*-benzylidene acetals[11] then liberated HO-4 prior to the glycoside syntheses.

RESULTS AND DISCUSSION

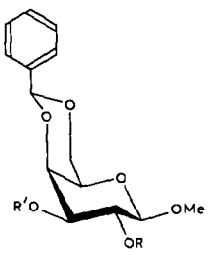
The starting material, methyl 2-*O*-benzyl-4,6-*O*-benzylidene-β-D-galactopyranoside[12] (**5**), has been synthesised[12] from **1** (22% yield, 5 steps). In investigating alternative routes to **5**, we found that methyl 4,6-*O*-benzylidene-β-D-galactopyranoside[13] (**2**) can be partially benzoylated[14] to give the 3-benzoate **3**[15] (80%). Attempted sodium hydride-mediated benzylation of HO-2 in **3** failed due to benzoyl migration. Acid-catalysed benzylation of **3** with benzyl trichloroacetimidate[16] gave the desired compound **4** (43%). Debenzoylation gave **5** (92%; 25% from **1**, 4 steps).

Partial benzylation of **2** with sodium hydride and benzyl bromide in *N,N*-dimethylformamide gave **5** (12%) and the isomeric benzyl ether **6** (31%). Phase-transfer catalysis conditions[17] improved the yields, and **5** (30%) and **6** (47%) were isolated by chromatography. Thus, **5** was produced in 24% overall yield in two steps from **1** with the formation of **6** as a useful by-product.

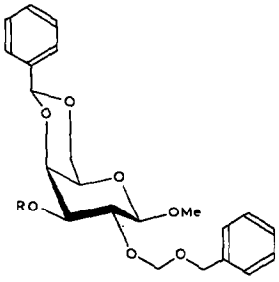
Partial protection of **2** with *tert*-butyldimethylsilyl chloride[18] gave 65% of the monosilyl ether **9** together with isomer **10** (20%). The basic conditions needed for benzylation lead to silyl group migration in **9**, whereas benzylation by the imidate method[16] resulted in extensive decomposition which made us abandon this route to **5**.

As an alternative to benzyl protection, the benzyloxymethyl group was introduced by treatment of **3** with benzyl chloromethyl ether. No benzoyl migration occurred and 96% of **7** was obtained. Debenzoylation then gave 97% (60% from **1**) of methyl 4,6-*O*-benzylidene-2-*O*-benzyloxymethyl-β-D-galactopyranoside (**8**).

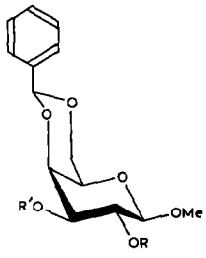
In contrast to the partial protections of **2** mentioned above, reaction with 2-(trimethylsilyl)ethoxymethyl chloride[19] (SEM-Cl) occurred at position 2 to give 50% of **11**. This route is inferior to the preparation of **8** from **1** and was not developed further.



2 R = R′ = H
3 R = H, R′ = Bz
4 R = Bzl, R′ = Bz
5 R = Bzl, R′ = H
6 R = H, R′ = Bzl

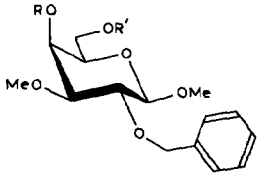


7 R = Bz
8 R = H

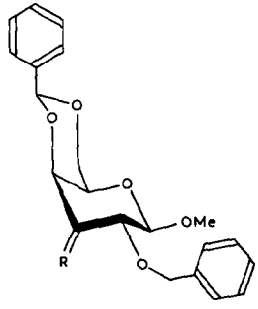


9 R = H, R′ = $^{t}BuMe_2Si$
10 R = $^{t}BuMe_2Si$, R′ = H
11 R = $CH_2OCH_2CH_2SiMe_3$, R′ = H

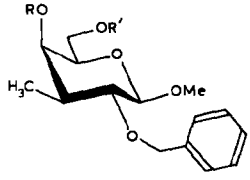
Routes to the 3-*O*-methyl (**13**), 3-*C*-methyl (**17**), and 3-deoxy (**24**) derivatives were then investigated. Methylation of **5** with sodium methylsulfinylmethanide[20] and methyl iodide gave **12** (90%). Reductive cleavage of the 4,6-*O*-benzylidene group in **12** with sodium cyanoborohydride and hydrogen chloride in ether[11] gave methyl 2,6-di-*O*-benzyl-3-*O*-methyl-β-D-galactopyranoside (**13**, 78%). In this and the following reductions of 4,6-*O*-benzylidene groups, the n.m.r. spectra of the acetylated products showed that HO-4 had been liberated in the reduction.



12 R, R′ = CHPh
13 R = H, R′ = Bzl



14 R = O
15 R = CH_2

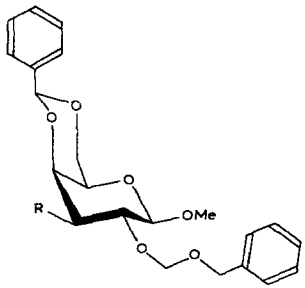


16 R, R′ = CHPh
17 R = H, R′ = Bzl

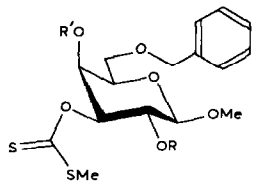
Swern oxidation[21] of **5** gave, after chromatography, 80% of a 4:1 mixture of ketones (δ 5.59 and 5.57 for PhC*H*) from which crystalline **14** (64%; δ 5.59) was isolated. Pure **14** was converted into the mixture of ketones on treatment with base and acid under conditions similar to those in the Swern oxidation, reflecting

epimerisation at one of the α-positions. The mixture of ketones was used in a Wittig reaction to give **15** (65%) which was then hydrogenated to give **16** as the sole product (98%). The equatorial orientation of the methyl group formed was established by the ^{1}H-n.m.r. data ($J_{2,3}$ 10.7 Hz), showing that the addition of hydrogen had occurred from the α-side of **15**. Reductive cleavage[11] of the 4,6-*O*-benzylidene group in **16** then gave methyl 2,6-di-*O*-benzyl-3-deoxy-3-*C*-methyl-β-D-galactopyranoside (**17**, 65%).

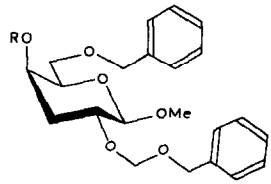
Treatment of **8** with sodium hydride and imidazole in tetrahydrofuran followed by addition of carbon disulfide and methyl iodide[10] gave 71% of the *S*-methyl dithiocarbonate **18**, whereas phase-transfer catalysis[22] yielded only 43%. Barton reduction[10] of **18** with tributyltin hydride gave **19** (71%) which reacted slowly when reductive cleavage[11] of the 4,6-*O*-benzylidene group was attempted, and there was extensive decomposition. Benzylidene reduction[11] of **18** gave **20** together with substantial amounts of **21**, which had lost the benzyloxymethyl group. The yield in this step was sensitive to the amount of ethereal hydrogen chloride added (typically, 40–60% of **20** and 25–30% of **21**). Since a direct Barton reduction of **20** gave numerous products, **20** was first acetylated to give **22** (98%) which was reduced to give the deoxy compound **23** (64%). Deacetylation then gave methyl 6-*O*-benzyl-2-*O*-benzyloxymethyl-3-deoxy-β-D-*xylo*-hexopyranoside (**24**, 94%), thus completing the synthesis in 9 steps (15% from **1**).



18 R = OCSSMe
19 R = H



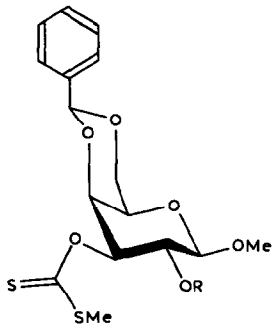
20 R = CH_2OCH_2Ph, R' = H
21 R = R' = H
22 R = CH_2OCH_2Ph, R' = Ac



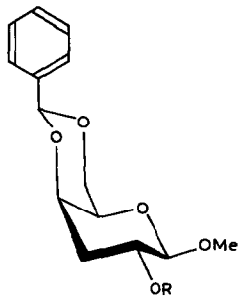
23 R = Ac
24 R = H

The lability of the benzyloxymethyl group in **19** towards acid prompted the use of a benzyl ether for the protection of HO-2. Due to the higher reactivity of HO-3 in **2**, the mono(*S*-methyl dithiocarbonate) **25** could be obtained (60%) by the ordinary procedure[10]. Barton reduction of **25** gave several products (*cf.* **20** above), which points to the need to protect neighbouring hydroxyl groups during this reduction[10]. Since problems with *S*-methyl dithiocarbonate migration were anticipated on benzylation, **25** was first acetylated to give **26** (96%). Barton reduction followed by deacetylation and benzylation[20] with sodium methylsulfinylmethanide and benzyl bromide then gave **27** (79%), **28** (98%), and **29** (98%), respectively. Benzylidene reduction[11] of **29** gave methyl 2,6-di-*O*-benzyl-3-deoxy-β-

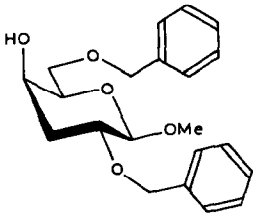
D-*xylo*-hexopyranoside (**30**, 61%) in 7 steps and 20% overall yield from **1**. Synthesis of the *S*-methyl dithiocarbonate of **5** followed by Barton reduction and benzylidene reduction would have provided a 5-step synthesis of **30** from **1**, but with an anticipated yield of only 6%.



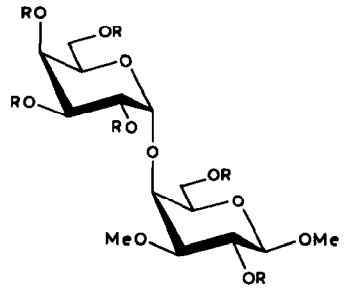
25 R = H
26 R = Ac



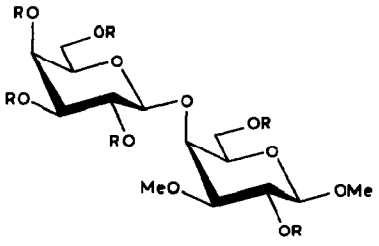
27 R = Ac
28 R = H
29 R = Bzl



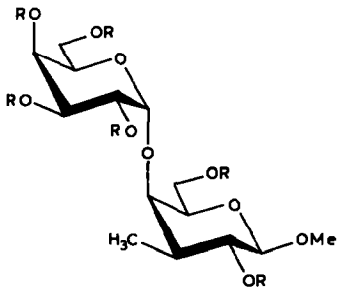
30



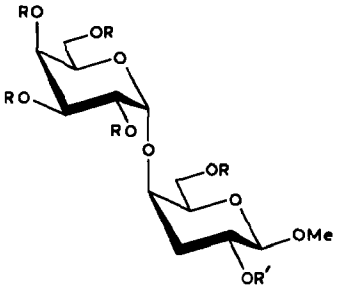
31 R = Bzl
32 R = H
33 R = Ac



34 R = Bzl
35 R = H
36 R = Ac



37 R = Bzl
38 R = H
39 R = Ac



40 R = Bzl, R′ = CH_2OCH_2Ph
41 R = R′ = H
42 R = R′ = Ac

The difficulties experienced in the reduction of the 4,6-*O*-benzylidene groups of **18** and **19** (as compared to that in **29**) illustrates problems encountered with the benzyloxymethyl protecting-group under acid conditions. However, this protecting group is still of value since it is easily introduced and removed [*cf.*, for example, the yields in the transformations of **1** into **5** (24%) and **8** (60%)].

The derivatives **13, 17**, and **24** were then galactosylated with 2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranosyl bromide[23a], using tetraethylammonium bromide as catalyst[23]. Compound **13** gave a mixture of the α- (**31**, 51%) and β-glycoside (**34**, 4%), and 25% of **13** was recovered. In a single experiment using silver trifluoromethanesulfonate as catalyst, only 12% of **31** and 6% of **34** were formed. Hydrogenolysis of the benzyl groups in **31** and **34** then gave methyl 4-*O*-α- (**32**) and -β-D-galactopyranosyl-3-*O*-methyl-β-D-galactopyranoside (**35**), respectively, in yields of >95%. The acetates **33** and **36** were prepared in order to simplify the interpretation of the ^{1}H-n.m.r. spectra. Galactosylation of **17** and **24** as above gave the respective α-linked disaccharides **37** (45%) and **40** (49%); unreacted **17** (40%) and **24** (42%) were recovered. Hydrogenolysis of the benzyl groups in **37** and **40** then gave methyl 3-deoxy-4-*O*-α-D-galactopyranosyl-3-*C*-methyl-β-D-galactopyranoside (**38**) and methyl 3-deoxy-4-*O*-α-D-galactopyranosyl-β-D-*xylo*-hexopyranoside (**41**) in yields of >95%. The structures of **38** and **41** were confirmed by ^{1}H-n.m.r. spectroscopy of the corresponding acetates **39** and **42**.

EXPERIMENTAL

General methods. — N.m.r. spectra were recorded with Nicolet WB360 and Varian XL-300 spectrometers. Me_4Si and sodium 3-(trimethylsilyl)propanesulfonate were used as internal standards for solutions in $CDCl_3$ and D_2O, respectively. Optical rotations were measured with a Perkin–Elmer 141 polarimeter. Recrystallisations were from ethyl acetate–hexane unless otherwise stated, and melting points were determined with a Reichert melting-point microscope. T.l.c. was performed on Kieselgel 60 F_{254} (Merck) with detection by u.v. light or charring with sulfuric acid. Column chromatography was performed on Kieselgel 60 (Merck, 230–400 mesh). Organic solutions were dried over Na_2SO_4. Methyl 4,6-*O*-benzylidene-β-D-galactopyranoside[13] (**2**) was prepared (80%) by a variation of a known procedure[24], using α,α-dimethoxytoluene and a trace of toluene-*p*-sulfonic acid in acetonitrile (room temp., 16 h). Methyl 3-*O*-benzoyl-4,6-*O*-benzylidene-β-D-galactopyranoside[15] (**3**) was obtained (80%) by reacting[14] **2** with benzoyl chloride in pyridine (0° → room temperature). Compounds **2** and **3** had m.p.s and optical rotations in agreement with literature data and gave satisfactory elemental analyses. 2,3,4,6-Tetra-*O*-benzyl-α-D-galactopyranosyl bromide was prepared as described[23a], but the excess of hydrogen bromide was neutralised with solid sodium hydrogencarbonate before filtration of the *p*-nitrobenzoic acid.

Satisfactory elemental analyses could not be obtained for the amorphous compounds **32, 35, 38**, and **41**, which were characterised on the basis of ^{1}H-n.m.r. data.

Methyl 3-O-benzoyl-2-O-benzyl-4,6-O-benzylidene-β-D-galactopyranoside (**4**). — To a solution of **3** (3.00 g, 7.77 mmol) and benzyl trichloroacetimidate[16] (3.29 g, 15.5 mmol) in dry dichloromethane–hexane (1:2, 90 mL) at room temperature was added trifluoromethanesulfonic acid (20 μL). The reaction was monitored by t.l.c. and quenched after 12 h by the addition of triethylamine (0.1 mL). Concentration of the solution followed by column chromatography (ethyl acetate–hexane, 1:3) of the residue gave **4** (1.59 g, 43%), m.p. 145–148°, $[\alpha]_D^{25}$ +145° (*c* 1, chloroform). ^{1}H-n.m.r. data ($CDCl_3$): δ 5.52 (s, 1 H, PhC*H*), 5.19 (dd, 1 H, *J* 10.0 and 3.7 Hz, H-3), 4.89 and 4.70 (ABq, 2 H, *J* 11.5 Hz, PhCH_2), 4.50 (bd, 1 H, *J* 3.2 Hz, H-4), 4.48 (d, 1 H, *J* 7.8 Hz, H-1), 4.38 (dd, 1 H, *J* 12.3 and 1.6 Hz, H-6), 4.10 (dd, 1 H, *J* 12.3 and 1.8 Hz, H-6), 4.00 (dd, 1 H, *J* 10.1 and 7.7 Hz, H-2), 3.63 (s, 3 H, MeO), 3.57 (bs, 1 H, H-5).

Anal. Calc. for $C_{28}H_{28}O_7$: C, 70.6; H, 5.92. Found: C, 70.4; H, 5.94.

Methyl 2-O-benzyl-4,6-O-benzylidene-β-D-galactopyranoside[12] (**5**). — A solution of **4** (1.55 g, 3.27 mmol) in dichloromethane–methanolic 0.1M sodium methoxide (2:1, 21 mL) was stirred for 12 h at room temperature, then neutralised with acetic acid (40 μL), and concentrated. Column chromatography (ethyl acetate) of the residue gave **5** (1.12 g, 92%), m.p. 108–111°, $[\alpha]_D^{25}$ +22° (*c* 1, chloroform); lit.[12] m.p. 118–119°, $[\alpha]_D^{25}$ +22° (*c* 0.8, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.56 (s, 1 H, PhC*H*), 4.95 and 4.72 (ABq, 2 H, *J* 11.3 Hz, PhCH_2), 4.34 (dd, 1 H, *J* 12.9 and 1.4 Hz, H-6), 4.32 (d, 1 H, *J* 7.6 Hz, H-1), 4.22 (bd, 1 H, *J* 3.8 Hz, H-4), 4.08 (dd, 1 H, *J* 12.3 and 1.8 Hz, H-6), 3.73 (dd, 1 H, *J* 9.7 and 3.6 Hz, H-3, shifted to δ 4.91 on acetylation), 3.61 (dd, 1 H, *J* 9.7 and 7.6 Hz, H-2), 3.59 (s, 3 H, MeO), 3.45 (bs, 1 H, H-5).

*Methyl 2- (**5**) and 3-O-benzyl-4,6-O-benzylidene-β-D-galactopyranoside* (**6**). — 1.25M Sodium hydroxide (50 mL) was added to **2** (2.50 g, 8.90 mmol), tetrabutylammonium hydrogensulfate (0.60 g, 1.75 mmol), and benzyl bromide (1.80 mL, 15 mmol) in dichloromethane (150 mL). The mixture was boiled under reflux with vigorous stirring for 24 h[17]. The aqueous phase was extracted with dichloromethane (100 mL), and the combined organic extracts were dried and concentrated. Column chromatography (ethyl acetate–hexane, 1:1) of the residue gave **5** (1.11 g, 30%) and **6** (1.56 g, 47%), m.p. 200–201°, $[\alpha]_D^{25}$ +56° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.46 (s, 1 H, PhC*H*), 4.77 and 4.73 (ABq, 2 H, *J* 12.2 Hz, PhCH_2), 4.33 (dd, 1 H, *J* 12.2 and 1.4 Hz, H-6), 4.24 (d, 1 H, *J* 7.6 Hz, H-1), 4.14 (bd, 1 H, *J* 2.9 Hz, H-4), 4.04 (dd, 1 H, *J* 12.4 and 2.0 Hz, H-6), 4.00 (dd, 1 H, *J* 9.7 and 7.9 Hz, H-2, shifted to δ 5.36 on acetylation), 3.57 (s, 3 H, MeO), 3.50 (dd, 1 H, *J* 9.7 and 3.6 Hz, H-3), 3.38 (bs, 1 H, H-5).

Anal. Calc. for $C_{21}H_{24}O_6$: C, 67.7; H, 6.50. Found: C, 68.1; H, 6.68.

Methyl 3-O-benzoyl-4,6-O-benzylidene-2-O-benzyloxymethyl-β-D-galactopyranoside (**7**). — A solution of **3** (1.96 g, 5.09 mmol), benzyl chloromethyl ether (2.13 mL, 15.3 mmol), and *N*-ethyldi-isopropylamine (3.92 mL, 22.9 mmol) in dry dichloromethane (40 mL) was boiled under reflux under nitrogen for 24 h, and then washed with water (20 mL) and cold 0.2M hydrochloric acid (125 mL). The

combined aqueous solutions were extracted with dichloromethane (40 mL). The combined organic extracts were washed with saturated aqueous sodium hydrogencarbonate (15 mL) and water (25 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 2:3) of the residue gave **7** (2.48 g, 96%), m.p. 145–147°, $[\alpha]_D^{25}$ +118° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.51 (s, 1 H, PhC*H*), 5.23 (dd, 1 H, *J* 10.3 and 3.4 Hz, H-3), 4.99 and 4.85 (ABq, 2 H, *J* 6.6 Hz, OCH_2O), 4.53 and 4.50 (ABq, 2 H, *J* 11.9 Hz, PhCH_2), 4.48 (d, 1 H, *J* 3.6 Hz, H-4), 4.45 (d, 1 H, *J* 7.9 Hz, H-1), 4.38 (bd, 1 H, *J* 12.2 Hz, H-6), 4.28 (dd, 1 H, *J* 10.1 and 7.9 Hz, H-2), 4.10 (bd, 1 H, *J* 12.2 Hz, H-6), 3.58 (s, 4 H, H-5 and MeO).

Anal. Calc. for $C_{29}H_{30}O_8$: C, 68.8; H, 5.97. Found: C, 68.8; H, 5.94.

*Methyl 4,6-O-benzylidene-2-O-benzyloxymethyl-β-*D*-galactopyranoside* (**8**). — Debenzoylation of **7** (1.50 g, 2.96 mmol) as described for **5**, with column chromatography (ethyl acetate–hexane, 1:1) of the product, gave **8** (1.16 g, 97%), m.p. 120–121°, $[\alpha]_D^{25}$ +40° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.56 (s, 1 H, PhC*H*), 4.96 (s, 2 H, OCH_2O), 4.77 and 4.66 (ABq, 2 H, *J* 11.7 Hz, PhCH_2), 4.35 (dd, 1 H, *J* 12.3 and 1.5 Hz, H-6), 4.29 (d, 1 H, *J* 7.5 Hz, H-1), 4.22 (bd, 1 H, *J* 3.6 Hz, H-4), 4.08 (dd, 1 H, *J* 12.4 and 2.0 Hz, H-6), 3.76 (dd, 1 H, *J* 9.4 and 7.6 Hz, H-2), 3.71 (dd, 1 H, *J* 9.4 and 3.6 Hz, H-3), 3.56 (s, 3 H, MeO), 3.47 (bs, 1 H, H-5).

Anal. Calc. for $C_{22}H_{26}O_7$: C, 65.7; H, 6.51. Found: C, 65.6; H, 6.42.

*Methyl 4,6-O-benzylidene-3- (***9***) and -2-O-*tert*-butyldimethylsilyl-β-*D*-galactopyranoside* (**10**). — Compound **2** (1.50 g, 5.32 mmol) was treated[18] with *tert*-butyldimethylsilyl chloride (1.04 g, 6.91 mmol) and imidazole (0.90 g, 13.3 mmol) in dry *N,N*-dimethylformamide (15 mL) at 40° for 16 h. The solution was diluted with dichloromethane (100 mL), washed with water (3 × 20 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 1:3) of the residue gave **9** (1.36 g, 65%) and **10** (0.42 g, 20%). Compound **9** had m.p. 64–68° (from methanol–water), $[\alpha]_D^{25}$ +34° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.52 (s, 1 H, PhC*H*), 4.36 (dd, 1 H, *J* 12.4 and 1.5 Hz, H-6), 4.24 (d, 1 H, *J* 7.6 Hz, H-1), 4.08 (dd, 1 H, *J* 12.4 and 1.7 Hz, H-6), 4.04 (bd, 1 H, *J* 3.5 Hz, H-4), 3.82 (dd, 1 H, *J* 9.5 and 7.6 Hz, H-2, shifted to δ 5.24 on acetylation), 3.72 (dd, 1 H, *J* 9.5 and 3.7 Hz, H-3), 3.57 (s, 3 H, MeO), 3.43 (bs, 1 H, H-5), 0.91 (s, 9 H, Me_3C), 0.13 (s, 3 H, MeSi), 0.12 (s, 3 H, MeSi).

Anal. Calc. for $C_{20}H_{32}O_6Si$: C, 60.6; H, 8.13. Found: C, 60.6; H, 8.08.

Compound **10** had m.p. 108–110°, $[\alpha]_D^{25}$ −14° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.55 (s, 1 H, PhC*H*), 4.34 (dd, 1 H, *J* 12.6 and 1.3 Hz, H-6), 4.21 (bd, 1 H, *J* 3.8 Hz, H-4), 4.12 (d, 1 H, *J* 7.1 Hz, H-1), 4.08 (dd, 1 H, *J* 12.4 and 2.0 Hz, H-6), 3.66 (dd, AB-type, 1 H, *J* 9.4 and 7.2 Hz, H-2), 3.60 (dd, AB-type, 1 H, *J* 9.3 and 3.4 Hz, H-3), 3.53 (s, 3 H, MeO), 3.45 (bs, 1 H, H-5), 0.90 (s, 9 H, Me_3C), 0.11 (s, 3 H, MeSi), 0.10 (s, 3 H, MeSi).

Anal. Calc. for $C_{20}H_{32}O_6Si$: C, 60.6; H, 8.13. Found: C, 60.7; H, 8.32.

*Methyl 4,6-O-benzylidene-2-O-(2-trimethylsilylethoxymethyl)-β-*D*-galacto-*

pyranoside (**11**). — Compound **2** (1.50 g, 5.32 mmol) was treated[19] with 2-trimethylsilylethoxymethyl chloride (1.41 mL, 7.98 mmol) and *N*-ethyldi-isopropylamine (3.64 mL, 21.3 mmol) in dry tetrahydrofuran–dichloromethane (1:1, 60 mL) at 40° under nitrogen for 24 h. The solution was then diluted with dichloromethane (75 mL) and washed with cold 0.4M hydrogen chloride (60 mL), saturated aqueous sodium hydrogencarbonate (20 mL), and water (20 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 3:2) of the residue gave **11** (1.09 g, 50%), $[\alpha]_D^{25}$ +31° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.56 (s, 1 H, PhC*H*), 4.90 and 4.83 (ABq, 2 H, *J* 6.6 Hz, OCH_2O), 4.34 (dd, 1 H, *J* 12.4 and 1.5 Hz, H-6), 4.28 (d, 1 H, *J* 7.6 Hz, virtually coupled[25] to H-3,4, H-1), 4.23 (m, 1 H, H-4), 4.08 (dd, 1 H, *J* 12.4 and 1.7 Hz, H-6), 3.81 (m, 1 H, OCH_2CH_2Si), 3.68 (m, 2 H, H-2 and H-3, H-3 shifted to δ 4.86 on acetylation), 3.63 (m, 1 H, OCH_2CH_2Si), 3.56 (s, 3 H, MeO), 3.46 (bs, 1 H, H-5), 0.96 (m, 2 H, OCH_2CH_2Si), 0.01 (s, 9 H, Me_3Si).

Anal. Calc. for $C_{20}H_{32}O_7Si$: C, 58.2; H, 7.82. Found: C, 58.2; H, 7.60.

*Methyl 2-O-benzyl-4,6-O-benzylidene-3-O-methyl-β-*D*-galactopyranoside* (**12**). — Sodium hydride dispersion (50% in oil, 194 mg, 4.04 mmol) was dissolved (sonication, 6 h) in methyl sulfoxide (10 mL) under nitrogen at room temperature[20]. Compound **5** (1.00 g, 2.69 mmol) was then added and, after stirring for 1 h, methyl iodide (334 μL, 5.38 mmol). After 3 h, the solution was diluted with dichloromethane (150 mL), washed with water (3 × 20 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 1:1) of the residue gave **12** (0.934 g, 90%), m.p. 137–139°, $[\alpha]_D^{25}$ +38° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.55 (s, 1 H, PhC*H*), 4.88 and 4.75 (ABq, 2 H, *J* 11.0 Hz, $PhCH_2$), 4.34 (dd, 1 H, *J* 12.6 and 1.4 Hz, H-6), 4.33 (d, 1 H, *J* 7.6 Hz, H-1), 4.29 (bd, 1 H, *J* 3.6 Hz, H-4), 4.08 (dd, 1 H, *J* 12.2 and 1.8 Hz, H-6), 3.77 (dd, 1 H, *J* 9.5 and 7.7 Hz, H-2), 3.59 (s, 3 H, MeO), 3.54 (s, 3 H, MeO), 3.39 (bs, 1 H, H-5), 3.36 (dd, 1 H, *J* 9.4 and 3.6 Hz, H-3).

Anal. Calc. for $C_{22}H_{26}O_6$: C, 68.4; H, 6.78. Found: C, 68.6; H, 6.82.

*Methyl 2,6-di-O-benzyl-3-O-methyl-β-*D*-galactopyranoside* (**13**). — Saturated, ethereal hydrogen chloride was added at room temperature to a solution of **12** (950 mg, 2.46 mmol) and sodium cyanoborohydride (1.40 g, 22.2 mmol) in dry tetrahydrofuran (20 mL) containing powdered molecular sieves (3 Å, 1 g)[11a]. The addition was discontinued when the solution became acidic (pH paper). The reaction was then monitored by t.l.c. and, when complete, solid sodium hydrogencarbonate was added, followed by dichloromethane (30 mL) and saturated aqueous sodium hydrogencarbonate (10 mL). The mixture was filtered, and the organic phase was dried and concentrated. Column chromatography (ethyl acetate–hexane, 2:1) of the residue gave **13** (741 mg, 78%), m.p. 66–68°, $[\alpha]_D^{25}$ −2° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.85 and 4.70 (ABq, 2 H, *J* 11.2 Hz, $PhCH_2$), 4.60 (s, 2 H, $PhCH_2$), 4.27 (d, 1 H, *J* 7.6 Hz, H-1), 4.08 (bs, 1 H, H-4, shifted to δ 5.52 on acetylation), 3.82 (dd, 1 H, *J* 9.7 and 5.8 Hz, H-6), 3.74 (dd, 1 H, *J* 9.7 and 5.8 Hz, H-6), 3.56 (s, 3 H, MeO), 3.51 (s, 3 H, MeO), 3.24 (dd, 1 H, *J* 9.4 and 3.2 Hz, H-3).

Anal. Calc. for $C_{22}H_{28}O_6$: C, 68.0; H, 7.27. Found: C, 67.9; H, 7.30.

*Methyl 2-O-benzyl-4,6-O-benzylidene-β-*D*-xylo-hexopyranosid-3-ulose* (**14**). — To a solution of oxalyl chloride (353 μL, 4.14 mmol) in dichloromethane (9 mL) at −45° under dry nitrogen[21] was added during 5 min a solution of methyl sulfoxide (646 μL, 9.11 mmol) in dichloromethane (2 mL). After stirring for 20 min, a solution of **5** (1.03 g, 2.76 mmol) in dichloromethane (3 mL) was added during 5 min. After stirring for a further 15 min, *N*-ethyldi-isopropylamine (3.17 mL, 18.5 mmol) was added during 5 min, and the solution was allowed to attain room temperature. Water (10 mL) was added, the mixture was stirred for 10 min, the phases were separated, and the aqueous phase was extracted with dichloromethane (10 mL). The combined organic phases were washed with 0.5M hydrogen chloride (40 mL), saturated aqueous sodium hydrogencarbonate (10 mL), and water (10 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 3:2) of the residue gave a syrup (819 mg, 80%) containing ~80% of **14** contaminated, presumably, by an epimeric product. Pure **14** (655 mg, 64%) was obtained by crystallisation from ethyl acetate–hexane and had m.p. 112–113°, $[\alpha]_D^{25}$ −42° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.58 (s, 1 H, PhC*H*), 4.80 and 4.72 (ABq, 2 H, *J* 11.5 Hz, PhCH_2), 4.52 and 4.50 (ABq, 2 H, *J* 7.9 Hz, H-1 and H-2), 4.45 (dd, 1 H, *J* 12.6 and 1.1 Hz, H-6), 4.44 (bs, 1 H, H-4), 4.15 (dd, 1 H, *J* 12.6 and 1.8 Hz, H-6), 3.61 (s, 3 H, MeO), 3.54 (bs, 1 H, H-5).

Anal. Calc. for $C_{21}H_{22}O_6$: C, 68.1; H, 5.99. Found: C, 68.2; H, 5.93.

*Methyl 2-O-benzyl-4,6-O-benzylidene-3-C-methylene-β-*D*-xylo-hexopyranoside* (**15**). — Butyl-lithium in hexane (2.47 mmol) was added at room temperature to a stirred suspension of finely ground methyltriphenylphosphonium bromide (880 mg, 2.47 mmol) in dry ether (15 mL) under nitrogen. After stirring for 1.5 h, a solution of crude **14** (730 mg, 1.97 mmol; ~80% pure, see above) in dry ether (40 mL) was added and the mixture was stirred for 16 h. Water (20 mL) was then added and, after stirring for 6 h, the phases were separated and the aqueous phase was extracted with ether (2 × 20 mL). The combined ether phases were dried and concentrated. Column chromatography (ethyl acetate–hexane, 1:3) of the residue gave **15** (467 mg, 65%), m.p. 86–87°, $[\alpha]_D^{25}$ +43° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.57 (s, 1 H, PhC*H*), 5.51 (t, 1 H, *J* 1.8 Hz, C=CH_2), 5.31 (t, 1 H, *J* 1.8 Hz, C=CH_2), 4.92 and 4.69 (ABq, 2 H, *J* 11.3 Hz, PhCH_2), 4.47 (bd, 1 H, *J* 1.4 Hz, H-4), 4.35 (dd, 1 H, *J* 12.4 and 1.3 Hz, H-6), 4.27 (d, AB-type, 1 H, *J* 7.9 Hz, H-1), 4.24 (dt, AB-type, J_{AB} 7.9 and *J* 1.8 Hz, H-2), 4.11 (dd, 1 H, *J* 12.4 and 2.0 Hz, H-6), 3.59 (s, 3 H, MeO), 3.44 (bs, 1 H, H-5).

Anal. Calc. for $C_{22}H_{24}O_5$: C, 71.7; H, 6.57. Found: C, 71.6; H, 6.53.

*Methyl 2-O-benzyl-4,6-O-benzylidene-3-deoxy-3-C-methyl-β-*D*-galactopyranoside* (**16**). — Pd/C (10%, 50 mg) was added to a solution of **15** (350 mg, 0.951 mmol) in dichloromethane–methanolic 0.03M sodium methoxide[4a] (2:3, 35 mL). The mixture was hydrogenated at atmospheric pressure until t.l.c. showed that **15** had been consumed. The solution was neutralised with acetic acid (42 μL), filtered, and concentrated. A solution of the crystalline residue in dichloromethane (50 mL)

was washed with water (2 × 10 mL), dried, and concentrated to give **16** (345 mg, 98%), m.p. 130–132°, $[\alpha]_D^{25}$ +35° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.50 (s, 1 H, PhC*H*), 4.94 and 4.55 (ABq, 2 H, *J* 11.1 Hz, PhCH_2), 4.32 (d, 1 H, *J* 7.6 Hz, H-1), 4.30 (dd, 1 H, *J* 12.2 and 1.5 Hz, H-6), 4.05 (dd, 1 H, *J* 12.2 and 2.0 Hz, H-6), 3.85 (bd, 1 H, *J* 2.7 Hz, H-4), 3.58 (s, 3 H, MeO), 3.43 (bs, 1 H, H-5), 3.40 (dd, 1 H, *J* 10.7 and 7.8 Hz, H-2), 1.86 (m, 1 H, H-3), 1.19 (d, 3 H, *J* 6.6 Hz, CH_3-C).

Anal. Calc. for $C_{22}H_{26}O_5$: C, 71.3; H, 7.07. Found: C, 71.0; H, 7.00.

*Methyl 2,6-di-*O*-benzyl-3-deoxy-3-C-methyl-β-*D*-galactopyranoside* (**17**). — Benzylidene reduction[11a] of **16** (290 mg, 0.784 mmol) as described for **13**, with column chromatography (ethyl acetate–hexane, 1:3) of the product, gave **17** as a syrup (190 mg, 65%), $[\alpha]_D^{25}$ +14° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.89 and 4.55 (ABq, 2 H, *J* 11.2 Hz, PhCH_2), 4.60 and 4.58 (ABq, 2 H, *J* 11.9 Hz, PhCH_2), 4.30 (d, 1 H, *J* 7.6 Hz, H-1), 3.75 (dd, AB-type, 1 H, J_{AB} 10.1 and *J* 5.4 Hz, H-6), 3.71 (bd, 1 H, *J* 3.6 Hz, H-4, shifted to δ 5.18 on acetylation), 3.70 (dd, AB-type, 1 H, J_{AB} 10.1 and *J* 4.7 Hz, H-6), 3.63 (bt, 1 H, *J* 5.0 Hz, H-5), 3.58 (s, 3 H, MeO), 3.24 (dd, 1 H, *J* 10.8 and 7.6 Hz, H-2), 1.70 (m, 1 H, H-3), 1.13 (d, 3 H, *J* 6.5 Hz, CH_3-C).

Anal. Calc. for $C_{22}H_{28}O_5$: C, 70.9; H, 7.58. Found: C, 70.8: H, 7.48.

*Methyl 4,6-*O*-benzylidene-2-*O*-benzyloxymethyl-3-*O*-[(methylthio)thiocarbonyl]-β-*D*-galactopyranoside* (**18**). — To a solution of **8** (1.30 g, 3.23 mmol) in dry tetrahydrofuran (15 mL) were added imidazole (5 mg) and sodium hydride (50% in oil; 310 mg, 6.46 mmol), and the mixture was stirred for 30 min at room temperature[10]. Carbon disulfide (1.75 mL) was added and the stirring was continued for 1 h. Methyl iodide (0.5 mL) was added, the reaction was continued for 30 min, and dichloromethane (50 mL) was added. The mixture was washed with water (15 mL), 0.2M hydrogen chloride (15 mL), saturated aqueous sodium hydrogencarbonate (15 mL), and water (15 mL), dried, and concentrated. Column chromatography (ethyl acetate–dichloromethane–hexane, 12:12:1) of the residue gave **18** (1.13 g, 71%), m.p. 111–113°, $[\alpha]_D^{25}$ +144° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.82 (dd, 1 H, *J* 10.1 and 3.7 Hz, H-3), 5.52 (s, 1 H, PhC*H*), 4.98 and 4.83 (ABq, 2 H, *J* 6.7 Hz, OCH_2O), 4.70 and 4.62 (ABq, 2 H, *J* 11.5 Hz, PhCH_2), 4.59 (bd, 1 H, *J* 3.7 Hz, H-4), 4.43 (d, 1 H, *J* 7.8 Hz, H-1), 4.37 (dd, 1 H, *J* 12.3 and 1.6 Hz, H-6), 4.30 (dd, 1 H, *J* 10.0 and 7.7 Hz, H-2), 4.09 (dd, 1 H, *J* 12.4 and 1.8 Hz, H-6), 3.56 (s, 3 H, MeO), 3.55 (bs, 1 H, H-5), 2.50 (s, 3 H, MeS).

Anal. Calc. for $C_{24}H_{28}O_7S_2$: C, 58.5; H, 5.73. Found: C, 58.3; H, 5.68.

*Methyl 4,6-*O*-benzylidene-2-*O*-benzyloxymethyl-3-deoxy-β-*D*-xylo-hexopyranoside* (**19**). — A solution of **18** (200 mg, 0.407 mmol) in dry toluene (4 mL) was added, under argon, to a refluxing solution of tributyltin hydride (162 μL, 0.61 mmol) in toluene (3 mL) during 1 h[10]. The solution was boiled under reflux for 16 h and then concentrated. Column chromatography (ethyl acetate–hexane, 1:2) of the residue gave **19** (112 mg, 71%), m.p. 73–77°, $[\alpha]_D^{25}$ −2° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.51 (s, 1 H, PhC*H*), 4.92 and 4.84 (ABq, 2 H, *J* 6.7

Hz, OCH_2O), 4.64 and 4.61 (ABq, 2 H, *J* 11.7 Hz, $PhCH_2$), 4.32 (bd, 1 H, *J* 12.6 Hz, H-6), 4.30 (d, 1 H, *J* 7.6 Hz, H-1), 4.07 (dd, 1 H, *J* 12.2 and 1.8 Hz, H-6), 4.07 (bs, 1 H, H-4), 3.95 (ddd, 1 H, *J* 11.5, 7.6, and 5.4 Hz, H-2), 3.55 (s, 3 H, MeO), 3.48 (bs, 1 H, H-5), 2.42 (ddd, 1 H, *J* 14.4, 5.4, and 2.5 Hz, H-3*e*), 1.76 (ddd, 1 H, *J* 14.1, 11.5, and 3.6 Hz, H-3*a*).

Anal. Calc. for $C_{22}H_{26}O_6$: C, 68.4; H, 6.78. Found: C, 68.0; H, 6.77.

Methyl 6-O-benzyl-2-benzyloxymethyl-3-O-[(methylthio)thiocarbonyl]-β-D-galactopyranoside (**20**) *and methyl 6-O-benzyl-3-O-[(methylthio)thiocarbonyl]-β-D-galactopyranoside* (**21**). — Benzylidene reduction[11a] of **18** (530 mg, 1.08 mmol) as described for **13**, with column chromatography (ethyl acetate–hexane, 1:2 → 1:1) of the product, gave **20** (318 mg, 60%) and **21** (102 mg, 25%) as syrups. The yield of **20** was dependent on the amount of acid added. Compound **20** had $[\alpha]_D^{25}$ +57° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.75 (dd, 1 H, *J* 9.9 and 3.1 Hz, H-3), 4.95 and 4.80 (ABq, 2 H, *J* 6.5 Hz, OCH_2O), 4.68 and 4.60 (ABq, 2 H, *J* 11.9 Hz, $PhCH_2$), 4.60 and 4.56 (ABq, 2 H, *J* 11.9 Hz, $PhCH_2$), 4.38 (bd, 1 H, *J* 3.1 Hz, H-4, shifted to δ 5.65 on acetylation), 4.37 (d, 1 H, *J* 7.6 Hz, H-1), 4.17 (dd, 1 H, *J* 9.9 and 7.7 Hz, H-2), 3.82 to 3.68 (m, 3 H, H-5,6,6), 3.55 (s, 3 H, MeO), 2.55 (s, 3 H, MeS).

Anal. Calc. for $C_{24}H_{30}O_7S_2$: C, 58.3; H, 6.11. Found: C, 58.4; H, 6.07.

Compound **21** had $[\alpha]_D^{25}$ +43° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.68 (dd, 1 H, *J* 10.1 and 3.2 Hz, H-3), 4.60 and 4.56 (ABq, 2 H, *J* 11.9 Hz, $PhCH_2$), 4.39 (bd, 1 H, *J* 3.2 Hz, H-4, shifted to δ 5.66 on acetylation), 4.30 (d, 1 H, *J* 7.6 Hz, H-1), 4.08 (dd, 1 H, *J* 10.1 and 7.6 Hz, H-2, shifted to δ 5.36 on acetylation), 3.82 to 3.69 (m, 3 H, H-5,6,6), 3.59 (s, 3 H, MeO), 2.60 (s, 3 H, MeS).

Anal. Calc. for $C_{16}H_{22}O_6S_2$: C, 51.3; H, 5.92. Found: C, 51.3; H, 5.95.

Methyl 4-O-acetyl-6-O-benzyl-2-O-benzyloxymethyl-3-O-[(methylthio)thiocarbonyl]-β-D-galactopyranoside (**22**). — Treatment of **20** (520 mg, 1.05 mmol) with acetic anhydride (5 mL) and pyridine (5 mL) for 16 h, then concentration, and column chromatography (ethyl acetate–hexane, 1:3) of the residue gave **22** (555 mg, 98%) as a syrup, $[\alpha]_D^{25}$ +19° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.90 (dd, 1 H, *J* 10.1 and 3.6 Hz, H-3), 5.65 (bd, 1 H, *J* 3.2 Hz, H-4), 4.95 and 4.79 (ABq, 2 H, *J* 6.7 Hz, OCH_2O), 4.65 and 4.59 (ABq, 2 H, *J* 11.5 Hz, $PhCH_2$), 4.56 and 4.45 (ABq, 2 H, *J* 11.7 Hz, $PhCH_2$), 4.40 (d, 1 H, *J* 7.9 Hz, H-1), 4.09 (dd, 1 H, *J* 9.9 and 7.7 Hz, H-2), 3.88 (bt, 1 H, *J* 6.1 Hz, H-5), 3.57 (s, 3 H, MeO), 3.60–3.50 (m, 2 H, H-6,6), 2.52 (s, 3 H, MeS), 2.05 (s, 3 H, Ac).

Anal. Calc. for $C_{26}H_{32}O_8S_2$: C, 58.2; H, 6.01. Found: C, 58.0; H, 5.68.

Methyl 4-O-acetyl-6-O-benzyl-2-O-benzyloxymethyl-3-deoxy-β-D-xylo-hexopyranoside (**23**). — Barton reduction[10] of **22** (510 mg, 0.951 mmol) as described for **19**, with column chromatography (ethyl acetate–hexane, 1:3) of the product, gave **23** (260 mg, 64%) as a syrup, $[\alpha]_D^{25}$ −40° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.11 (bs, 1 H, H-4), 4.90 and 4.79 (ABq, 2 H, *J* 6.8 Hz, OCH_2O), 4.60 (s, 2 H, $PhCH_2$), 4.57 and 4.45 (ABq, 2 H, *J* 11.9 Hz, $PhCH_2$), 4.30 (d, 1 H, *J* 7.9 Hz, H-1), 3.81 (bt, 1 H, *J* 6.3 Hz, H-5), 3.75 (ddd, 1 H, *J* 11.9, 7.2, and 4.7 Hz,

H-2), 3.57–3.54 (m, 2 H, H-6,6), 3.55 (s, 3 H, MeO), 2.33 (ddd, 1 H, *J* 14.4, 5.4, and 3.2 Hz, H-3*e*), 2.00 (s, 3 H, Ac), 1.70 (ddd, 1 H, *J* 14.4, 11.5, and 2.9 Hz, H-3*a*).

Anal. Calc. for $C_{24}H_{30}O_7$: C, 67.0; H, 7.02. Found: C, 66.8; H, 6.86.

*Methyl 6-O-benzyl-2-O-benzyloxymethyl-3-deoxy-β-*D-xylo-*hexopyranoside* (**24**). — A solution of **23** (253 mg, 0.589 mmol) in methanol–dichloromethane (1:1, 8 mL) was treated with methanolic 0.1M sodium methoxide (1 mL) for 24 h, then neutralised with acetic acid (6 μL), and concentrated. Column chromatography (ethyl acetate–hexane, 1:1) of the residue gave **24** (215 mg, 94%) as a syrup, $[\alpha]_D^{25}$ −7° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.90 and 4.82 (ABq, 2 H, *J* 6.7 Hz, OCH_2O), 4.62 and 4.61 (ABq, 2 H, *J* 11.9 Hz, PhCH_2), 4.60 and 4.56 (ABq, 2 H, *J* 12.2 Hz, PhCH_2), 4.27 (d, 1 H, *J* 7.6 Hz, H-1), 3.99 (bs, 1 H, H-4), 3.86 (ddd, 1 H, *J* 11.5, 7.6, and 5.2 Hz, H-2), 3.74 (dd, AB-type, 1 H, *J* 10.1 and 5.4 Hz, H-6), 3.70 (dd, AB-type, 1 H, *J* 10.1 and 4.7 Hz, H-6), 3.65 (bt, 1 H, *J* 5.0 Hz, H-5), 3.54 (s, 3 H, MeO), 2.32 (ddd, 1 H, *J* 13.9, 5.2, and 3.2 Hz, H-3*e*), 1.62 (ddd, 1 H, *J* 14.0, 11.5, and 3.1 Hz, H-3*a*).

Anal. Calc. for $C_{22}H_{28}O_6$: C, 68.0; H, 7.27. Found: C, 67.8; H, 7.01.

*Methyl 4,6-O-benzylidene-3-*O-*[(methylthio)thiocarbonyl]-β-*D-*galactopyranoside* (**25**). — A mixture of **2** (2.82 g, 10 mmol), imidazole (30 mg), and sodium hydride dispersion (50% in oil; 620 mg, 13 mmol) was stirred in dry tetrahydrofuran (40 mL) for 30 min at room temperature. Carbon disulfide (5 mL) was added, followed by methyl iodide (1.5 mL) after 1 h. Dichloromethane (150 mL) was added after 1 h, and the organic phase was washed with water (50 mL) and saturated aqueous sodium hydrogencarbonate (50 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 1:2) of the residue gave **25** (2.18 g, 59%), m.p. 155–158°, $[\alpha]_D^{25}$ +150° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.75 (dd, 1 H, *J* 10.0 and 3.9 Hz, H-3), 5.52 (s, 1 H, PhC*H*), 4.62 (bd, 1 H, *J* 3.7 Hz, H-4), 4.37 (dd, 1 H, *J* 12.3 and 1.5 Hz, H-6), 4.35 (d, 1 H, *J* 7.6 Hz, H-1), 4.22 (dd, 1 H, *J* 10.3 and 7.8 Hz, H-2, shifted to δ 5.59 on acetylation), 4.10 (dd, 1 H, *J* 12.4 and 2.0 Hz, H-6), 3.60 (s, 3 H, MeO), 3.56 (bs, 1 H, H-5), 2.58 (s, 3 H, MeS).

Anal. Calc. for $C_{16}H_{20}O_6S_2$: C, 51.6; H, 5.41. Found: C, 51.7; H, 5.43.

*Methyl 2-O-acetyl-4,6-*O-*benzylidene-3-*O-*[(methylthio)thiocarbonyl]-β-*D-*galactopyranoside* (**26**). — Acetylation of **25** (1.50 g, 4.03 mmol) as described for **22**, with column chromatography (ethyl acetate–hexane, 1:3) of the product, gave **26** (1.60 g, 96%), m.p. 179–180°, $[\alpha]_D^{25}$ +116° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.84 (dd, 1 H, *J* 10.3 and 3.7 Hz, H-3), 5.59 (dd, 1 H, *J* 10.2 and 8.0 Hz, H-2), 5.53 (s, 1 H, PhC*H*), 4.62 (bd, 1 H, *J* 3.9 Hz, H-4), 4.52 (d, 1 H, *J* 8.0 Hz, H-1), 4.38 (dd, 1 H, *J* 12.4 and 1.7 Hz, H-6), 4.11 (dd, 1 H, *J* 12.3 and 1.8 Hz, H-6), 3.58 (bs, 1 H, H-5), 3.54 (s, 3 H, MeO), 2.50 (s, 3 H, MeS), 2.07 (s, 3 H, Ac).

Anal. Calc. for $C_{18}H_{22}O_7S_2$: C, 52.2; H, 5.35. Found: C, 52.0; H, 5.34.

*Methyl 2-O-acetyl-4,6-*O-*benzylidene-3-deoxy-β-*D-xylo-*hexopyranoside* (**27**). — Barton reduction[10] of **26** (1.24 g, 3.00 mmol) as described for **19**, with column chromatography (ethyl acetate–hexane, 2:3) of the product, gave **27** (734 mg,

79%), m.p. 170–171°, $[\alpha]_D^{25}$ −54° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.52 (s, 1 H, PhC*H*), 5.10 (ddd, 1 H, *J* 11.1, 7.9, and 5.4 Hz, H-2), 4.42 (d, 1 H, *J* 8.0 Hz, H-1), 4.33 (dd, 1 H, *J* 12.3 and 1.4 Hz, H-6), 4.08 (dd, 1 H, *J* 12.3 and 2.1 Hz, H-6), 4.08 (m, 1 H, H-4), 3.53 (s, 3 H, MeO), 3.52 (bs, 1 H, H-5), 2.46 (ddd, 1 H, *J* 13.7, 5.3, and 2.6 Hz, H-3*e*), 2.06 (s, 3 H, Ac), 1.75 (ddd, 1 H, *J* 13.7, 11.5, and 3.7 Hz, H-3*a*).

Anal. Calc. for $C_{16}H_{20}O_6$: C, 62.3; H, 6.54. Found: C, 62.4; H, 6.60.

*Methyl 4,6-O-benzylidene-3-deoxy-β-*D-xylo-*hexopyranoside* (**28**). — A solution of **27** (675 mg, 2.19 mmol) in dichloromethane (10 mL) was treated with methanolic 0.1M sodium methoxide (1.0 mL) for 16 h, then neutralised with acetic acid (6 μL), washed with water (3 mL), dried, and concentrated to give **28** (571 mg, 98%), m.p. 237–238°, $[\alpha]_D^{25}$ −93° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$ plus 1 drop of D_2O): δ 5.52 (s, 1 H, PhC*H*), 4.33 (dd, 1 H, *J* 12.3 and 1.1 Hz, H-6), 4.19 (d, 1 H, *J* 7.8 Hz, H-1), 4.10 (bs, 1 H, H-4), 4.09 (dd, 1 H, *J* 12.4 and 2.0 Hz, H-6), 3.88 (ddd, 1 H, *J* 11.3, 7.7, and 5.3 Hz, H-2), 3.58 (s, 3 H, MeO), 3.50 (bs, 1 H, H-5), 2.38 (ddd, 1 H, *J* 13.9, 5.2, and 2.7 Hz, H-3*e*), 1.71 (ddd, 1 H, *J* 14.0, 11.6, and 3.5 Hz, H-3*a*).

Anal. Calc. for $C_{14}H_{18}O_5$: C, 63.2; H, 6.81. Found: C, 63.2; H, 6.86.

*Methyl 2-O-benzyl-4,6-O-benzylidene-3-deoxy-β-*D-xylo-*hexopyranoside* (**29**). — Sodium hydride (50% in oil, 154 mg, 3.20 mmol) was dissolved (sonication, 6 h) in methyl sulfoxide (10 mL) under nitrogen at room temperature[20]. Compound **28** (530 mg, 1.99 mmol) was added with stirring, followed by benzyl bromide (478 μL, 4.00 mmol) after 30 min. Dichloromethane (100 mL) was added after 3 h and the solution was washed with water (3 × 10 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 2:3) of the residue gave **29** (694 mg, 98%), m.p. 97–106°, $[\alpha]_D^{25}$ −23° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.51 (s, 1 H, PhC*H*), 4.86 and 4.61 (ABq, 2 H, *J* 11.5 Hz, PhCH_2), 4.34 (d, 1 H, *J* 7.8 Hz, H-1), 4.32 (dd, 1 H, *J* 12.4 and 1.5 Hz, H-6), 4.07 (bs, 1 H, H-4), 4.06 (dd, 1 H, *J* 12.4 and 2.0 Hz, H-6), 3.73 (ddd, 1 H, *J* 11.5, 7.6, and 5.1 Hz, H-2), 3.59 (s, 3 H, MeO), 3.46 (bs, 1 H, H-5), 2.40 (ddd, 1 H, *J* 14.2, 5.1, and 2.7 Hz, H-3*e*), 1.74 (ddd, 1 H, *J* 14.2, 11.5, and 3.4 Hz, H-3*a*).

Anal. Calc. for $C_{21}H_{24}O_5$: C, 70.8; H, 6.79. Found: C, 70.9; H, 6.84.

*Methyl 2,6-di-O-benzyl-3-deoxy-β-*D-xylo-*hexopyranoside* (**30**). — Benzylidene reduction[11a] of **29** (534 mg, 1.50 mmol) as described for **13**, with column chromatography (ethyl acetate–hexane–dichloromethane, 1:2:4) of the product, gave **30** (330 mg, 61%) as a syrup, $[\alpha]_D^{25}$ −25° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.81 and 4.62 (ABq, 2 H, *J* 11.7 Hz, PhCH_2), 4.62 and 4.56 (ABq, 2 H, *J* 12.0 Hz, PhCH_2), 4.31 (d, 1 H, *J* 7.6 Hz, H-1), 4.00 (m, 1 H, H-4, shifted to δ 5.08 on acetylation), 3.75 (dd, AB-type, 1 H, *J* 10.3 and 5.4 Hz, H-6), 3.71 (dd, AB-type, 1 H, *J* 10.0 and 4.6 Hz, H-6), 3.63 (ddd, 1 H, *J* 11.5, 7.6, and 5.2 Hz, H-2), 3.62 (bt, 1 H, *J* 4.6 Hz, H-5), 3.57 (s, 3 H, MeO), 2.30 (ddd, 1 H, *J* 13.7, 5.2, and 3.3 Hz, H-3*e*), 1.60 (ddd, *J* 13.4, 11.5, and 3.2 Hz, H-3*a*).

Anal. Calc. for $C_{21}H_{26}O_5$: C, 70.4; H, 7.31. Found: C, 70.1; H, 7.17.

*Methyl 2,6-di-*O*-benzyl-3-*O*-methyl-4-*O*-(2,3,4,6-tetra-*O*-benzyl-α- and -β-*D*-galactopyranosyl)-β-*D*-galactopyranoside* (**31** *and* **34**). — A mixture of **13** (125 mg, 0.323 mmol), tetraethylammonium bromide (81 mg, 0.39 mmol), and molecular sieves (4 Å, 0.5 g) was dried at 0.1 Torr overnight. A solution of freshly prepared 2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranosyl bromide (~0.94 mmol) in dichloromethane (7 mL) was then added followed by dry *N,N*-dimethylformamide (0.3 mL). The mixture was protected from light and boiled under reflux for 4 days under dry nitrogen[26], and then filtered through Celite using dichloromethane (25 mL). The organic phase was washed with saturated aqueous sodium hydrogencarbonate (5 mL) and water (5 mL), dried, and concentrated. Column chromatography (ethyl acetate–hexane, 2:5; then ethyl acetate–dichloromethane, 1:19) of the residue gave **31** (150 mg, 51%) and **34** (12 mg, 4%) as syrups; **13** (32 mg, 25%) was recovered. Compound **31** had $[\alpha]_D^{25}$ +41° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.96 (d, 1 H, *J* 3.6 Hz, H-1'), 4.24 (d, 1 H, *J* 7.6 Hz, H-1), 3.54 (s, 3 H, MeO), 3.34 (s, 3 H, MeO).

Anal. Calc. for $C_{56}H_{62}O_{11}$: C, 73.8; H, 6.86. Found: C, 73.4; H, 6.69.

Compound **34** was characterised as the hepta-acetate **36** (see below).

*Methyl 4-*O*-α-D-galactopyranosyl-3-*O*-methyl-β-D-galactopyranoside* (**32**) *and methyl 2,6-di-*O*-acetyl-3-*O*-methyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl)-β-D-galactopyranoside* (**33**). — Pd/C (10%, 90 mg) was added to a solution of **31** (157 mg, 0.173 mmol) in acetic acid (7.5 mL). The mixture was hydrogenated for 30 min at atmospheric pressure, then filtered, and concentrated. A solution of the syrupy residue in water (4 mL) was lyophilised to give amorphous **32** (63 mg, 98%), $[\alpha]_D^{25}$ +114° (*c* 1, water). ^{1}H-N.m.r. data (D_2O): δ 4.92 (d, 1 H, *J* 3.6 Hz, H-1'), 4.36 (d, 1 H, *J* 7.6 Hz, H-1), 4.27 (bs, 1 H, H-4), 4.23 (t, 1 H, *J* 6.8 Hz, H-5'), 4.04 (bs, 1 H, H-4'), 3.56 (s, 3 H, MeO), 3.47 (s, 3 H, MeO), 3.34 (dd, 1 H, *J* 10.3 and 2.7 Hz, H-3).

Conventional acetylation of **32** (~2 mg) gave **33** sufficient to obtain the following ^{1}H-n.m.r. data ($CDCl_3$): δ 5.54 (bd, 1 H, *J* 3.2 Hz, H-4'), 5.36 (dd, 1 H, *J* 10.8 and 3.2 Hz, H-3'), 5.23 (dd, 1 H, *J* 11.2 and 3.6 Hz, H-2'), 5.07 (dd, 1 H, *J* 10.1 and 7.6 Hz, H-2), 5.06 (d, 1 H, *J* 3.6 Hz, H-1'), 4.60 (bt, 1 H, *J* 6.8 Hz, H-5'), 4.42 (dd, 1 H, *J* 11.0 and 6.3 Hz, H-6), 4.33 (d, 1 H, *J* 7.6 Hz, H-1), 4.12 to 4.04 (m, 3 H, H-6,6',6'), 4.00 (bd, 1 H, *J* 2.5 Hz, H-4), 3.69 (bt, 1 H, *J* 6.8 Hz, H-5), 3.48 (s, 3 H, MeO), 3.41 (s, 3 H, MeO), 3.25 (dd, 1 H, *J* 10.1 and 2.9 Hz, H-3), 2.12, 2.10, 2.09, 2.07, 2.04, and 1.97 (6 s, each 3 H, 6 Ac).

*Methyl 4-*O*-β-D-galactopyranosyl-3-*O*-methyl-β-D-galactopyranoside* (**35**) *and methyl 2,6-di-*O*-acetyl-3-*O*-methyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-β-D-galactopyranoside* (**36**). — Debenzylation of **34** (28.3 mg, 31.0 μmol), as described for **32**, and lyophilisation gave amorphous **35** (10.9 mg, 95%), $[\alpha]_D^{25}$ +14° (*c* 1, water). ^{1}H-N.m.r. data (D_2O): δ 4.47 (d, 1 H, *J* 7.6 Hz, H-1 or H-1'), 4.42 (bd, 1 H, *J* 2.4 Hz, H-4 or H-4'), 4.30 (d, 1 H, *J* 7.8 Hz, H-1 or H-1'), 3.85 (bd, 1 H, *J* 3.0 Hz, H-4 or H-4'), 3.51 (s, 3 H, MeO), 3.44 (s, 3 H, MeO), 3.37 (dd, 1 H, *J* 10.0 and 2.9 Hz, H-3).

Conventional acetylation of **35** (10.9 mg, 29.5 μmol) and column chromatography (ethyl acetate–hexane, 2:1) of the product gave **36** (16 mg, 87%), m.p. 157–158°, $[\alpha]_D^{25}$ −8° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.37 (bd, 1 H, *J* 2.2 Hz, H-4′), 5.17 (dd, 1 H, *J* 10.4 and 7.9 Hz, H-2′), 5.05 (dd, 1 H, *J* 10.4 and 3.6 Hz, H-3′), 5.05 (dd, 1 H, *J* 10.1 and 7.9 Hz, H-2), 4.76 (d, 1 H, *J* 7.9 Hz, H-1′), 4.40 (dd, 1 H, *J* 11.9 and 4.7 Hz, H-6), 4.28 (d, 1 H, *J* 7.9 Hz, H-1), 4.22 (dd, 1 H, *J* 11.9 and 7.2 Hz, H-6), 4.14 (dd, AB-type, 1 H, *J* 10.8 and 6.5 Hz, H-6′), 4.13 (bd, 1 H, *J* 3.2 Hz, H-4), 4.08 (dd, AB-type, 1 H, *J* 10.8 and 6.5 Hz, H-6′), 3.86 (bt, 1 H, *J* 6.8 Hz, H-5′), 3.62 (bt, 1 H, *J* 6.1 Hz, H-5), 3.45 (s, 3 H, MeO), 3.42 (s, 3 H, MeO), 3.26 (dd, 1 H, *J* 9.9 and 2.7 Hz, H-3), 2.16, 2.11, 2.08, 2.08, 2.04, and 1.96 (6 s, each 3 H, 6 Ac).

Anal. Calc. for $C_{26}H_{38}O_{17}$: C, 50.2; H, 6.15. Found: C, 50.2; H, 6.16.

*Methyl 2,6-di-*O*-benzyl-3-deoxy-3-*C*-methyl-4-*O*-(2,3,4,6-tetra-*O*-benzyl-α-*D*-galactopyranosyl)-β-*D*-galactopyranoside* (**37**). — Reaction of **17** (120 mg, 0.323 mmol) with 2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranosyl bromide (~1.01 mmol), as described for **31**, gave, after column chromatography (ethyl acetate–hexane, 4:19) of the product, **37** (130 mg, 45%) as a syrup, and **17** (48 mg, 40%) was recovered. Compound **37** had $[\alpha]_D^{25}$ +43° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.28 (d, 1 H, *J* 7.6 Hz, H-1), 3.58 (s, 3 H, MeO), 3.25 (dd, 1 H, *J* 11.0 and 7.6 Hz, H-2), 1.75 (m, 1 H, H-3), 1.18 (d, 3 H, *J* 6.8 Hz, CH_3-CH).

Anal. Calc. for $C_{56}H_{62}O_{10}$: C, 75.1; H, 6.98. Found: C, 75.1; H, 6.80.

*Methyl 3-deoxy-4-*O*-α-D-galactopyranosyl-3-*C*-methyl-β-D-galactopyranoside* (**38**) *and methyl 2,6-di-*O*-acetyl-3-deoxy-3-*C*-methyl-4-*O*-(2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl)-β-D-galactopyranoside* (**39**). — Debenzylation of **37** (123 mg, 0.138 mmol), as described for **32**, gave amorphous **38** (48 mg, 98%), $[\alpha]_D^{25}$ +100° (*c* 1, water). ^{1}H-N.m.r. data (D_2O): δ 4.92 (d, 1 H, *J* 3.9 Hz, H-1′), 4.34 (d, 1 H, *J* 7.8 Hz, H-1), 4.16 (bt, 1 H, *J* 6.8 Hz, H-5′), 4.01 (bd, 1 H, *J* 3.0 Hz, H-4′), 3.55 (s, 3 H, MeO), 3.33 (dd, 1 H, *J* 11.2 and 7.8 Hz, H-2), 1.86 (m, 1 H, H-3), 1.16 (d, 3 H, *J* 6.6 Hz, CH_3CH).

Conventional acetylation of **38** (~2 mg) gave **39** sufficient to obtain the following ^{1}H-n.m.r. data ($CDCl_3$): δ 5.52 (bd, 1 H, *J* 2.9 Hz, H-4′), 5.35 (dd, AB-type, 1 H, *J* 11.1 and 3.0 Hz, H-3′), 5.27 (dd, AB-type, 1 H, *J* 11.1 and 3.5 Hz, H-2′), 5.09 (d, 1 H, *J* 3.7 Hz, H-1′), 4.87 (dd, 1 H, *J* 11.5 and 7.6 Hz, H-2), 4.48 (bt, 1 H, *J* 6.2 Hz, H-5′), 4.38 (dd, 1 H, *J* 11.2 and 6.8 Hz, H-6), 4.33 (d, 1 H, *J* 7.6 Hz, H-1), 4.23 (dd, 1 H, *J* 11.2 and 6.1 Hz, H-6), 4.13 (dd, AB-type, 1 H, *J* 11.1 and 6.7 Hz, H-6′), 4.08 (dd, AB-type, 1 H, *J* 11.0 and 6.6 Hz, H-6′), 3.73 (bt, 1 H, *J* 6.1 Hz, H-5), 3.71 (bs, 1 H, H-4), 3.49 (s, 3 H, MeO), 2.13, 2.12, 2.09, 2.07, 2.03, and 1.98 (6 s, each 3 H, 6 Ac), 1.90 (m, 1 H, H-3), 1.12 (d, 3 H, *J* 6.8 Hz, CH_3-CH).

*Methyl 6-*O*-benzyl-2-*O*-benzyloxymethyl-3-deoxy-4-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranosyl)-β-D-xylo-hexopyranoside* (**40**). — Reaction of **24** (100 mg, 0.258 mmol) with 2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranosyl bromide (~0.77 mmol) as described for **31**, with column chromatography (ethyl acetate–

hexane, 1:2 → 1:1) of the product, gave **40** (116 mg, 49%) as a syrup, and **24** (42 mg, 42%) was recovered. Compound **40** had $[\alpha]_D^{25}$ +21° (*c* 1, chloroform). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.99 (d, 1 H, *J* 2.9 Hz, H-1′), 3.55 (s, 3 H, MeO), 2.62 (m, 1 H, H-3*e*), 1.58 (m, 1 H, H-3*a*).

Anal. Calc. for $C_{56}H_{62}O_{11}$: C, 73.8; H, 6.86. Found: C, 73.4; H, 6.70.

*Methyl 3-deoxy-4-*O*-α-*D*-galactopyranosyl-β-*D*-xylo-hexopyranoside* (**41**) *and methyl 2,6-di-*O*-acetyl-3-deoxy-4-*O*-(2,3,4,6-tetra-*O*-acetyl-α-*D*-galactopyranosyl)-β-*D*-xylo-hexopyranoside* (**42**). — Debenzylation of **40** (86 mg, 94.6 μmol), as described for **32**, gave amorphous **41** (30 mg, 93%), $[\alpha]_D^{25}$ +62° (*c* 1, water). ^{1}H-N.m.r. data (D_2O): δ 4.98 (d, 1 H, *J* 4.0 Hz, H-1′), 4.35 (d, 1 H, *J* 7.9 Hz, H-1), 3.55 (s, 3 H, MeO), 2.33 (m, 1 H, H-3*e*), 1.71 (m, 1 H, H-3*a*).

Conventional acetylation of **41** (~2 mg) gave **42** sufficient to obtain the following ^{1}H-N.m.r. data ($CDCl_3$): δ 5.55 (bd, 1 H, *J* 2.9 Hz, H-4′), 5.37 (dd, 1 H, *J* 10.8 and 3.2 Hz, H-3′), 5.17 (d, AB-type, 1 H, *J* 4.0 Hz, H-1′), 5.12 (dd, AB-type, 1 H, *J* 10.6 and 3.8 Hz, H-2′), 4.87 (ddd, 1 H, *J* 11.9, 7.7, and 4.7 Hz, H-2), 4.49 (bt, 1 H, *J* 6.8 Hz, H-5′), 4.38 (d, 1 H, *J* 7.9 Hz, H-1), 4.37 (dd, 1 H, *J* 10.8 and 6.8 Hz, H-6), 4.16 (dd, 1 H, *J* 11.0 and 6.3 Hz, H-6′), 4.10 (dd, 1 H, *J* 10.8 and 6.5 Hz, H-6), 4.09 (dd, 1 H, *J* 10.8 and 7.2 Hz, H-6′), 3.79 (bt, 1 H, *J* 5.8 Hz, H-5), 3.76 (bs, 1 H, H-4), 3.53 (s, 3 H, MeO), 2.58 (ddd, 1 H, *J* 13.7, 4.5, and 3.6 Hz, H-3*e*), 2.13, 2.09, 2.06, 2.04, 2.01, and 1.98 (6 s, each 3 H, 6 Ac), 1.62 (ddd, 1 H, *J* 13.8, 11.5, and 2.7 Hz, H-3*a*).

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