

Preparation of 4,6-cyclo-4,6-dideoxy-hexopyranoses by palladium-mediated intramolecular cyclodehalogenation *

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ABSTRACT

4,6-Cyclo-4,6-dideoxy-hexopyranoses were obtained by palladium-mediated intramolecular cyclodehalogenation. Thus, methyl 2,3-di-*O*-acetyl-4,6-dideoxy-4,6-diiodo- β -D-galactopyranoside (**3**) afforded methyl 2,3-di-*O*-acetyl-4,6-cyclo-4,6-dideoxy- β -D-galactopyranoside (**5**) in 56% yield upon treatment with hydrogen in the presence of palladium-on-charcoal and diethylamine. The structure of **5** was proven by MS, NMR including NOE measurements, and by independent conversion of **4** to **5** by zinc-mediated Wurtz synthesis. Similarly, methyl 2,3-di-*O*-acetyl-4,6-cyclo-4,6-dideoxy- α -D-galactopyranoside (**6**) and *O*-(2,3-di-*O*-acetyl-4,6-cyclo-4,6-dideoxy- α -D-galactopyranosyl)-(1 \rightarrow 4)-1,2,3,6-tetra-*O*-acetyl- β -D-glucopyranose (**17**) were obtained along with the respective 4,6-dideoxy analogues. Also methyl 2,3-di-*O*-acetyl-4,6-dideoxy-4,6-diiodo- β -D-glucopyranoside (**19**) gave *galacto*-configured **5** stereoselectively.

INTRODUCTION

A number of cyclopropanated sugars have been described which are either spiro-cyclopropyl derivatives [in positions C-1 (ref 1), C-2 (ref 2), C-3 (ref 3), C-4 (ref 4), and C-5 (refs 5 and 6) of pyranoses] or ring-anellated compounds. Of the latter, besides a small number of 3,4-*C*-methylene-furanoses^{6–8}, mainly 2,3-*C*-methylene-furanoses were prepared⁹, to some extent as nucleoside analogues¹⁰. In the pyranose series, the corresponding 2,3-*C*-methylene derivatives¹¹ were synthesized, and more recently also 3,4-*C*-methylene-pyranoses¹². 3-Alkoxy-2-oxanorcaranes, which can be viewed as simple 4,5-*C*-methylene-pyranoses, were prepared as acid-labile compounds¹³. We now describe the synthesis of pyranoid sugars with a 4,5-anellated cyclopropyl ring starting from 4,6-dideoxy-4,6-diiodo-hexopyranosides.

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RESULTS AND DISCUSSION

Although the hydrogenation of monoiododeoxy sugars to yield deoxy sugars is a standard conversion, the analogous hydrogenation of diiodo sugars in the presence of palladium catalysts is cumbersome so that, in one successful reaction of that kind, no yield was given¹⁴. We studied the reaction of methyl 2,3-di-*O*-acetyl-4,6-dideoxy-4,6-diiodo- β -D-galacto-pyranoside (**3**), obtained in excellent yield (95%) by treatment of the known diol **1** (ref 15) with iodine, imidazole, and triphenylphosphine according to Garegg et al.¹⁴. When **3** was subjected to hydrogenation in the presence of palladium-on-carbon and diethylamine¹⁶ in 1,4-dioxane, methyl 2,3-di-*O*-acetyl-4,6-cyclo-4,6-dideoxy- β -D-galactopyranoside * (**5**) was isolated as the main product (56%) along with the dideoxy compound **7** (24%).

The formation of a cyclopropyl ring in **5** was supported by the MS data and was obvious from the ¹H NMR spectrum which typically showed two protons at high field (0.87 and 0.77 ppm in CDCl₃). The assignments of the pyranose ring protons in the ¹H NMR spectrum of **5** were confirmed by a series of selective decoupling experiments. Since the coupling constant $J_{3,4}$ does not unequivocally allow determination of the configuration at C-4, the latter was deduced from NOE experiments (see Table I). Thus, a NOE from H-2 to H-6 was only compatible with a *galacto* configuration, NOEs from H-1 or H-3 to H-6, as expected for a *gluco* configuration, were not detected. The H-6 proton showing a NOE upon saturation of H-2 is H-6_{endo} by definition. As a control for this assignment, saturation of H-5 gave only an NOE for the second H-6 which is H-6_{exo}. Thus, H-6_{endo} (δ 0.87) is downfield of H-6_{exo} (δ 0.77), opposite to the expectation for a carbocyclic system¹⁷. The assignment of H-6_{endo} and H-6_{exo} is, however, in keeping with literature data¹⁸ on smaller ³J_{H,Htrans} values (e.g., $J_{4,6endo}$ 7.2 Hz) than ³J_{H,Hcis} values (e.g., $J_{4,6exo}$ 10.2 Hz). Very remarkable, in the ¹H NMR spectrum of **5**, are the big differences in the coupling constants of the *trans* protons ($J_{4,6endo}$ 7.2, $J_{5,6endo}$ 2.9 Hz) as well as the *cis* protons ($J_{4,6exo}$ 10.2, $J_{5,6exo}$ 5.8 Hz), which means that the cyclopropyl ring largely deviates from its ideal symmetry. This effect is probably due to the influence of the pyranose ring oxygen since, in the published sugar-anellated cyclopropyl ring structures, the respective *cis* and *trans* couplings were found identical or very similar ($\Delta \delta < 0.5$ Hz)^{10,11,19}. Based on the practically unchanged coupling constant of $J_{1,2}$ 8.2 Hz compared to **3** the conformation of **5** can be described as ²H₁ half-chair conformation (or a sofa conformation). Half-chair conformations were also found for other cyclopropyl anellated pyranoses^{12,19}. A boat conformation, as assigned to some pyranoid epoxides²⁰ or sugar aziridines²¹, can be excluded on the basis of the coupling constants determined.

* This name is developed from a 4,6-dideoxyhexose parent by applying IUPAC Rule F-4.1, using the prefix "cyclo" with appropriate locants to establish a direct link between two atoms in a parent structure. The stereochemistry at C-4 is defined in the *galacto* designator.

conditions, as described above for the conversion of **3** in a very clean reaction, furnished the cyclopropyl derivative **6** and the known¹⁴ dideoxy compound **8** in a 3:2 ratio. For compound **6**, ¹H NMR coupling constants $J_{2,3}$, $J_{3,4}$, and $J_{4,5}$ were found comparable to **5**, inferring the same configuration for the cyclopropyl attachment and a similar conformation.

Analogous disaccharide diiodides were prepared because of their good crystallinity. The known²³ allyl 4',6'-*O*-isopropylidene- β -maltoside (**9**) was acetylated to give crystalline **10** (89%), which was hydrolyzed in aqueous acetic acid to afford 90% of crystalline **11**. This diol was converted to the crystalline diiodo derivative **12**, following the Garegg procedure¹⁴. For the de-allylation of **12**, we employed palladium chloride–sodium acetate–aqueous acetic acid²⁴ with additional sonication²⁵. In the present example, after acetylation of the crude product mixture, the expected anomeric acetates **13** and **14** were formed (1:1 ratio) in 50–70% yield. In one case, a chromatographic separation gave 7.4% of pure **13** and 22% of pure **14** along with 28% yield of **13**–**14** mixture (28%). In addition, the oxopropyl β -maltoside **15** was isolated in 30% yield. Its structure is supported by the FAB MS data, as well as from the occurrence of methylene protons and an additional acetyl signal in the ¹H NMR spectrum. As judged by TLC, this compound is formed during the treatment with palladium chloride. The fact that only a β -oxopropyl derivative was isolated hints at the direct oxidation of the β -allyl precursor **12**. Analogous oxopropyl glycosides obtained during de-allylation were reported by Ogawa and associates²⁶. It is noted, in the ¹H NMR spectra of all *galacto*-configured iodides **2**, **4**, and **12**–**15**, that H-4 resonates at very low field ($\delta_{\text{H-4}}$ 4.84–4.93).

Hydrogenation of the diiodide **13** in the presence of palladium-on-carbon afforded a 1:1 mixture of the dideoxy compound **16** and the cyclopropyl derivative **17** in 70–90% yield, the latter being easily identified on TLC due to its blue-violet colour after sulfuric acid treatment and heating. The structure of **17** was confirmed by the ¹H NMR spectrum which shows coupling constants for the cyclopropyl-anelated ring nearly identical to those in monosaccharide **6**. Compound **17** crystallised as fine needles that, up to now, failed to furnish crystals suitable for X-ray analysis.

Finally, the reaction of a *gluco*-configured 4,6-diiodo derivative was investigated. Thus, compound **19** was synthesized from methyl 2,3-di-*O*-acetyl- β -D-galactopyranoside²⁷ (**18**) by standard iodination¹⁴. Hydrogenation of **19** furnished the same *galacto*-configured 4,6-cyclo-hexapyranoside **5** which was obtained from the *galacto*-diiodide **3** in a clean reaction together with **7**, albeit in a somewhat lower proportion (**5** to **7** = 2:3).

Almost similar results were obtained in zinc-mediated cyclopropanations²⁸ in ethanol which further chemically proves the cyclopropyl structures obtained. Treatment of **4** gave **6** in 15% yield, and **19** also gave the *galacto*-configured derivative **5** as well, in a lower yield of 9%. Low yields in intramolecular Wurtz syntheses with 1,3-diiodo derivatives are imminent²⁹.

The palladium-mediated reaction investigated by us is not a Wurtz type reaction

since treatment of **4** with palladium, under the usual reaction conditions but without employing hydrogen, did not lead to any conversion. As investigated for the conversion of **4** to **6** and **8**, base is imperative for the reaction, whereas the nonprotic solvent can be varied. High pressure resulted in a better yield of **6** with respect to **8**, but the reaction time had no significant influence. The reactions, presented in this paper, can thus be described as stereoselective palladium-catalyzed intramolecular cyclodehalogenations. A related type of conversion has been described only for chlorinated aromatic compounds³⁰.

The 4,6-cyclo-4,6-dideoxy-hexopyranosides, described here for the first time, complement the series of known carbohydrate cyclopropyl derivatives, and they may have potential as glycosidase inhibitors.

EXPERIMENTAL

General. — Solvents and reagents were purchased from Fluka. Solutions were evaporated below 50°C on a Büchi rotary evaporator. Qualitative TLC was performed with precoated silica gel 60F₂₅₄ plates (Merck) and compounds were detected by UV light (254 nm) and spraying with a 10% solution of H₂SO₄ in MeOH followed by charring. Medium pressure liquid chromatography (MPLC) was carried out on Lobar columns (Merck Lichroprep Si 60, 40–63 µm) at 2–5 bar (Labomatic MD 80/100 pump). Melting points were determined with a Büchi 510 capillary apparatus and are uncorrected. Optical rotations were measured on a Perkin–Elmer 241 spectrometer in a 1-dm cell. ¹H NMR spectra were recorded on Bruker AC 250 (250 MHz) and AM-400 (400 MHz) spectrometers with an Aspect 3000 and process controller. Chemical shifts are given in ppm relative to Me₄Si as the internal standard. Mass spectra were recorded on the following equipment: MS 902 with data system DS 2050 (VG) for fab, VG 7070F with SS 300 (Finnigan MAT) for CI (NH₃), TSP 46 (Finnigan MAT) for thermospray, and API III Sciex, Perkin–Elmer for electrospray.

Methyl 2,3-di-O-acetyl-β-D-glucopyranoside (1). — Obtained according to ref 15: mp 110°C, Lit.¹⁵: 109–111°C; ¹H NMR (250 MHz, CDCl₃): δ 5.03 (dd ~ t, 1 H, J_{3,4} 9.0 Hz, H-3), 4.92 (dd, 1 H, J_{2,3} 9.7 Hz, H-2), 4.44 (d, 1 H, J_{1,2} 7.8 Hz, H-1), 3.95 (dd, 1 H, J_{5,6a} 3.6, J_{6a,6b} 12.0 Hz, H-6a), 3.85 (dd, 1 H, J_{5,6b} 4.4 Hz, H-6b), 3.77 (dd ~ t, 1 H, J_{4,5} 9.7 Hz, H-4), 3.51 (s, 3 H, OCH₃), 3.44 (ddd, 1 H, H-5), 2.10 and 2.06 (2s, 6 H, OAc).

Methyl 2,3-di-O-acetyl-4,6-dideoxy-4,6-diiodo-β-D-galactopyranoside (3). — To a solution of **1** (ref 15, 650 mg, 2.3 mmol) in 2:1 toluene–MeCN (15 mL) were added Ph₃P (1.5 g, 5.74 mmol), imidazole (390 mg, 5.72 mmol), and I₂ (1.16 g, 4.57 mmol). After stirring for 3 h at 70°C, the same amounts of Ph₃P, imidazole and I₂ were added, and stirring was continued for 16 h at 70°C. After cooling, the mixture was filtered over filter aid and washed with toluene. The filtrate was washed with cold water, and the organic phase was separated, dried over MgSO₄, and evapo-

rated. Chromatography (1:1 EtOAc–hexane) furnished **3** (1.1 g, 95%) as a solid, $[\alpha]_D^{20} + 29.4^\circ$ (*c* 0.5, dioxane); ^1H NMR data (250 MHz, CDCl_3): δ 5.26 (dd, 1 H, $J_{2,3}$ 10.0 Hz, H-2), 4.84 (dd, 1 H, $J_{3,4}$ 4.0, $J_{4,5}$ 1.5 Hz, H-4), 4.42 (d, 1 H, $J_{1,2}$ 7.9 Hz, H-1), 4.37 (dd, 1 H, H-3), 3.53 (s, 3 H, OCH_3), 3.42 (dd, 1 H, $J_{5,6a}$ 6.6, $J_{6a,6b}$ 10.0 Hz, H-6a), 3.20 (dd, 1 H, $J_{5,6b}$ 6.7 Hz, H-6b), 3.02 (ddd ~ dt, 1 H, H-5), 2.11 (s, 3 H, Ac), 2.07 (s, 3 H, Ac); MS (electrospray): m/z 521 (75%, $[\text{M} + \text{Na}]^+$), 516 (90%, $[\text{M} + \text{NH}_4]^+$), 499 (35%, $[\text{M} + \text{H}]^+$), 467 (100%, $[\text{M} - \text{OCH}_3]^+$). Anal. Calcd for $\text{C}_{11}\text{H}_{16}\text{O}_6$: C, 26.5; H, 3.2. Found: C, 26.7; H, 3.2.

Methyl 2,3-di-O-acetyl-4,6-cyclo-4,6-dideoxy-β-D-galactopyranoside (5). — A. A solution of **3** (200 mg, 0.40 mmol) in dioxane (10 mL) and diethylamine (0.4 mL) was hydrogenated in the presence of Pd–C (160 mg) at 175 bar and room temperature. After 1 h, the catalyst was removed by filtration. The filtrate was evaporated and chromatographed (1:3 acetone–hexane and 2:1 toluene–EtOAc) to give **5** (55 mg, 56%) along with methyl 2,3-di-O-acetyl-4,6-dideoxy-β-D-xylohexopyranoside (**7**, 24 mg, 24%).

B. A solution of **19** (100 mg, 0.20 mmol) in dioxane (5 mL) and diethylamine (0.2 mL) was hydrogenated in the presence of Pd–C (80 mg) at 190 bar and room temperature. After 1 h the catalyst was removed by filtration. The filtrate was evaporated and chromatographed (4:1 toluene–EtOAc) to furnish **5** and **7** (49 mg, ~ 100%) in a 2:3 ratio as determined by NMR (integration of OCH_3 -signals).

C. To a solution of **19** (1.0 g, 2.0 mmol) in EtOH (5 mL) was added zinc powder (ca. 350 mg). After refluxing for 30 min, the mixture was cooled and filtered over Celite. The filtrate was evaporated and purified by column chromatography (4:1 toluene–EtOAc) to give pure **5** (46 mg, 9%) as a syrup, $[\alpha]_D^{20} + 13^\circ$ (*c* 0.1, CHCl_3); ^1H NMR (400 MHz, CDCl_3): δ 5.39 (dd ~ t, 1 H, $J_{3,4}$ 7.4 Hz, H-3), 4.72 (dd ~ t, 1 H, $J_{2,3}$ 8.0 Hz, H-2), 4.34 (d, 1 H, $J_{1,2}$ 8.2 Hz, H-1), 3.69 (ddd, 1 H, $J_{5,6\text{exo}}$ 5.8, $J_{5,6\text{endo}}$ 2.9 Hz, H-5), 3.48 (s, 3 H, OCH_3), 2.07 and 2.06 (2s, 6 H, OAc), 1.59 (dddd ~ dq, 1 H, $J_{4,6\text{exo}}$ 10.2, $J_{4,5}$ 6.5, $J_{4,6\text{endo}}$ 7.2 Hz, H-4), 0.87 (ddd ~ dt, 1 H, $J_{6\text{exo},6\text{endo}}$ 6.2 Hz, H-6_{endo}), 0.77 (ddd ~ dt, 1 H, H-6_{exo}); MS (thermospray): m/z 262 (30%, $[\text{M} + \text{NH}_4]^+$), 185 (100%, $[\text{M} + \text{H}]^+ - \text{AcOH}$). Anal. Calcd for $\text{C}_{11}\text{H}_{16}\text{O}_6$: C, 54.1; H, 6.6. Found: C, 54.4; H, 6.8.

Compound 7 was then eluted as a syrup; $[\alpha]_D^{20} + 11.3^\circ$ (*c* 0.3, dioxane); ^1H NMR (250 MHz, CDCl_3): δ 4.96 (ddd, 1 H, $J_{3,4a}$ 11.2, $J_{3,4e}$ 5.0 Hz, H-3), 4.86 (dd, 1 H, $J_{2,3}$ 9.4 Hz, H-2), 4.30 (d, 1 H, $J_{1,2}$ 7.7 Hz, H-1), 3.64 (ddq, 1 H, $J_{4e,5}$ 1.9, $J_{4a,5}$ 10.9 Hz, H-5), 3.48 (s, 3 H, OCH_3), 2.10 (ddd, 1 H, $J_{4e,4a}$ 12.5 Hz, H-4e), 2.06, 2.02 (2s, 6 H, OAc), 1.50 (ddd ~ br q, 1 H, H-4a), 1.29 (d, 3 H, $J_{5,6}$ 6.2 Hz, H-6); MS (thermospray): m/z 264 (22%, $[\text{M} + \text{NH}_4]^+$), 215 (100%, $[\text{M} + \text{H} - \text{MeOH}]^+$). Anal. Calcd for $\text{C}_{11}\text{H}_{18}\text{O}_6$: C, 53.7; H, 7.4. Found: C, 53.7; H, 7.5.

Methyl 2,3-di-O-acetyl-α-D-glucopyranoside (2). — Obtained according to ref. 22: $[\alpha]_D^{20} + 120^\circ$ (*c* 0.3, dioxane); lit. ²² $[\alpha]_D^{25} + 112.4^\circ$ (*c* 1.0, H_2O); lit. ³¹, $[\alpha]_D^{22} + 75^\circ$ (*c* 0.72, CHCl_3); ^1H NMR (250 MHz, CDCl_3): δ 5.30 (m_c, 1 H, H-3), 4.91 (d, 1 H, $J_{1,2}$ 3.6 Hz, H-1), 4.83 (dd, 1 H, $J_{2,3}$ 10.1 Hz, H-2), 3.87 (m_c, 2 H, H-4, H-5), 3.70 (m_c, 2 H, H-6), 3.40 (s, 3 H, OCH_3), 2.10 and 2.09 (2s, 6 H, OAc).

Methyl 2,3-di-O-acetyl-4,6-dideoxy-4,6-diiodo- α -D-galactopyranoside (4). — To a solution of **2** (ref 22, 14.0 g, 50.3 mmol) in 2:1 toluene–MeCN (500 mL) were added Ph_3P (33.0 g, 125.8 mmol), imidazole (8.56 g, 125.8 mmol), and I_2 (25.53 g, 100.6 mmol). After stirring for 1 h at 70°C, the same amounts of Ph_3P , imidazole, and I_2 were added, and stirring was continued for 4 h at 70°C. The mixture was cooled and filtered over Celite. The filtrate was diluted with toluene and washed with cold water, the organic phase was dried over MgSO_4 , evaporated, and subjected to column chromatography (1:3 EtOAc–hexane) to give pure **4**, mp 88–89°C; $[\alpha]_{\text{D}}^{20} + 126^\circ$ (c 0.5, dioxane); ^1H NMR (250 MHz, CDCl_3): δ 5.15 (dd, 1 H, $J_{1,2}$ 3.8, $J_{2,3}$ 10.5 Hz, H-2), 4.95 (d, 1 H, H-1), 4.86 (dd, 1 H, $J_{4,5} \sim 1$ Hz, H-4), 4.59 (dd, 1 H, $J_{3,4}$ 4.0 Hz, H-3), 3.48 (s, 3 H, OCH_3), 3.41–3.32 (m, 2 H, H-5, H-6a), 3.10 (m, 1 H, H-6b), 2.12 (s, 3 H, OAc), 2.09 (s, 3 H, OAc); FABMS: m/z 537 (10%, $[\text{M} + \text{K}]^+$), 521 (18%, $[\text{M} + \text{Na}]^+$), 499 (30%, $[\text{M} + \text{H}]^+$), 467 (100%, $[\text{MH} - \text{CH}_3\text{OH}]^+$), 407 (40%, $[467 - \text{AcOH}]^+$), 365 (80%, $[407 - \text{CH}_2\text{CO}]^+$). Anal. Calcd for $\text{C}_{11}\text{H}_{16}\text{I}_2\text{O}_6$: C, 26.5; H, 3.2. Found: C, 26.7; H, 3.0.

Methyl 2,3-di-O-acetyl-4,6-cyclo-4,6-dideoxy- α -D-galactopyranoside (6). — A. To a solution of **4** (500 mg, 1.0 mmol) in EtOH (8 mL) was added zinc (ca. 350 mg). After heating at 90°C for 30 min, the mixture was cooled and filtered over celite. The filtrate was evaporated and purified by column chromatography (1:4 EtOAc–toluene) to furnish pure **6** as a colourless syrup (36 mg, 15%).

B. A solution of **4** (100 mg, 0.20 mmol) in dioxane (5 mL) and diethylamine (0.2 mL) was hydrogenated in the presence of 10% Pd–C (80 mg) at 190 bar for 1 h. After filtration, the filtrate was evaporated and chromatographed (1:4 EtOAc–toluene) to furnish 49 mg ($\sim 100\%$) of **6** and methyl 2,3-di-O-acetyl-4,6-dideoxy- α -D-xylo-hexopyranoside¹⁴ (**8**) in a 3:2 ratio as judged by NMR (integrals of OCH_3 and H-3 of both compounds).

Compound **6** was a syrup; $[\alpha]_{\text{D}}^{20} + 185^\circ$ (c 0.1, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.48 (dd, 1 H, $J_{2,3}$ 9.0, $J_{3,4}$ 7.4 Hz, H-3), 4.68 (dd, 1 H, $J_{1,2}$ 2.6 Hz, H-2), 4.60 (d, 1 H, H-1), 3.50 (ddd, 1 H, $J_{4,5}$ 7.0, $J_{5,6\text{endo}}$ 3.4, $J_{5,6\text{exo}}$ 5.4 Hz, H-5), 3.42 (s, 3 H, OCH_3), 2.09 and 2.07 (2s, 6 H, OAc), 1.74 (dddd \sim dq, 1 H, $J_{4,6\text{endo}}$ 7.2, $J_{4,6\text{exo}}$ 9.8 Hz, H-4), 0.80–0.74 (m, 2 H, H-6); ^1H NMR (250 MHz, C_6D_6): δ 5.92 (dd, 1 H, $J_{2,3}$ 9.0, $J_{3,4}$ 7.4 Hz, H-3), 5.00 (dd, 1 H, H-2), 4.70 (d, 1 H, $J_{1,2}$ 2.6 Hz, H-1), 3.14 (ddd, 1 H, $J_{4,5}$ 7.0, $J_{5,6\text{endo}}$ 3.0, $J_{5,6\text{exo}}$ 5.7 Hz, H-5), 3.09 (s, 3 H, OCH_3), 1.69, 1.64 (2s, 6 H, OAc), 1.57 (dddd \sim dq, $J_{4,6\text{exo}}$ 10.0 Hz, H-4), 0.64 (ddd \sim dt, $J_{4,6\text{endo}}$ 7.2 Hz, H-6_{endo}), 0.32 (ddd \sim dt, $J_{6\text{endo},6\text{exo}}$ 6.5 Hz, H-6_{exo}). Anal. Calcd for $\text{C}_{11}\text{H}_{16}\text{O}_6$: C, 54.1; H, 6.6. Found: C, 54.3; H, 6.8.

Allyl O-(2,3-di-O-acetyl-4,6-O-isopropylidene- α -D-glucopyranosyl)-(1 \rightarrow 4)-2,3,6-tri-O-acetyl- β -D-glucopyranoside (10). — To a solution of **9** (ref 23, 40.4 g, 95.6 mmol) in pyridine (226 mL) was added Ac_2O (113 mL) dropwise during 30 min at 0°C. After 16 h at room temperature the solution was concentrated and partitioned between CH_2Cl_2 and water. The organic phase was dried over MgSO_4 , evaporated to dryness, and co-evaporated with toluene. Crystallization of the residue from acetone–hexane furnished colourless crystals of **10** (54.1 g, 89%), mp 182.9–183.1°C;

$[\alpha]_D^{20} + 19.0^\circ$ (*c* 0.2, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.84, 5.27, 5.20, 4.31 and 4.09 (5 H, allyl), 5.31 (d, 1 H, H-1'), 5.27 and 5.25 (2dd \sim t, 2 H, H-3, H-3'), 4.85 (dd, 1 H, $J_{1,2}$ 8.0, $J_{2,3}$ 9.1 Hz, H-2), 4.82 (dd, 1 H, $J_{1',2'}$ 4.0, $J_{2',3'}$ 10.0 Hz, H-2'), 4.57 (d, 1 H, H-1), 4.52 (dd, 1 H, $J_{5,6a}$ 2.6, $J_{6a,6b}$ 12.0 Hz, H-6a), 4.24 (dd, 1 H, $J_{5,6b}$ 4.0 Hz, H-6b), 4.00 (dd \sim t, 1 H, H-4), 3.84–3.81 (m, 1 H, H-5'), 3.73–3.64 (m, 4 H, H-4', H-5, H-6_{a,b}), 2.13 (s, 3 H, OAc), 2.04 (s, 6 H, OAc), 2.02 and 2.00 (2s, 6 H, OAc), 1.44 and 1.37 (2s, 6 H, CH_3); MS (thermospray): *m/z* 650 (100%, $[\text{M} + \text{NH}_4]^+$). Anal. Calcd for $\text{C}_{28}\text{H}_{40}\text{O}_{16}$: C, 53.2; H, 6.4. Found: C, 52.9; H, 6.4.

Allyl O-(2,3-di-O-acetyl- α -D-glucopyranosyl)-(1 \rightarrow 4)-2,3,6-tri-O-acetyl- β -D-glucopyranoside (11). — A solution of **10** (54.0 g, 85.4 mmol) in 80% aq acetic acid (600 mL) was kept at room temperature for 16 h. Evaporation, co-evaporation with toluene, and crystallization from EtOAc–hexane gave pure **11** (45.3 g, 90%), mp 112–114°C; $[\alpha]_D^{20} + 30.0^\circ$ (*c* 0.2, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.84, 5.27, 5.20, 4.32, and 4.10 (5 H, allyl), 5.35 (d, 1 H, $J_{1,2}$ 4.0 Hz, H-1'), 5.25 (dd \sim t, 2 H, H-3, H-3'), 4.87 (dd, 1 H, $J_{1,2}$ 8.0, $J_{2,3}$ 9.5 Hz, H-2), 4.76 (dd, 1 H, $J_{2',3'}$ 10.5 Hz, H-2'), 4.58 (d, 1 H, H-1), 4.53 (dd, 1 H, $J_{5,6a}$ 2.3, $J_{6a,6b}$ 12.1 Hz, H-6a), 4.21 (dd, 1 H, $J_{5,6b}$ 4.2 Hz, H-6b), 4.01 (dd \sim t, 1 H, H-4), 3.82 (br s, 2 H), 3.70–3.66 (m, 3 H), 3.01 (br s, 1 H, OH), 2.27 (br s, 1 H, OH), 2.14, 2.09, 2.05, 2.03, and 2.00 (5s, 15 H, OAc); MS (thermospray): *m/z* 610 (100%, $[\text{M} + \text{NH}_4]^+$). Anal. Calcd for $\text{C}_{25}\text{H}_{36}\text{O}_{16}$: C, 50.7; H, 6.1. Found: C, 50.5; H, 6.1.

Allyl O-(2,3-di-O-acetyl-4,6-dideoxy-4,6-diiodo- α -D-galactopyranosyl)-(1 \rightarrow 4)-2,3,6-tri-O-acetyl- β -D-glucopyranoside (12). — To a solution of **11** (45.3 g, 76.5 mmol) in 1: toluene–tetrahydrofuran (200 mL), were added Ph_3P (60.0 g, 229 mmol), imidazole (31 g, 457 mmol), and I_2 (54 g, 213 mmol). After stirring for 3.5 h at 80°C, the mixture was filtered over Celite. The filtrate was washed with cold water, dried over MgSO_4 , and evaporated. Chromatography over silica gel using 1:1 EtOAc–hexane as eluent and crystallization of the main fraction from EtOAc–hexane furnished pure **12** (45.7 g, 74%), mp 143–148°C; $[\alpha]_D^{20} + 74^\circ$ (*c* 0.2, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.84, 5.27, 5.20, 4.31 and 4.09 (5 H, allyl), 5.39 (d, 1 H, $J_{1,2}$ 4.1 Hz, H-1'), 5.22 (dd \sim t, 1 H, H-3), 5.15 (dd, 1 H, $J_{2',3'}$ 10.7 Hz, H-2'), 4.91 (br d, 1 H, H-4'), 4.86 (dd, $J_{2,3}$ 9.1 Hz, H-2), 4.62 (dd, $J_{5,6a}$ 2.6, $J_{6a,6b}$ 12.1 Hz, H-6a), 4.57 (d, 1 H, $J_{1,2}$ 8.0 Hz, H-1), 4.47 (dd, 1 H, $J_{3',4'}$ 4.0 Hz, H-3'), 4.25 (dd, 1 H, $J_{5,6b}$ 4.7 Hz, H-6b), 4.03 (dd \sim t, 1 H, $J_{3,4}$ 9.4 Hz, H-4), 3.78 (dd, 1 H, $J_{5',6a}$ 5.9, $J_{6a',6b'}$ 10.0 Hz, H-6a'), 3.65 (ddd, 1 H, $J_{4,5}$ 9.4 Hz, H-5), 3.35 (ddd \sim br t, 1 H, $J_{4',5'} \leq 2$ Hz, H-5'), 3.14 (dd, 1 H, $J_{5',6b'}$ 8.0 Hz, H-6b'), 2.16 and 2.11 (2s, 6 H, OAc), and 2.03 (s, 6 H, OAc); MS (thermospray): *m/z* 702 (10%, $[\text{M} + \text{NH}_4]^+ - \text{HI}$), 576 (50%, $[\text{M} + \text{NH}_4 - \text{I}_2]^+$); FABMS: *m/z* 835 (5%, $[\text{M} + \text{Na}]^+$), 830 (4%, $[\text{M} + \text{NH}_4]^+$), 813 (5%, $[\text{M} + \text{H}]^+$). Anal. Calcd for $\text{C}_{25}\text{H}_{34}\text{I}_2\text{O}_{14}$: C, 36.9; H, 4.2; I, 31.2. Found: C, 37.0; H, 4.2; I, 30.9.

O-(2,3-Di-O-acetyl-4,6-dideoxy-4,6-diiodo- α -D-galactopyranosyl)-(1 \rightarrow 4)-1,2,3,6-tetra-O-acetyl- β -D-glucopyranose (13) and O-(2,3-Di-O-acetyl-4,6-dideoxy-4,6-diiodo- α -D-galactopyranosyl)-(1 \rightarrow 4)-1,2,3,6-tetra-O-acetyl- α -D-glucopyranose (14). — A solution of allyl maltoside **12** (10.0 g, 12.3 mmol) in 90% aq acetic acid (500 mL)

was sonicated in the presence of PdCl_2 (8.73 g, 49.3 mmol) and NaOAc (8.73 g) for 2.5 h. The mixture was filtered over a pad of speedex which was washed with toluene. Evaporation gave a crude product which was acetylated with Ac_2O (150 mL) and pyridine (300 mL). After 18 h at room temperature, the mixture was concentrated and partitioned between EtOAc and ice–water. The organic phase was washed with dil H_2SO_4 , NaHCO_3 solution, and water, dried over Na_2SO_4 , and evaporated. One separation using MPLC (4:1 toluene– EtOAc) afforded pure **13** (740 mg, 7.4%) followed by a mixture of **13** and **14** (2.81 g, 28%), and pure **14** (2.20 g, 22%). Finally, oxopropyl *O*-(2,3-di-*O*-acetyl-4,6-dideoxy-4,6-diiodo- α -D-galactopyranosyl)-(1 \rightarrow 4)-2,3,6-tri-*O*-acetyl- β -D-glucopyranoside (**15**, 3.05 g, 30%) was eluted.

Compound **13**: colourless crystals, mp 211–212°C; $[\alpha]_{\text{D}}^{20} + 84.6^\circ$ (*c* 0.24, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.74 (d, 1 H, $J_{1,2}$ 8.1 Hz, H-1), 5.38 (dd, 1 H, $J_{1',2'}$ 4.1 Hz, H-1'), 5.26 (dd ~ t, 1 H, $J_{3,4}$ 8.6 Hz, H-3), 5.16 (dd, 1 H, $J_{2',3'}$ 10.7 Hz, H-2'), 4.98 (dd ~ t, 1 H, $J_{2,3}$ 9.5 Hz, H-2), 4.92 (dd ~ br d, 1 H, H-4'), 4.58 (dd, 1 H, $J_{5,6a}$ 2.5, $J_{6a,6b}$ 12.2 Hz, H-6a), 4.47 (dd, 1 H, $J_{3',4'}$ 4.0 Hz, H-3'), 4.24 (dd, 1 H, $J_{5,6b}$ 4.8 Hz, H-6b), 4.04 (dd ~ t, 1 H, $J_{4,5}$ 9.9 Hz, H-4), 3.81 (ddd, 1 H, H-5), 3.33 (ddd ~ br t, 1 H, H-5'), 3.28 (dd, 1 H, $J_{5',6a'}$ 6.0, $J_{6a',6b'}$ 10.0 Hz, H-6a'), 3.12 (dd, 1 H, $J_{5',6b'}$ 7.5 Hz, H-6b'), 2.16, 2.12, 2.10, 2.07, 2.04, and 2.01 (6s, 18 H, OAc); FABMS: *m/z* 837 (28%, $[\text{M} + \text{Na}]^+$), 755 (45%, $[\text{M} + \text{H} - \text{AcOH}]^+$), 695 (10%, $[\text{M} + \text{H} - 2\text{AcOH}]^+$). Anal. Calcd for $\text{C}_{24}\text{H}_{32}\text{I}_2\text{O}_{15}$: C, 35.4; H, 4.0; I, 31.2. Found: C, 35.7; H, 3.9; I, 31.4.

Compound **14**: Colourless foam, $[\alpha]_{\text{D}}^{20} + 125^\circ$ (*c* 0.2, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 6.24 (d, 1 H, $J_{1,2}$ 3.8 Hz, H-1), 5.49 (dd, 1 H, $J_{2,3}$ 10.1, $J_{3,4}$ 8.5 Hz, H-3), 5.40 (d, 1 H, $J_{1',2'}$ 4.1 Hz, H-1'), 5.18 (dd, 1 H, $J_{2',3'}$ 10.7 Hz, H-2'), 4.97 (dd, 1 H, H-2), 4.93 (dd, 1 H, $J_{4',5'}$ 1.5 Hz, H-4'), 4.60 (dd, 1 H, $J_{5,6a}$ 2.2, $J_{6a,6b}$ 12.3 Hz, H-6a), 4.51 (dd, 1 H, $J_{3',4'}$ 4.0 Hz, H-3'), 4.22 (dd, 1 H, $J_{5,6b}$ 3.7 Hz, H-6b), 4.09 (ddd, 1 H, H-5), 4.04 (dd ~ t, 1 H, $J_{4,5}$ ~ 9.5 Hz, H-4), 3.35 (ddd ~ br t, 1 H, H-5'), 3.28 (dd, 1 H, $J_{5',6a'}$ 5.6, $J_{6a',6b'}$ 10.0 Hz, H-6a'), 3.14 (dd, 1 H, $J_{5',6b'}$ 8.2 Hz, H-6b'), 2.20, 2.16, 2.12, 2.09, 2.06, and 2.00 (6s, 18 H, OAc); FABMS: *m/z* 837 (10%, $[\text{M} + \text{Na}]^+$), 755 (80%, $[\text{M} + \text{H} - \text{AcOH}]^+$), 695 (30%, $[\text{M} + \text{H} - 2\text{AcOH}]^+$). Anal. Calcd for $\text{C}_{24}\text{H}_{32}\text{I}_2\text{O}_{15}$: C, 35.4; H, 4.0; I, 31.2. Found: C, 35.6; H, 4.1; I, 29.7.

Compound **15**: Colourless crystals, mp 132–133°C, $[\alpha]_{\text{D}}^{20} + 71^\circ$ (*c* 0.3, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.39 (d, 1 H, $J_{1',2'}$ 4.1 Hz, H-1'), 5.25 (dd ~ t, 1 H, $J_{3,4}$ 8.9 Hz, H-3), 5.15 (dd, 1 H, $J_{2',3'}$ 10.7 Hz, H-2'), 4.92 (dd ~ t, 2 H, $J_{2,3}$ 9.1 Hz, H-2; dd, H-4'), 4.61 (dd, 1 H, $J_{5,6a}$ 2.6, $J_{6a,6b}$ 12.1 Hz, H-6a), 4.58 (d, 1 H, $J_{1,2}$ 7.9 Hz, H-1), 4.47 (dd, 1 H, $J_{3',4'}$ 4.0 Hz, H-3'), 4.24 (dd, 1 H, $J_{5,6b}$ 4.9 Hz, H-6b), 4.22, 4.14 (2d, 2 H, J_{gem} 16.7 Hz, OCH_2), 4.02 (dd ~ t, 1 H, $J_{4,5}$ 9.7 Hz, H-4), 3.65 (ddd, 1 H, H-5), 3.34 (ddd ~ dt, 1 H, $J_{4',5'}$ 1.3 Hz, H-5'), 3.29 (dd, 1 H, $J_{5',6a'}$ 6.0, $J_{6a',6b'}$ 9.9 Hz, H-6a'), 3.13 (dd, 1 H, $J_{5',6b'}$ 7.5 Hz, H-6b'); 2.16, 2.15, 2.12, 2.06, 2.04, and 2.00 (6s, 18 H, OAc); FABMS: *m/z* 867 (15%, $[\text{M} + \text{K}]^+$), 851 (35%, $[\text{M} + \text{Na}]^+$). Anal. Calcd for $\text{C}_{25}\text{H}_{34}\text{I}_2\text{O}_{15}$: C, 36.9; H, 4.3; I, 29.6. Found: C, 36.9; H, 4.2; I, 29.5.

O-(2,3-Di-O-acetyl-4,6-cyclo-4,6-dideoxy- α -D-galactopyranosyl)-(1 \rightarrow 4)-1,2,3,6-tetra-O-acetyl- β -D-glucopyranose (**17**) and O-(2,3-Di-O-acetyl-4,6-dideoxy- α -D-xylohexopyranosyl)-(1 \rightarrow 4)-1,2,3,6-tetra-O-acetyl- β -D-glucopyranose (**16**). — A solution of **13** (814 mg, 1.0 mmol) in dioxane (25 mL) and dimethylamine (1 mL) was hydrogenated in the presence of 10% Pd-C (400 mg) for 19 h at room temperature and normal pressure. The mixture was filtered over a pad of Celite, and the filtrate was evaporated and purified over silica gel using 3:2 toluene-EtOAc as eluent to give a 1:1 mixture of **16** and **17** (474 mg, 84%). MPLC (1:3 acetone-hexane) afforded successively pure **16** (80 mg, 14%) and **17** (147 mg, 26%).

Compound **16**: Colourless crystals from ether, mp 171.2–172.0°C, $[\alpha]_D^{20} + 62.0^\circ$ (c 0.2, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.74 (d, 1 H, $J_{1,2}$ 8.3 Hz, H-1), 5.32 (d, 1 H, $J_{1',2'}$ 3.9 Hz, H-1'), 5.28 (dd ~ t, 1 H, $J_{3,4}$ 8.7 Hz, H-3), 5.13 (ddd ~ dt, 1 H, $J_{3',4'eq}$ 4.9, $J_{3',4'ax}$ 10.9 Hz, H-3'), 4.98 (dd, 1 H, $J_{2,3}$ 9.3 Hz, H-2), 4.78 (dd, 1 H, $J_{2',3'}$ 10.7 Hz, H-2'), 4.98 (dd, 1 H, $J_{2,3}$ 9.3 Hz, H-2), 4.43 (dd, 1 H, $J_{5,6a}$ 2.2, $J_{6a,6b}$ 12.3 Hz, H-6a), 4.21 (dd, 1 H, $J_{5,6b}$ 4.2 Hz, H-6b), 4.07 (dd ~ t, 1 H, $J_{4,5}$ 9.5 Hz, H-4), 3.88 (ddq, 1 H, $J_{4'eq,5'}$ 2.0, $J_{4'ax,5'}$ 10.9 Hz, H-5'), 3.80 (ddd, 1 H, H-5), 2.14 (ddd, 1 H, H-4'eq), 2.13, 2.10, 2.06 (3s, 9 H, OAc), 2.01 (s, 9 H, OAc), 1.41 (ddd ~ q, 1 H, $J_{4'eq,4'ex}$ ~ 14 Hz, H-4'ax), 1.17 (d, 3 H, H-6'); FABMS: m/z 601 (25%, $[\text{M} + \text{K}]^+$), 585 (50%, $[\text{M} + \text{Na}]^+$), 503 (5%, $[\text{M} + \text{H} - \text{AcOH}]^+$). Anal. Calcd for $\text{C}_{24}\text{H}_{34}\text{O}_{15}$: C, 51.3; H, 6.1. Found: C, 51.3; H, 6.1.

Compound **17**: Colourless crystals from acetone-hexane, mp 163°C, $[\alpha]_D^{20} + 141^\circ$ (c 0.2, dioxane); ^1H NMR (400 MHz, CDCl_3): δ 5.73 (d, 1 H, $J_{1,2}$ 8.3 Hz, H-1), 5.42 (dd, 1 H, $J_{2',3'}$ 9.2, $J_{3',4'}$ 6.8 Hz, H-3'), 5.31 (dd ~ t, 1 H, $J_{3,4}$ 8.8 Hz, H-3), 5.01 (d, 1 H, $J_{1',2'}$ 2.8 Hz, H-1'), 4.98 (dd, 1 H, $J_{2,3}$ 9.7 Hz, H-2), 4.52 (dd, 1 H, H-2'), 4.51 (dd, 1 H, $J_{5,6a}$ 2.1, $J_{6a,6b}$ 12.1 Hz, H-6a), 4.19 (dd, 1 H, $J_{5,6b}$ 5.2 Hz, H-6b), 4.01 (dd ~ t, 1 H, $J_{4,5}$ 10.0 Hz, H-4), 3.79 (ddd, 1 H, H-5), 3.45 (ddd, 1 H, $J_{4',5'}$ 6.8, $J_{5'6'endo}$ 3.5, $J_{5'6'exo}$ 5.8 Hz, H-5'), 2.13, 2.11, 2.06, 2.05, 2.00, and 1.99 (6s, 18 H, OAc), 1.75 (dddd ~ dq, 1 H, $J_{4',6'exo}$ 9.8, $J_{4',6'endo}$ ~ 7.2 Hz, H-4'), and 0.83–0.69 (m, 2 H, H-6'); CIMS: m/z 578 (100%, $[\text{M} + \text{NH}_4]^+$). Anal. Calcd for $\text{C}_{24}\text{H}_{32}\text{O}_{15}$: C, 51.4; H, 5.8. Found: C, 51.5; H, 5.9.

Methyl 2,3-di-O-acetyl-4,6-dideoxy-4,6-diido- β -D-glucopyranoside (19). — To a solution of **18** (ref 27, 4.88 g, 17.5 mmol) in 2:1 toluene-MeCN (50 mL) were added Ph_3P (11.6 g, 44.5 mmol), imidazole (2.98 g, 43.8 mmol), and I_2 (8.9 g, 35.1 mmol). After stirring for 1 h at 70°C the same amounts of Ph_3P , imidazole, and I_2 were added, and stirring was continued for 65 h at 70°C. After cooling, the mixture was filtered over a pad of Celite which was washed with toluene. The filtrates were washed with cold water, dried over MgSO_4 , and evaporated. The crude product was chromatographed (3:1 EtOAc-toluene) to give pure **18** as an oil (4.08 g, 47%) along with slightly impure fractions (4.6 g), $[\alpha]_D^{20} - 50.2^\circ$ (c 0.5, dioxane); ^1H NMR (250 MHz, CDCl_3): δ 5.34 (dd, 1 H, $J_{3,4}$ 10.7 Hz, H-3), 4.86 (dd, 1 H, $J_{2,3}$ 9.4 Hz, H-2), 4.48 (d, 1 H, $J_{1,2}$ 8.0 Hz, H-1), 3.87 (dd ~ t, 1 H, $J_{4,5}$ 10.2 Hz, H-4), 3.85 (dd, 1 H, $J_{5,6a}$ 2.2, $J_{6a,6b}$ 10.5 Hz, H-6a), 3.54 (dd, 1 H, $J_{5,6b}$ 6.3 Hz, H-6b), 3.53 (s, 3 H, OCH_3), 3.45 (ddd, 1 H, H-5), 2.10, 2.04 (2s, 6 H, OAc); MS (electrospray): m/z

521 (75%, $[M + Na]^+$), 516 (80%, $[M + NH_4]^+$), 467 (100%, $[M + H - CH_3OH]^+$).
Anal. Calcd for $C_{11}H_{16}I_2O_6$: C, 26.5; H, 3.2. Found: C, 26.9; H, 3.2.

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REFERENCES

- 1 J.-P. Praly, Z. El Kharraf, and G. Descotes, *Tetrahedron Lett.*, 30 (1990) 4441–4444; A. Vasella and C.A.A. Waldraff, *Helv. Chim. Acta*, 74 (1991) 585–593.
- 2 S.W. Jones, F. Scheinmann, B.J. Wakefield, D. Middlewiss, and R.F. Newton, *J. Chem. Soc., Chem. Commun.*, (1986) 1260–1261;
M.C. Pirrung and P.M. Kenney, *J. Org. Chem.*, 52 (1987) 2335–2336;
R.C. Petter and D.G. Powers, *Tetrahedron Lett.*, 30 (1989) 659–662;
R.C. Petter, G. Kumaravel, D.G. Powers, and C.T. Chang, *Tetrahedron Lett.*, 32 (1991) 449–452.
- 3 H. Hashimoto, N. Kawauchi, and J. Yoshimura, *Chem. Lett.*, (1985) 965–968.
- 4 R.E. Dolle and K.C. Nicolaou, *J. Chem. Soc., Chem. Commun.*, (1985) 1016–1018.
- 5 A. Aubry, J. Protas, P. Duchaussoy, P. Di Cesare, and B. Gross, *Acta Crystallogr., Sect. B*, 37 (1981) 1477–1480;
R. Huber, L.-P. Molleyres, and A. Vasella, *Helv. Chim. Acta*, 73 (1990) 1329–1337.
- 6 P. Duchaussoy, P. Di Cesare, and B. Gross, *Synthesis*, (1979) 198–200.
- 7 T. Adachi, T. Iwasaki, M. Miyoshi, and I. Inoue, *J. Chem. Soc., Chem. Commun.*, (1977) 248–249.
- 8 R. Herges and I. Ugi, *Chem. Ber.*, 119 (1986) 829–836.
- 9 G. Maier and T. Sayrac, *Angew. Chem.*, 5 (1966) 959;
P.M. Collins, J.R. Hurford, and W.G. Overend, *J. Chem. Soc., Perkin Trans. 1*, (1975) 2178–2181;
B. Fraser-Reid, N.L. Holder, D.R. Hicks, and D.L. Walker, *Can. J. Chem.*, 55 (1977) 3978–3985;
H.H. Baer, F. Linhart, and H.R. Hamma, *Can. J. Chem.*, 56 (1978) 3087–3095;
S. Takano, M. Tanaka, K. Seo, M. Hiram, and K. Ogasawara, *J. Org. Chem.*, 50 (1985) 931–936;
J. Mann and A. Thomas, *Tetrahedron Lett.*, 27 (1986) 3533–3534.
- 10 S.Y.-K. Tam and B. Fraser-Reid, *Can. J. Chem.*, 55 (1977) 3996–4001;
M. Okabe and R.-C. Sun, *Tetrahedron Lett.*, 30 (1989) 2203–2206;
J.C. Wu and J. Chattopadhyaya, *Tetrahedron*, 46 (1990) 2587–2592;
A.R. Beard, P.I. Butler, J. Mann, and N.K. Partlett, *Carbohydr. Res.*, 205 (1990) 87–91.
- 11 W. Meyer zu Reckendorf and U. Kamprath-Scholtz, *Angew. Chem., Int. Ed. Eng.*, 7 (1968) 142–143;
E.L. Albano, D. Horton, and J.H. Lauterbach, *Chem. Commun.*, (1968) 357–358;
E.L. Albano, D. Horton, and J.H. Lauterbach, *Carbohydr. Res.*, 9 (1969) 149–161;
B. Fraser-Reid and B. Radatus, *Can. J. Chem.*, 48 (1970) 2146–2148; 50 (1972) 2919–2927;
W. Meyer zu Reckendorf and U. Kamprath-Scholtz, *Chem. Ber.*, 105 (1972) 673–685; 686–695;
W.G. Dauben, L. Schutte, G.W. Shaffer, and R.B. Gagosian, *J. Am. Chem. Soc.*, 95 (1973) 468–471;
B.K. Radatus and B. Fraser-Reid, *J. Chem. Soc., Perkin Trans. 1*, (1975) 1872–1875;
N.A. Porter, D.H. Roberts, C.B. Ziegler, Jr., *J. Am. Chem. Soc.*, 102 (1980) 5912–5913;
B.J. Fitzsimmons and B. Fraser-Reid, *Tetrahedron*, 40 (1984) 1279–1287;
N.A. Porter, C.B. Ziegler, Jr., F.F. Khawi, and D.H. Roberts, *J. Org. Chem.*, 50 (1985) 2252–2258;
D.L.J. Clive and S. Daigneault, *J. Chem. Soc., Chem. Commun.*, (1989) 332–335.
- 12 M.S. Shekhani, F. Latif, A. Fatima, A. Malik, and W. Voelter, *J. Chem. Soc., Chem. Commun.*, (1988) 1419–1420;
M.S. Shekhani and W. Voelter, *Chem. Ztg.*, 113 (1989) 1–3;
F. Zaman, A. Fatima, and W. Voelter, *Liebigs Ann. Chem.*, (1991) 1101–1104.

- 13 R.C. de Selms and T.-W. Liu, *Tetrahedron*, 23 (1967) 1479–1488;
J. d'Angelo and Vu Moc Thuy, *Bull. Soc. Chim. Fr.*, (1968) 2823–2827;
Vu Moc Thuy and P. Maitte, *Bull. Soc. Chim. Fr.*, (1970) 4423–4428;
A.J. Duggan and S.S. Hall, *J. Org. Chem.*, 40 (1975) 2234–2237;
G.F. Weber and S.S. Hall, *J. Org. Chem.*, 44 (1979) 447–449.
- 14 P.J. Garegg, R. Johansson, C. Ortega, and B. Samuelsson, *J. Chem. Soc., Perkin Trans. I*, (1982) 681–683.
- 15 D. Horton and J.H. Lauterbach, *Carbohydr. Res.*, 43 (1975) 9–33.
- 16 W. Schüep and E. Hardegger, *Helv. Chim. Acta*, 53 (1970) 1336–1339.
- 17 W.G. Dauben and W.T. Wipke, *J. Org. Chem.*, 32 (1967) 2976–2980.
- 18 D.G. Morris, in Z. Rappoport (Ed.), *The Chemistry of the Cyclopropyl Group*, Part 1, Wiley, Chichester, 1987, pp. 101–172.
- 19 A. Fatima, F. Zaman, M.S. Shekhani, A. Malik, and W. Voelter, *Liebigs Ann. Chem.*, (1990) 389–392.
- 20 S. Ogawa, C. Uchida, and Y. Shibata, *Carbohydr. Res.*, 223 (1992) 279–286.
- 21 H. Paulsen, M. Matzke, B. Orthen, R. Nuck, and W. Reutter, *Liebigs Ann. Chem.*, (1990) 953–963.
- 22 R.L. Whistler and S.J. Kazeniac, *J. Am. Chem. Soc.*, 76 (1954) 3044–3045.
- 23 Y. Takahashi and T. Ogawa, *Carbohydr. Res.*, 164 (1987) 277–296.
- 24 T. Ogawa and S. Nakabayashi, *Carbohydr. Res.*, 93 (1981) C1–C5.
- 25 H.P. Wessel, unpublished results.
- 26 K.K. Sadozai, T. Kitajima, Y. Nakahara, T. Ogawa, and A. Kobata, *Carbohydr. Res.*, 152 (1986) 173–182;
K.K. Sadozai, T. Nukada, Y. Ito, Y. Nakahara, T. Ogawa, and A. Kobata, *ibid.*, 157 (1986) 101–123.
- 27 A. Müller, M. Móricz, and G. Verner, *Ber.*, 72 (1939) 745–753.
- 28 D.E. McGreer, *Can. J. Chem.*, 38 (1960) 1638–1639.
- 29 D. Wendisch, in E. Müller (Ed.), *Houben-Weyl, Methoden der Organischen Chemie*, Vol IV/3, Thieme, Stuttgart, 1971, pp. 32–42.
- 30 D.G. Bloomfield, C. Upton, and H.J. Vipond, *J. Chem. Soc., Perkin Trans. I*, (1986) 857–860;
C. Upton, *J. Chem. Res. (S)*, (1992) 119.
- 31 G. Randazzo, R. Capasso, M.R. Cicala, and A. Evidente, *Carbohydr. Res.*, 85 (1980) 298–301.