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CYCLIC ACETALS OF 4,1′,6′-TRICHLORO-4,1′,6′-TRIDEOXY-*galacto*-SUCROSE* AND THEIR CONVERSION INTO METHYL ETHER DERIVATIVES†

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ABSTRACT

The acid-catalysed reaction of 4,1′,6′-trichloro-4,1′,6′-trideoxy-*galacto*-sucrose[2] (**1**) with 5.5 equiv. of 2-methoxypropene in *N,N*-dimethylformamide followed by acetylation gave 3′,4′-di-*O*-acetyl-4,1′,6′-trichloro-4,1′,6′-trideoxy-2,3-*O*-isopropylidene-6-*O*-(1-methoxy-1-methylethyl)-*galacto*-sucrose (**2**, 2%), 6,3′,4′-tri-*O*-acetyl-4,1′,6′-trichloro-4,1′,6′-trideoxy-2,3-*O*-isopropylidene-*galacto*-sucrose (**3**, 31%), 3′,4′-di-*O*-acetyl-4,1′,6′-trichloro-4,1′,6′-trideoxy-2,3-*O*-isopropylidene-*galacto*-sucrose (**4**, 38%), 3′-*O*-acetyl-4,1′,6′-trichloro-4,1′,6′-trideoxy-2,3-*O*-isopropylidene-*galacto*-sucrose (**5**, 13%), and 2,3′,4′-tri-*O*-acetyl-4,1′,6′-trichloro-4,1′,6′-trideoxy-*galacto*-sucrose (**6**, 13%). Methylation of **4** followed by removal of the protecting groups gave 4,1′,6′-trichloro-4,1′,6′-trideoxy-6-*O*-methyl-*galacto*-sucrose (**8**). 4,1′,6′-Trichloro-4,1′,6′-trideoxy-3-*O*-methyl-*galacto*-sucrose (**11**) was synthesised from **6** by preferential *tert*-butyldiphenylsilylation of HO-6 followed by methylation and removal of the protecting groups. Likewise, 4,1′,6′-trichloro-4,1′,6′-trideoxy-4′-*O*-methyl-*galacto*-sucrose (**14**) was synthesised from **5**. Treatment of **3** with aqueous acetic acid followed by methylation and removal of the protecting groups afforded 4,1′,6′-trichloro-4,1′,6′-trideoxy-2,3-di-*O*-methyl-*galacto*-sucrose (**17**).

INTRODUCTION

Acetonation is a widely used method for the protection of carbohydrate diols[2]. We have described[3] the acetonation of sucrose, using 2-methoxypropene–*N,N*-dimethylformamide–toluene-*p*-sulphonic acid, to afford kinetic products. We now report the application of this reagent to 4,1′,6′-trichloro-4,1′,6′-trideoxy-*galacto*-sucrose[4] (**1**).

*4-Chloro-4-deoxy-α-D-galactopyranosyl 1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside.

†Sucrochemistry, Part 42. For Part 41, see ref. 1, which is incorrectly numbered Part 40.

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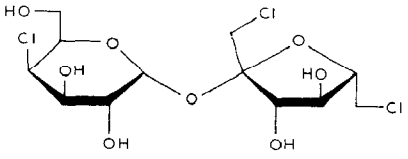
RESULTS AND DISCUSSION

The kinetic acetonation of **1** with 5.5 mol. equiv. of the 2-methoxypropene reagent at 70° for 3 h followed by acetylation gave, after chromatography on silica gel, 4-chloro-4-deoxy-2,3-*O*-isopropylidene-6-*O*-(1-methoxy-1-methylethyl)-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**2**, 2%), 6-*O*-acetyl-4-chloro-4-deoxy-2,3-*O*-isopropylidene-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**3**, 31%), 4-chloro-4-deoxy-2,3-*O*-isopropylidene-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**4**, 38%), 4-chloro-4-deoxy-2,3-*O*-isopropylidene-α-D-galactopyranosyl 3-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**5**, 13%), and 2-*O*-acetyl-4-chloro-4-deoxy-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**6**, 13%). Formation of the partially acetylated derivatives **4**–**6**, under the conditions in which a large excess of acetic anhydride was used, can be explained on the basis that the corresponding acyclic acetal [$Me_2C(OMe)$] groups were lost in the work-up after acetylation.



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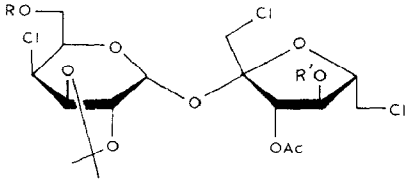
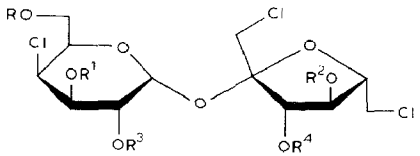


2 R = CMe_2OMe, R′ = Ac
3 R = R′ = Ac
4 R = H, R′ = Ac
5 R = R′ = H
7 R = Me, R′ = Ac
12 R = $^tBuPh_2Si$, R′ = H



6 R = R^1 = H, R^2 = R^3 = R^4 = Ac
8 R = Me, R^1 = R^2 = R^3 = R^4 = H
9 R = $^tBuPh_2Si$, R^1 = H, R^2 = R^3 = R^4 = Ac
10 R = $^tBuPh_2Si$, R^1 = Me, R^2 = R^3 = R^4 = Ac
11 R = R^2 = R^3 = R^4 = H, R^1 = Me
14 R = R^1 = R^3 = R^4 = H, R^2 = Me
15 R = R^2 = R^4 = Ac, R^1 = R^3 = H
16 R = R^2 = R^4 = Ac, R^1 = R^3 = Me
17 R = R^2 = R^4 = H, R^1 = R^3 = Me

The ^{1}H-n.m.r. spectrum of **2** contained resonances for 4 Me groups (δ 1.92, 1.42, 1.36) and a MeO group (δ 3.17), which indicated the presence of an acyclic and a cyclic acetal group. The resonances due to H-2 (δ 4.02) and H-3 (δ 4.08) appeared at a relatively higher field, consistent with a 2,3-acetal. The low-field signals at δ 5.68 (d) and 5.38 (t), assigned to H-3′ and H-4′ ($J_{3',4'}$ 6.5 Hz), reflected acetylation at positions 3′ and 4′. It was concluded that **2**, which was not stable at room temperature, had an acyclic acetal group at C-6.

The ^{1}H-n.m.r. spectrum of **3** indicated a 2,3-acetal group at C-2,3 and acetate groups at positions 3′, 4′, and 6. The ^{1}H-n.m.r. spectrum of **4** contained signals at δ 1.41 and 1.45 (2 s, CMe_2), and 2.05 and 2.10. The resonances due to H-3′,4′ appeared at δ 5.70 and 5.46, respectively, confirming the location of the acetate groups. Addition of trichloroacetyl isocyanata to the n.m.r. solution caused the appearance of a singlet at δ 9.36 due to the imino proton and shifted the signals due to H-6 (δ 4.44 → 4.56), which confirmed that HO-6 in **4** was not substituted. Similarly, the presence of a 2,3-acetal, AcO-3′, and HO-4′,6 in **5** were confirmed by ^{1}H-n.m.r. spectroscopy. The ^{1}H-n.m.r. spectrum of **6** contained signals at δ 1.94, 2.00, and 2.10 due to AcO-2 (H-2, δ 5.22), AcO-3′ (H-3′, δ 5.63), and AcO-4′ (H-4′, δ 5.64), but no signals for CMe_2.

Methylation of **4** with diazomethane–boron trifluoride etherate[5] at 0° gave the 6-methyl ether **7** (82%), the ^{1}H-n.m.r. spectrum of which contained a singlet for MeO at δ 3.40. The resonances due to H-6,6′ were at δ 3.83 and 3.87, and were shifted upfield (0.77 p.p.m.) when compared to the signals for the 6-acetate. The mass spectrum of **7** contained a 3:1 doublet at *m/z* 235 and a 9:6:1 triplet at *m/z* 283 due to hexopyranosyl and ketofuranosyl cations, respectively. Treatment of **7** with aqueous acetic acid for 10 min at 70° followed by deacetylation with methanolic sodium methoxide gave the 6-methyl ether **8** (70%). In the ^{13}C-n.m.r. spectrum of **8**, the signal of C-6 appeared downfield (10 p.p.m.) and that of C-5 upfield (4 p.p.m.) when compared with those of **1**[6] and sucrose[7].

Synthesis of the 3-methyl ether **11** from **6** involved treatment with 1.1 equiv. of *tert*-butyldiphenylsilyl chloride in pyridine in the presence of a catalytic amount of 4-dimethylaminopyridine at room temperature for 24 h to give, after chromatography, the 6-*tert*-butyldiphenylsilyl ether **9** (67%). Methylation of **9** with diazomethane–boron trifluoride etherate in dichloromethane at 0° gave the 3-methyl ether **10**, desilylation of which, with tetrabutylammonium fluoride followed by Zemplén deacetylation, gave **11**. The ^{13}C-n.m.r. spectrum of **11** showed that the resonance due to C-3 was shifted downfield (9 p.p.m.) relative to the corresponding signals for **1** and sucrose[7]. The β-effect was observed only for C-4 (+6.0 p.p.m.). These results coupled with the ^{1}H-n.m.r. and mass-spectral data for **9** and **10** confirmed the structures of **9**–**11**.

The crystalline 4′-methyl ether **14** (81%) was synthesised from **5** by selective *tert*-butyldiphenylsilylation of HO-6 (→ **12**), followed by methylation (→ **13**), desilylation, deacetylation, and deacetalation with aqueous acetic acid. The ^{13}C resonance for C-4′ of **14** was shifted downfield (9 p.p.m.) compared to those for **1** and sucrose[7]. Little or no β-effect was observed for C-5′ or C-3′.

Deacetalation of **3** with aqueous acetic acid for 10 min at 70° gave 97% of crystalline **15**. Methylation of **15** (→ **16**) and then deacetylation gave the 2,3-dimethyl ether **17** (60%). In the ^{13}C-n.m.r. spectrum of **17**, the signals of C-2 and C-3 appeared downfield (7.7 p.p.m.) when compared with those of **1** and sucrose[7]. A β-effect was observed for C-4 (+5.0 p.p.m.). These results, coupled with the ^{1}H-n.m.r. and mass-spectral data for **15** and **16**, confirmed the structures of **15–17**.

EXPERIMENTAL

For details of general procedures, see ref. 8.

Reaction of **1** *with 2-methoxypropene in* N,N-*dimethylformamide.* — A solution of **1** (18 g) in dry *N,N*-dimethylformamide (100 mL) was stirred with 2-methoxypropene (18 mL, 5.5 mol. equiv.) in the presence of dry toluene-*p*-sulphonic acid (80 mg) for 3 h at 70°. The mixture was treated with acetic anhydride (75 mL) and pyridine (100 mL) at room temperature and then poured into ice–water, the precipitate was collected and washed with water, and a solution in ether was dried (Na_2SO_4) and concentrated. The residue was eluted from a column of silica gel (600 g) with ether–light petroleum (1:1). The following products were obtained thus.

4-Chloro-4-deoxy-2,3-*O*-isopropylidene-6-*O*-(1-methoxy-1-methylethyl)-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**2**; 0.5 g, 1.9%). ^{1}H-n.m.r. data (250 MHz, $CDCl_3$): δ 5.68 (d, 1 H, $J_{1,2}$ 3.0 Hz, H-1), 4.02 (dd, 1 H, $J_{2,3}$ 7.0 Hz, H-2), 4.08 (dd, 1 H, $J_{3,4}$ 3.0 Hz, H-3), 4.53 (bs, 1 H, H-4), 4.15–4.50 (m, 4 H, H-5,5′,6a,6b), 5.68 (d, 1 H, $J_{3',4'}$ 6.5 Hz, H-3′), 5.38 (t, 1 H, $J_{4',5'}$ 6.5 Hz, H-4′), 3.50–3.80 (m, 4 H, H-1′a,1′b,6′a,6′b), 3.17 (s, 3 H, OMe), 1.92 (s, 6 H, 2 Me), 1.34, 1.42 (2 s, 6 H, 2 Me), 2.02, 2.04 (2 s, 6 H, 2 Ac). Compound **2** was not stable on storage at 0°.

6-*O*-Acetyl-4-chloro-4-deoxy-2,3-*O*-isopropylidene-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**3**; 8 g, 31.3%), $[\alpha]_D$ +45° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.68 (d, 1 H, $J_{1,2}$ 3.0 Hz, H-1), 4.03 (dd, 1 H, $J_{2,3}$ 7.0 Hz, H-2), 4.08 (dd, 1 H, $J_{3,4}$ 3.0 Hz, H-3), 4.53 (bs, 1 H, H-4), 4.15–4.50 (m, 4 H, H-5,5′,6a,6b), 5.66 (d, 1 H, $J_{3',4'}$ 6.5 Hz, H-3′), 5.38 (t, 1 H, $J_{4',5'}$ 6.5 Hz, H-4′), 3.50–3.80 (m, 4 H, H-1′a,1′b,6′a,6′b), 1.38, 1.43 (2 s, 6 H, 2 Me), 2.05, 2.07, 2.09 (3 s, 9 H, 3 Ac). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 263 (a), 283 (b), 223 (b).

Anal. Calc. for $C_{21}H_{29}Cl_3O_{11}$: C, 44.8; H, 5.2; Cl, 18.7. Found: C, 44.4; H, 5.1; Cl, 18.5.

4-Chloro-4-deoxy-2,3-*O*-isopropylidene-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**4**; 9.1 g, 38%), $[\alpha]_D$ +48° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.74 (d, 1 H, $J_{1,2}$ 3.0 Hz, H-1), 4.06 (dd, 1 H, $J_{2,3}$ 7.0 Hz, H-2), 4.10 (dd, 1 H, $J_{3,4}$ 3.0 Hz, H-3), 4.70 (bs, 1 H, H-4), 4.20–4.55 (m, 2 H, H-5,5′), 5.70 (d, 1 H, $J_{3',4'}$ 7.0 Hz, H-3′), 5.46 (t, 1 H,

$J_{4',5'}$ 7.0 Hz, H-4′), 3.60–4.0 (m, 4 H, H-1′a,1′b,6′a,6′b), 1.41, 1.45 (2 s, 6 H, 2 Me), 2.21, 2.20 (2 s, 6 H, 2 Ac); after the addition of trichloroacetyl isocyanate, δ 5.76 (d, 1 H, $J_{1,2}$ 3.0 Hz, H-1), 4.06 (dd, 1 H, $J_{2,3}$ 6.0 Hz, H-2), 4.12 (dd, 1 H, $J_{3,4}$ 2.5 Hz, H-3), 4.66 (bs, 1 H, H-4), 4.44–4.56 (m, 2 H, H-6a,6b), 4.11–4.40 (m, 2 H, H-5,5′), 5.72 (d, 1 H, $J_{3',4'}$ 8.0 Hz, H-3′), 5.54 (t, 1 H, $J_{4',5'}$ 8.0 Hz, H-4′), 3.50–3.80 (m, 4 H, H-1′a,1′b,6′a,6′b), 9.36 (s, 1 H, NH), 1.43, 1.48 (2 s, 6 H, 2 Me), 2.10, 2.20 (2 s, 6 H, 2 Ac). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 283 (b), 223 (b), 221 (a).

Anal. Calc. for $C_{19}H_{27}Cl_3O_{10}$: C, 43.7; H, 5.2; Cl, 20 Found: C, 44.2; H, 5.3; Cl, 20.2.

4-Chloro-4-deoxy-2,3-*O*-isopropylidene-α-D-galactopyranosyl 3-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**5**; 2.8 g, 12.9%), $[\alpha]_D$ +49° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.74 (d, 1 H, $J_{1,2}$ 2.5 Hz, H-1), 4.02–4.20 (m, 2 H, H-2,3), 5.38 (bs, 1 H, H-4), 4.20–4.50 (m, 4 H, H-5,5′,6a,6b), 5.47 (d, 1 H, $J_{3',4'}$ 8.0 Hz, H-3′), 3.56–4.0 (m, 4 H, H-1′a,1′b,6′a,6′b), 1.42, 1.46 (s, 6 H, 2 Me), 2.18 (s, 3 H, 1 Ac); after the addition of trichloroacetyl isocyanate, δ 5.72 (d, 1 H, $J_{1,2}$ 3.0 Hz, H-1), 4.06 (dd, 1 H, $J_{2,3}$ 7.0 Hz, H-2), 4.14 (dd, 1 H, $J_{3,4}$ 2.5 Hz, H-3), 4.68 (bs, 1 H, H-4), 4.44–4.60 (m, 4 H, H-5,5′,6a,6b), 5.73 (d, 1 H, $J_{3',4'}$ 7.5 Hz, H-3′), 5.54 (t, 1 H, $J_{4',5'}$ 7.5 Hz, H-4′), 3.60–4.0 (m, 4 H, H-1′a,1′b,6′a,6′b), 1.42, 1.46 (2 s, 2 Me), 2.20 (s, 3 H, Ac), 8.86, 8.98 (s, 2 H, NH). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 241 (b), 221 (a).

Anal. Calc. for $C_{17}H_{25}Cl_3O_9$: C, 42.5; H, 5.2; Cl, 22.2. Found: C, 42.2; H, 5.5; Cl, 20.8.

2-*O*-Acetyl-4-chloro-4-deoxy-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**6**; 3.1 g, 13.1%), $[\alpha]_D$ +9° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.76 (d, 1 H, $J_{1,2}$ 2.9 Hz, H-1), 5.22 (dd, 1 H, $J_{2,3}$ 10.6 Hz, H-2), 4.09–4.55 (m, 2 H), 4.06–4.21 (m, 4 H), 3.53–3.63 (2 d, 2 H, $J_{1'a,1'b}$ 12.0 Hz, H-1′a,1′b), 5.63 (t, 1 H, $J_{3',4'}$ 10.5 Hz, H-3′), 5.64 (dd, 1 H, $J_{4',5'}$ 13.8 Hz, H-4′), 3.75–3.91 (m, 2 H), 1.96, 2.0, 2.1 (3 s, 9 H, 3 Ac). Mass spectrum [9:6:1 triplet due to ketofuranosyl cation]: *m/z* 283, 223.

Anal. Calc. for $C_{18}H_{25}Cl_3O_{11}$: C, 41.3; H, 4.8; Cl, 20.3. Found: C, 40.8; H, 4.5; Cl, 20.3.

*4-Chloro-4-deoxy-2,3-*O*-isopropylidene-6-*O*-methyl-α-D-galactopyranosyl 3,4-di-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside* (**7**). — Compound **4** (4.15 g) was stirred with a freshly prepared solution of diazomethane in dichloromethane (50 mL) and boron trifluoride etherate (0.05 mL) for 2 h at −5°. The mixture was filtered, washed with aqueous sodium hydrogencarbonate and water, dried (Na_2SO_4), and concentrated. The residue was eluted from a column of silica gel (150 g), using ether–light petroleum (2:3), to give **7**, isolated as a syrup (3.5 g, 82.1%), $[\alpha]_D$ +53° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.69 (d, 1 H, $J_{1,2}$ 3.0 Hz, H-1), 4.01 (dd, 1 H, $J_{2,3}$ 9.6 Hz, H-2), 4.18 (dd, 1 H, $J_{3,4}$ 3.1 Hz, H-3), 4.55 (bs, 1 H, $J_{4,5}$ 1.8 Hz, H-4), 4.23–4.27 (m, 2 H, H-5,5′), 3.83, 3.87

(dd, 2 H, H-6a,6b), 5.70 (d, 1 H, $J_{3',4'}$ 7.0 Hz, H-3'), 5.44 (t, 1 H, $J_{4',5'}$ 7.0 Hz, H-4'), 3.55–3.69 (m, 4 H, H-1'a, 1'b,6'a,6'b), 3.40 (s, 3 H, OMe), 2.09, 2.10 (2 s, 6 H, 2 Ac), 1.39, 1.46 (2 s, 6 H, 2 Me). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 283 (b), 235 (a), 223 (b).

Anal. Calc. for $C_{20}H_{29}Cl_3O_{10}$: C, 44.8; H, 5.4; Cl, 19.9. Found: C, 44.3; H, 5.4; Cl, 19.8.

4-Chloro-4-deoxy-6-O-methyl-α-D-galactopyranosyl 1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**8**). — A solution of **7** (3.5 g) in aq. 60% acetic acid (25 mL) was heated for 10 min at 70°, then co-concentrated with toluene, and the resulting syrup was treated with a catalytic amount of sodium methoxide in methanol (50 mL) for 5 h at room temperature. The solution was deionised with Zerolit DM-F mixed-bed resin (CO_2^- form) and concentrated, and the syrupy residue was eluted from a column of silica gel (200 g) with ethyl acetate–acetone (1:1) to give **8** (1.9 g, 70.7%), $[\alpha]_D$ +76° (*c* 1, water). ^{13}C-N.m.r. data (60 MHz, D_2O): δ 104.7 (C-2'), 94.0 (C-1), 82.6 (C-5'), 77.5 (C-3'), 77.0 (C-4'), 74.0 (C-5), 70.4 (C-6), 69.4, 69.0 (C-2, C-3), 64.7 (C-4), 60.2 (MeO), 46.1 (C-6'), 45.0 (C-1').

Anal. Calc. for $C_{13}H_{21}Cl_3O_8$: C, 37.9; H, 5.1; Cl, 25.9. Found: C, 37.4; H, 5.3; Cl, 24.1.

2-O-Acetyl-6-O-tert-butyldiphenylsilyl-4-chloro-4-deoxy-α-D-galactopyranosyl 3,4-di-O-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**9**). — A solution of **6** (3.3 g) in dry pyridine was stirred with *tert*-butyldiphenylsilyl chloride (1.75 mL, 1.1 mol. equiv.) and 4-dimethylaminopyridine (200 mg) for 24 h at room temperature, then poured into ice-water, and extracted with ether. The extract was dried (Na_2SO_4) and concentrated. The syrupy residue was eluted from a column of silica gel, using ether–light petroleum (1:2), to afford **9** (3.82 g, 79.6%), $[\alpha]_D$ +40° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.51 (d, 1 H, $J_{1,2}$ 4.0 Hz, H-1), 5.61 (dd, 1 H, $J_{2,3}$ 10.0 Hz, H-2), 4.67 (sd, 1 H, H-4), 4.00–4.50 (m, 4 H, H-5, H-6a,6b,5'), 5.64 (d, 1 H, $J_{3',4'}$ 7.0 Hz, H-3'), 5.35 (t, 1 H, $J_{4',5'}$ 7.0 Hz, H-4'), 2.14, 2.02, 2.01 (3 s, 9 H, 3 Ac), 7.20–7.80 (aromatic). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 457 (a), 283 (b), 223 (b).

Anal. Calc. for $C_{34}H_{43}Cl_3O_{11}Si$: C, 53.6; H, 5.6; Cl, 14.0. Found: C, 53.4; H, 5.3; Cl, 13.7.

2-O-Acetyl-6-O-tert-butyldiphenylsilyl-4-chloro-4-deoxy-3-O-methyl-α-D-galactopyranosyl 3,4-di-O-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**10**). — Methylation of **9** (3.3 g), as described for **7**, gave **10** as a syrup (3.25 g, 97%), $[\alpha]_D$ +57° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.57 (d, 1 H, $J_{1,2}$ 3.85 Hz, H-1), 5.16 (dd, 1 H, $J_{2,3}$ 10.29 Hz, H-2), 3.79 (dd, 1 H, $J_{3,4}$ 3.75 Hz, H-3), 4.70 (sd, 1 H, $J_{4,5}$ 2.0 Hz, H-4), 4.35 (t, 1 H, $J_{5,6a} = J_{5,6b}$ = 6.50 Hz, H-5), 3.73–3.83, 4.22 (m, 3 H, $J_{6a,6b}$ 12.0 Hz, H-6a,6b,5'), 5.68 (d, 1 H, $J_{3',4'}$ 6.62 Hz, H-3'), 5.41 (t, 1 H, $J_{4',5'}$ 6.62 Hz, H-4'), 3.46–3.69 (m, 4 H, H-1'a,1'b,6'a,6'b), 3.48 (s, 3 H, OMe), 3.46–3.69 (s, 9 H, 3 Ac), 7.30–7.80 (m, aromatic). Mass spectrum

[(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 471 (a), 283 (b), 223 (b).

Anal. Calc. for $C_{35}H_{45}Cl_3O_{11}Si$: C, 54.1; H, 5.8; Cl, 13.7. Found: C, 54.0; H, 5.7; Cl, 13.3.

*4-Chloro-4-deoxy-3-*O*-methyl-α-*D*-galactopyranosyl 1,6-dichloro-1,6-dideoxy-β-*D*-fructofuranoside* (**11**). — A solution of **10** (3.5 g) in dry tetrahydrofuran (40 mL) was treated with M tetrabutylammonium fluoride in tetrahydrofuran (4.5 mL, 1.2 mol. equiv.) for 4 h at room temperature, then concentrated. The syrupy residue was deacetylated with sodium methoxide in methanol to give a syrup which, on elution from a column of silica gel (dichloromethane–methanol, 15:1), afforded **11** (1.1 g, 59.3%), $[\alpha]_D$ +57° (*c* 1, water). ^{13}C-N.m.r. data (60 MHz, D_2O): δ 105.9 (C-2′), 95.0 (C-1), 83.8 (C-5′), 79.5 (C-2), 78.5 (C-3′), 77.8 (C-4′), 73.1 (C-5), 69.2 (C-3), 64.0 (C-6), 61.1 (MeO), 58.6 (C-4), 47.3 (C-6′), 46.1 (C-1′).

Anal. Calc. for $C_{13}H_{21}Cl_3O_8$: C, 38.0; H, 5.1; Cl, 25.9. Found: C, 37.6; H, 5.1; Cl, 23.3.

*6-*O*-tert-Butyldiphenylsilyl-4-chloro-4-deoxy-2,3-*O*-isopropylidene-α-*D*-galactopyranosyl 3-*O*-acetyl-1,6-dichloro-1,6-dideoxy-β-*D*-fructofuranoside* (**12**). — A solution of **5** (3 g) in dry pyridine (30 mL) was stirred with *tert*-butyldiphenylsilyl chloride (2 mL, 1.1 mol. equiv.) and 4-dimethylaminopyridine (200 mg) for 24 h at room temperature, then poured into ice–water, and extracted with ether. The extract was dried (Na_2SO_4) and concentrated. The residue was eluted from a column of silica gel, using ether–light petroleum (1:2), to afford **12**, isolated as a syrup (3.0 g, 66.8%), $[\alpha]_D$ +25° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.63 (d, 1 H, $J_{1,2}$ 3.0 Hz, H-1), 4.02–4.20 (m, 2 H, H-2,3), 4.80 (bs, 1 H, H-4), 4.50 (m, 1 H, H-5), 4.20 (m, 2 H, H-6a,6b), 5.58 (d, 1 H, $J_{3',4'}$ 7.0 Hz, H-3′), 3.56–4.0 (m, 4 H, H-1′a,1′b,6′a,6′b), 1.41, 1.42 (2 s, 6 H, 2 Me), 2.06 (s, 3 H, Ac). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 459 (a), 241 (b), 303 (a).

Anal. Calc. for $C_{33}H_{43}Cl_3O_9Si$: C, 55.2; H, 6.0; Cl, 14.8. Found: C, 55.2; H, 6.1; Cl, 14.5.

*6-*O*-tert-Butyldiphenylsilyl-4-chloro-4-deoxy-2,3-*O*-isopropylidene-α-*D*-galactopyranosyl 3-*O*-acetyl-1,6-dichloro-1,6-dideoxy-4-*O*-methyl-β-*D*-fructofuranoside* (**13**). — Methylation of **12** (2 g), as described for **7**, gave, after chromatography on silica gel, **13** (1.9 g, 93.2%), m.p. 109–110° (from ether–light petroleum), $[\alpha]_D$ +2° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$: δ 5.65 (d, 1 H, $J_{1,2}$ 2.8 Hz, H-1), 3.94 (dd, 1 H, $J_{2,3}$ 9.6 Hz, H-2), 4.02 (dd, 1 H, $J_{3,4}$ 2.7 Hz, H-3), 4.81 (bs, 1 H, H-4), 5.77–5.90 (m, 2 H, H-5,5′), 3.75, 3.93 (dd, 2 H, $J_{5,6a}$ 5.5 Hz, $J_{5,6b}$ 9.6 Hz, H-6a,6b), 3.61, 3.71 (d, 2 H, $J_{1'a,1'b}$ 12.0 Hz, H-1′a,1′b), 5.56 (d, 1 H, $J_{3',4'}$ 6.0 Hz, H-3′), 3.96 (t, 1 H, $J_{4',5'}$ 6.0 Hz, H-4′), 3.55, 3.64 (dd, 2 H, $J_{5',6a}$ 5.2, $J_{5',5b}$ 5.7, $J_{6'a,6'b}$ 9.7 Hz, H-6′a,6′b), 3.37 (s, 3 H, OMe), 2.10 (s, 3 H, Ac), 1.42, 1.46 (2 s, 6 H, 2 Me), 7.00–8.00 (aromatic). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 459 (a), 255 (b), 223 (b), 203 (a).

Anal. Calc. for $C_{34}H_{45}Cl_3O_9Si$: C, 55.7; H, 6.2; Cl, 14.5. Found: C, 55.8; H, 6.4; Cl, 14.5.

4-Chloro-4-deoxy-α-D-galactopyranosyl 1,6-dichloro-1,6-deoxy-4-O-methyl-β-D-fructofuranoside (**14**). — Desilylation of **13** (1.2 g) and then deacetylation, as described for **11**, gave **14** (0.5 g, 74.1%), m.p. 68–69° (from ether–light petroleum), $[\alpha]_D$ +94° (*c* 1, water). ^{13}C-N.m.r. data (60 MHz, D_2O): δ 106.5 (C-2′), 95.3 (C-1), 87.3 (C-4′), 83.0 (C-5′), 78.5 (C-3′), 73.4 (C-5), 70.7 (C-2), 70.2 (C-3), 65.6 (C-4), 64.0 (C-6), 61.1 (MeO), 47.8 (C-6′), 46.0 (C-1′).

Anal. Calc. for $C_{13}H_{21}Cl_3O_8$: C, 37.9; H, 5.1; Cl, 25.9. Found: C, 37.4; H, 5.2; Cl, 25.3.

6-O-Acetyl-4-chloro-4-deoxy-α-D-galactopyranosyl 3,4-di-O-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**15**). — Compound **3** (5.0 g) was deacetalated with aq. 60% acetic acid, as described for **8**, to give **15** (4.2 g, 94.4%), m.p. 143–144° (from ether), $[\alpha]_D$ +45° (*c* 1, chloroform). ^{1}H-N.m.r. data (250 MHz, $CDCl_3$): δ 5.49 (d, 1 H, $J_{1,2}$ 2.70 Hz, H-1), 2.96 (d, 1 H, $J_{2,3}$ 7.0 Hz, H-2), 3.26 (d, 1 H, $J_{3,4}$ 3.1 Hz, H-3), 4.45 (st, 1 H, $J_{4,5}$ 2.0 Hz, H-4), 4.52 (m, 1 H, H-5), 4.21, 4.32 (dd, 2 H, $J_{5,6a}$ 4.9, $J_{5,6b}$ 4.6, $J_{6a,6b}$ 10.6 Hz, H-6a,6b), 5.67 (d, 1 H, $J_{3',4'}$ 7.0 Hz, H-3′), 5.45 (t, 1 H, $J_{4',5'}$ 7.0 Hz, H-4′), 3.96 (m, 1 H, H-5′), 3.82, 3.83 (s, 2 H, H-1′a,1′b), 3.77 (s, 2 H, $J_{6'a,6'b}$ 0.0 Hz, H-6′a,6′b), 2.09, 2.10, 2.13 (3 s, 9 H, 3 Ac). Mass spectrum [9:6:1 triplet due to ketofuranosyl cation]: *m/z* 283, 223.

Anal. Calc. for $C_{18}H_{25}Cl_3O_{11}$: C, 41.3; H, 4.8; Cl, 20.3. Found: C, 41.5; H, 4.5; Cl, 20.2.

6-O-Acetyl-4-chloro-4-deoxy-2,3-di-O-methyl-α-D-galactopyranosyl 3,4-di-O-acetyl-1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**16**). — Methylation of **15** (4.0 g), as described for **7**, and elution of the resulting syrup from a column of silica gel, using ether–light petroleum (1:1), gave **16** (2.5 g, 59.3%), m.p. 120–121° (from ether–light petroleum), $[\alpha]_D$ +52° (*c* 1, chloroform). N.m.r. data: ^{1}H (250 MHz, $CDCl_3$), δ 5.50 (d, 1 H, $J_{1,2}$ 2.9 Hz, H-1), 3.78 (dd, 1 H, $J_{2,3}$ 6.3 Hz, H-2), 3.84 (dd, 1 H, $J_{3,4}$ 2.9 Hz, H-3), 4.44–4.49 (m, 2 H, H-4,5), 4.22, 4.35 (dd, 2 H, $J_{5,6a}$ 4.0, $J_{5,6b}$ 4.5, $J_{6a,6b}$ 11.6 Hz, H-6a,6b), 3.63, 3.67 (s, 2 H, H-1′a,1′b), 5.75 (d, 1 H, $J_{3',4'}$ 7.0 Hz, H-3′), 5.43 (t, 1 H, $J_{4',5'}$ 7.0 Hz, H-4′), 4.14–4.28 (m, 1 H, H-5′), 3.57–3.62 (t, 2 H, H-6′a,6′b), 6.51, 6.54 (2 sd, 6 H, 2 OMe), 2.11, 2.09, 2.10 (3 s, 9 H, 3 Ac); ^{13}C (60 MHz, CD_6CO), δ 104.10 (C-2′), 93.3 (C-1), 81.4 (C-5′), 76.4 (C-3′), 75.9 (C-4′), 71.9 (C-5), 69.7 (C-2), 68.9 (C-3), 64.7 (C-6), 62.3 (C-4), 46.1 (C-6′), 45.4 (C-1′). Mass spectrum [(a) 3:1 doublet due to hexopyranosyl cation, (b) 9:6:1 triplet due to ketofuranosyl cation]: *m/z* 283 (b), 251 (a), 223 (b), 219 (a).

Anal. Calc. for $C_{20}H_{29}Cl_3O_{11}$: C, 43.5; H, 5.3; Cl, 19.3. Found: C, 43.4; H, 5.2; Cl, 19.0.

4-Chloro-4-deoxy-2,3-di-O-methyl-α-D-galactopyranosyl 1,6-dichloro-1,6-dideoxy-β-D-fructofuranoside (**17**). — Conventional deacetylation of **16** (2.4 g) gave **17** (1.75 g, 95%), m.p. 163–164° (from acetone–ether), $[\alpha]_D$ +105° (*c* 1, methanol). ^{13}C-N.m.r. data (60 MHz, C_2D_6CO): δ 104.4 (C-2′), 91.4 (C-1), 83.6 (C-5′), 77.8 (C-4′), 77.7, 77.3 (C-2, C-3), 71.2 (C-5), 62.9 (C-6), 60.7 (C-4), 59.9, 56.2 (2 MeO), 46.4 (C-6′), 44.8 (C-1′).

Anal. Calc. for $C_{14}H_{23}Cl_3O_8$: C, 39.5; H, 5.4; Cl, 25.0. Found: C, 39.6; H, 5.6; Cl, 24.8.

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