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Carbohydrate Research 281 (1996) 61–68

CARBOHYDRATE
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A convenient new pathway for stereospecific epimerization of monosaccharide moieties in disaccharides [1]

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Received 19 June 1995; accepted 12 September 1995

Abstract

The disaccharides benzyl 4,6-*O*-benzylidene-2-*O*-α-D-mannopyranosyl-β-D-glucopyranoside (**2**), 6-*O*-β-D-galactopyranosyl-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (**4**), and phenyl 4-*O*-β-D-galactopyranosyl-1-thio-β-D-glucopyranoside (**7**) were selectively acetalated with chloral–dicyclohexylcarbodiimide in a nonclassical pathway. During acetalation, the D-mannopyranosyl moiety of the disaccharide **2** and the unprotected β-D-galactopyranosyl moieties of **4** and **7** were epimerized at their 3-positions, generating D-altro- and D-gulo-pyranosyl moieties, respectively.

Keywords: Carbohydrates; Disaccharides; Epimerization; Chloral acetals

1. Introduction

In 1992 it was found that the reaction of hexafluoroacetone and dicyclohexylcarbodiimide (DCC) with bis-*vicinal* triols having a *cis,trans* sequence of hydroxyl groups resulted in the formation of cyclic acetals in which the central carbon of the triol had the inverted configuration [1]. This nonclassical pathway involves the in situ formation of a cyclic imidocarbonic ester intermediate, followed by an intramolecular S_N2-attack by a deprotonated neighboring hemiacetal moiety [2]; Scheme 1 (see also ref. [3]).

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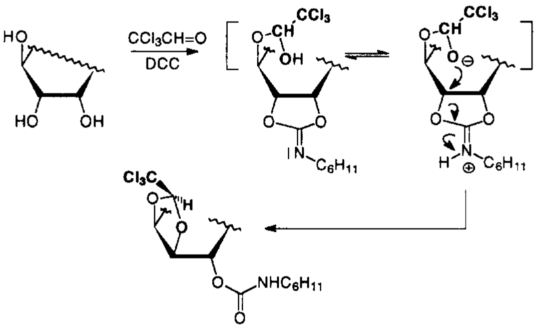
[1] Dedicated to Professor Dr R.R. Schmidt (Konstanz, Germany) on the occasion of his 60th birthday.

SSDI 0008-6215(95)00338-X



Scheme 1.

Moreover, we have shown that chloral likewise generates cyclic acetals from suitable pyranosides in the presence of DCC [4–7]. Generally, such an acetalation accompanied by inversion of the configuration at C-3 results when the starting pyranosides have a 2,3-*cis*-/3,4-*trans*- or 2,3-*trans*-/3,4-*cis*-arrangement of OH groups. Thus, unprotected methyl pyranosides [4–6], phenyl thiopyranosides [6], or 1,6-anhydro sugars [6] reacted in this way with chloral and DCC in dichloroethane. Glycosides of the following monosaccharides were epimerized in this way:

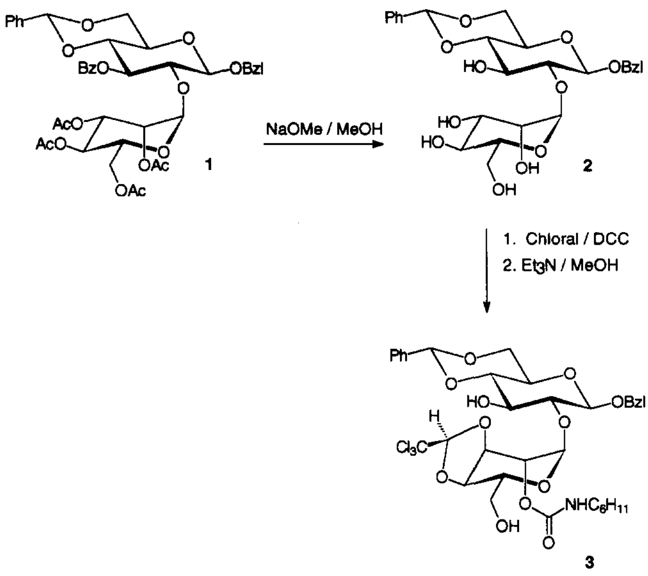
D-Arabinose → D-Lyxose [6]
D-Lyxose → D-Arabinose [5]
L-Arabinose → L-Lyxose [5]
D-Mannose → D-Altrose [4,6]
D-Galactose → D-Gulose [5,6]
L-Rhamnose → 6-Deoxy-L-altrose [4]
L-Fucose → 6-Deoxy-L-gulose [6]

In three cases [methyl 3,4-*O*-(2,2,2-trichloroethylidene)-α-D-arabinopyranoside, 2-*O*-cyclohexylcarbamoyl-6-*O*-formyl-3,4-*O*-(2,2,2-trichloroethylidene)-α-D-altropyranosyl fluoride, and methyl 2-*O*-cyclohexylcarbamoyl-6-deoxy-3,4-*O*-(hexafluoroisopropylidene)-α-L-altropyranoside], suitable crystals were obtained to confirm additionally the structures of these epimerized compounds by X-ray experiments [8].

A chloral acetal protecting group can be dehalogenated to an ethylidene acetal using Raney-Ni [9] or tributylstannane [10], so that deprotection may easily follow.

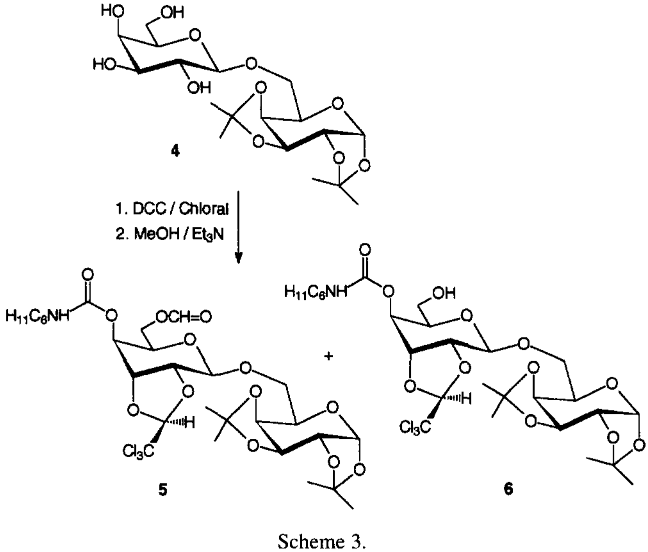
2. Results and discussion

The new method of stereoselective epimerization of monosaccharides was extended to disaccharides with the object of selectively epimerizing only one of the two monosaccharide moieties. We first chose benzyl 4,6-*O*-benzylidene-2-*O*-α-D-man-

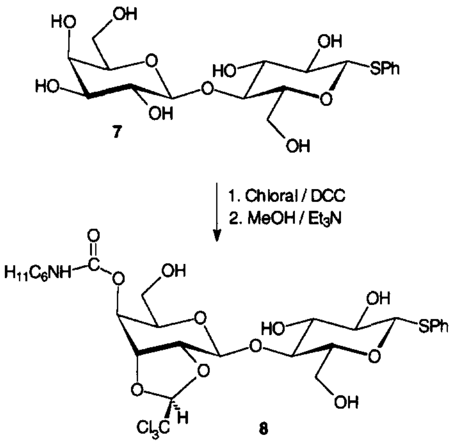


Scheme 2.

nopyranosyl-β-D-glucopyranoside (**2**), which was obtained by deesterification of compound **1**, itself synthesized by a Helferich-type coupling reaction starting from benzyl 3-*O*-benzoyl-4,6-*O*-benzylidene-β-D-glucopyranoside [11] as acceptor. Two galactosides, 6-*O*-β-D-galactopyranosyl-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (**4**) [12] and phenyl 4-*O*-β-D-galactopyranosyl-1-thio-β-D-glucopyranoside (**7**), which can be obtained very easily from lactose [13], were also examined (Schemes 2–4). Compounds **2**, **4**, and **7** have very different hydrophilicities. The D-mannopyranosyl unit in **2** and the



Scheme 3.



Scheme 4.

unprotected D-galactopyranosyl moieties in **4** and **7** have the required arrangement of the OH groups (Scheme 1) in order to generate cyclic acetals by treatment with the chloral–DCC reagent, whereas the D-glucopyranosyl moiety of the thio-lactoside **7** does not react because of the all-*trans* arrangement of its nonglycosidic OH groups.

The epimerization reactions were carried out with chloral and DCC in 1,2-dichloroethane as recently reported for monosaccharides [4–7]. However, a longer reaction time, reflux for 6–8 h instead of 4–5 h, was necessary in the case of the disaccharides. Thus, the D-mannopyranosyl moiety of **2** was completely converted into a D-altropyranosyl derivative (Scheme 2) after a 6-h reaction time. The corresponding benzyl 4,6-*O*-benzylidene-2-*O*-[2-*O*-cyclohexylcarbamoyl-3,4-*O*-(2,2,2-trichloroethylidene)-α-D-altropyranosyl]-β-D-glucopyranoside (**3**) was obtained in a yield of 42%. The *endo*-H/*exo*-H diastereomeric ratio of cyclic acetals was shown to be 25:1.

6-*O*-β-D-Galactopyranosyl-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (**4**) formed 6-*O*-[4-*O*-cyclohexylcarbamoyl-2,3-*O*-(2,2,2-trichloroethylidene)-β-D-gulopyranosyl]-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (**6**) in the same way (Scheme 3). However, the conversion of the unprotected D-galactopyranosyl unit into a D-gulopyranosyl moiety required heating for 8 h. Finally, the more hydrophilic disaccharide **7**, containing a D-glucopyranosyl as well as a D-galactopyranosyl moiety (unprotected at all the nonglycosidic positions), also reacted selectively with the chloral–DCC reagent. Phenyl 4-*O*-[4-*O*-cyclohexylcarbamoyl-2,3-*O*-(2,2,2-trichloroethylidene)-β-D-gulopyranosyl]-1-thio-β-D-glucopyranoside (**8**) was isolated, after refluxing for 8 h and treatment of the crude product with methanolic triethylamine, in a yield of 47.4% (*endo*-H/*exo*-H diastereomeric mixture, ≈ 5:1) (Scheme 4). It is noteworthy that the crude products **6** and **8**, before the addition of the amine, contained portions of the 6-*O*-formyl derivatives of these compounds. Formylated byproducts result from a haloform reaction of the chloral, also observed in acetalations of monosaccharides [5–7].

The main advantage of these epimerization reactions is that they do not require protected starting materials (excluding the glycosidic position) and that they can also be applied in the case of thioglycosides. Thus, the latter compounds can be transformed into a suitably functionalized glycosyl donor, and used for the synthesis of complex oligosaccharides [14,15].

The structures of the disaccharides **3**, **5**, **6**, and **8** are supported by ^{1}H and ^{13}C NMR spectroscopy. The assignment of the signals of these compounds has unambiguously been achieved by recording the 2D correlation spectra (H,H-COSY and C,H-COSY) and by comparison of the ^{1}H and ^{13}C NMR data with those of corresponding monosaccharides [5,6]. Thus, the converted sugar moieties of the disaccharides **5**, **6**, and **8** were compared to methyl 4-*O*-cyclohexylcarbamoyl-2,3-*O*-(2,2,2-trichloroethylidene)-α-D-gulopyranoside [5], methyl 4-*O*-cyclohexylcarbamoyl-6-*O*-formyl-2,3-*O*-(2,2,2-trichloroethylidene)-α-D-gulopyranoside [5], and to the analogous phenyl 1-thio-β-D-gulopyranoside derivatives [6]. The chemical shifts and the coupling constants were very similar. The *endo*-H/*exo*-H diastereomeric ratio was determined using the integrals of the acetal protons.

3. Experimental

General.—^{1}H and ^{13}C NMR: Bruker AC 250 spectrometer; internal standard Me_4Si; J values in Hz. TLC: Silica Gel 60 F_{254} foils (Merck). Column chromatography: Silica Gel 60 (63–200 μm) (Merck). Melting points: polarizing microscope Leitz Laborlux 12 Pol equipped with a hot-stage Mettler FP 90. Chemicals: chloral (Riedel de Haen), dicyclohexylcarbodiimide (Aldrich). The *endo*/*exo* isomers of the chloral acetals were not separated in all cases. Therefore, the $[\alpha]_D$ values were not determined for the *endo*-H/*exo*-H diastereomeric mixtures. The ^{1}H NMR data are given only for the major diastereomer (*endo*-H form).

Benzyl 3-O-benzoyl-4,6-O-benzylidene-2-O-(2,3,4,6-tetra-O-acetyl-α-D-mannopyranosyl)-β-D-glucopyranoside (**1**).—Benzyl 3-*O*-benzoyl-4,6-*O*-benzylidene-β-D-glucopyranoside [12] (925 mg, 2 mmol) was dissolved in a mixture of benzene (30 mL) and $MeNO_2$ (30 mL), and the solution was concentrated at atmospheric pressure to 20 mL. After cooling to 40 °C, $Hg(CN)_2$ (556 mg, 2 mmol) and 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl bromide (905 mg, 2.2 mmol) were added, and the mixture was stirred at 40 °C with the exclusion of moisture. After 2 h, TLC indicated the absence of the acceptor. The inorganic salts were removed from the cooled solution by filtration, the filtrate was evaporated, and the residue dissolved in CH_2Cl_2 (60 mL). The mixture was filtered and the filtrate successively washed with aq 5% KI (3 × 15 mL) and water (3 × 10 mL), dried (Na_2SO_4), and evaporated. The residue was crystallized from EtOH (25 mL) and then recrystallized twice to yield pure **1** (1.28 g, 80.7%); mp 151 °C; $[\alpha]_D^{20}$ +11.24° (c 0.71, $CHCl_3$); R_f 0.60 (95:5 CH_2Cl_2–acetone); ^{1}H NMR ($CDCl_3$): δ 1.82, 2.01, 2.06, 2.12 (Me), 3.52 (dd, 1 H, $J_{5',6a'}$ 2.5, $J_{6a',6b'}$ 12.4 Hz, H-6a′), 3.57 (m, 1 H, H-5), 3.63 (dd, 1 H, $J_{5',6b'}$ 3.8 Hz, H-6b′), 3.72 (ddd, 1 H, $J_{4',5'}$ 10.2 Hz, H-5′), ca. 3.76 (m, 2 H, H-4,6a), 3.89 (dd, 1 H, $J_{1,2}$ 7.5, $J_{2,3}$ 9.4 Hz, H-2), 4.41 (dd, 1 H, $J_{5,6b}$ 5.1, $J_{6a,6b}$ 10.6 Hz, H-6b), 4.62–4.90 (2 H, Ph-CH_2), 4.73 (d, 1 H, H-1), 5.12 (m, 2 H, H-3′,4′), 5.31 (dd, 1 H, $J_{1',2'}$ 1.9, $J_{2',3'}$ 2.8 Hz, H-2′), 5.33 (d, 1 H, H-1′), 5.50 (s, 1 H, PhCH), 5.63 (dd, 1 H, $J_{3,4}$ 9.6 Hz, H-3), 7.32–8.17 (10 H, Ph); ^{13}C NMR ($CDCl_3$): δ 20.4, 20.5, 20.7 (Me), 61.4 (C-5), 65.1 (C-4′), 66.3 (C-6′), 68.4, 68.5, 68.6, 68.9 (C-6,C-2′,C-3′,C-5′), 71.8 (Ph-*C*H$_2$), 72.2 (C-3), 76.7 (C-2), 78.9 (C-4), 97.5 (C-1′), 101.5 (Ph*C*H), 102.2 (C-1), 126.1–136.7 (Ph-*C*), 165 (Ph*C*=O), 169.2, 169.5, 170.3 (Me*C*=O). Anal. Calcd for $C_{41}H_{44}O_{16}$ (792.76): C, 62.15; H, 5.59. Found: C, 62.08; H, 5.66.

Benzyl 4,6-O-benzylidene-2-O-α-D-mannopyranosyl-β-D-glucopyranoside (**2**).—A solution of the disaccharide **1** (157 mg, 0.169 mmol) in methanolic 1% NaOMe (3 mL) was allowed to stand for 5 h at room temperature, followed by neutralization with an acidic ion-exchange resin. After filtration the stirring was continued for 30 min in the presence of charcoal. The filtered solution was concentrated and the residue recrystallized from EtOH, giving the deacylated disaccharide **2** (74 mg, 84%); mp 209–213 °C. Anal. Calcd for $C_{26}H_{34}O_{11}$ (522.5): C, 59.76; H, 6.56. Found: C, 60.01; H, 6.32.

Benzyl 4,6-O-benzylidene-2-O-[2-O-cyclohexylcarbamoyl-3,4-O-(2,2,2-trichloroethylidene)-α-D-altropyranosyl]-β-D-glucopyranoside (**3**).—A suspension of **2** (60 mg, 0.12 mmol), chloral (63.5 mg, 0.43 mmol), and dicyclohexylcarbodiimide (63.5 mg, 0.31 mmol) in 1,2-dichloroethane (3 mL) was refluxed for 6 h. TLC showed two components (R_f 0.38 and 0.64). After cooling to room temperature MeOH (1 mL) and triethylamine (0.2 mL) were added, and the reaction mixture was refluxed for 10 min followed by the addition of 0.1 M HCl (5 mL) and shaking for 10 min. The organic layer was separated and subsequently washed with saturated aq $NaHCO_3$ (5 mL) and water (5 mL), dried with Na_2SO_4, and concentrated. The major product (R_f 0.64) was purified by column chromatography (eluent: 3:1 toluene–EtOAc), giving the amorphous solid **3** (39 mg, 42%) as a diastereomeric mixture (*endo*-H/*exo*-H = 25:1); softening range 117–124 °C (from *n*-hexane); $[\alpha]_D^{20}$ +2.68° (*c* 1, $CHCl_3$); ^1H NMR ($CDCl_3$): 0.84–1.37 (10 H, cycohexyl-C*H*$_2$), 3.38 (1 H, cyclohexyl-C*H*), 3.30–3.88 (6 H), 4.14–4.43 (4 H), 4.56 (d, 1 H, $J_{NH,CH}$ 7.6 Hz, NH), 4.57 (d, 1 H, $J_{1,2}$ 7.6 Hz, H-1), 4.60–4.95 (2 H, PhC*H*$_2$), 5.11–5.18 (m, 2 H, H-1′,2′), 5.50 (s, 1 H, Ph-C*H*), 5.53 (s, 1 H, *endo*-Cl_3C-C*H*); 5.29 (s, *exo*-Cl_3C-C*H*); ^{13}C NMR ($CDCl_3$): 24.7, 25.4, 33.0 (cyclohexyl-*C*H$_2$), 50.1 (cyclohexyl-*C*H), 63.2 (C-6′), 65.9 (C-5), 68.6 2 (C-6), 70.7, 71.6 (Ph-*C*H$_2$), 72.2, 74.7, 78.8, 79.0, 80.9, 98.8 (C-1′), 99.4 (*C*Cl$_3$), 101.9 (Ph*C*H), 102.6 (C-1), 108.0 (Cl_3C-*C*H), 126.4–137.1 (Ph-*C*), 154.0 (NH-C=O). Anal. Calcd for $C_{35}H_{40}Cl_3NO_{12}$ (775.9): C, 54.18; H, 5.57; N, 1.81. Found: C, 53.81; H, 6.60; N, 2.03.

6-O-[4-O-Cyclohexylcarbamoyl-6-O-formyl-2,3-O-(2,2,2-trichloroethylidene)-β-D-gulopyranosyl]-1,2:3,4-di-O-isopropylidene-α-D-galactopyranose (**5**) *and 6*-O-[4-O-cyclohexylcarbamoyl-2,3-O-(2,2,2-trichloroethylidene)-β-D-*gulopyranosyl]-1,2:3,4-di*-O-*isopropylidene-α-D-galactopyranose* (**6**).—To a solution of 6-*O*-β-D-galactopyranosyl-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (**4**) [12] (0.9 g, 2.13 mmol) in 1,2-dichloroethane (10 mL) were added chloral (1.1 g, 7.46 mmol) and DCC (1.1 g, 5.33 mmol) and the mixture was refluxed for 8 h. TLC (3:1 toluene–EtOAc) showed two spots (major product **5**, R_f 0.45; byproduct **6**, R_f 0.17). The reaction mixture was shaken for 15 min with aq 20% acetic acid (15 mL), and the precipitated dicyclohexylurea was removed by filtration. The organic layer was neutralized by shaking with saturated aq $NaHCO_3$ (10 mL), then washed twice with water (10 mL) and dried with Na_2SO_4.

Workup procedure A.—The separated organic phase was concentrated in a rotary evaporator and the residue was purified by column chromatography (eluent: 3:1

toluene–EtOAc), yielding 0.6 g (39.6%) of crystalline **5**; mp 183–185 °C; as an *endo*-H/*exo*-H diastereomeric mixture (4.9:1); and 93 mg (6.2%) of **6**. Recrystallization of **5** from 1:1 pentane–ether gave enrichment of the *exo*-H diastereomer in the precipitate.

5: ^{1}H NMR (Me_2SO-d_6): δ 1.16–1.79 (m, 10 H, cyclohexyl-CH_2), 1.28, 1.35, 1.44 (3 s, 12 H, 2 Me_2C), 3.24 (d, cyclohexyl-C*H*), 3.61 (dd, 1 H, $J_{6'a,6'b}$ 11.9 Hz, H-6′a), 3.81–4.15 (m, 5 H, H-5,5′,6a,6b,6′b), 4.21 (dd, 1 H, $J_{2',3'}$ 2.4 Hz, H-2′), 4.25 (dd, 1 H, H-4), 4.34 (dd, 1 H, $J_{2,3}$ 2.4 Hz, H-2), 4.54 (dd, 1 H, $J_{3',4'}$ 2.1 Hz, H-3′), 4.59 (dd, 1 H, $J_{3,4}$ 7.9 Hz, H-3), 4.78 (d, 1 H, $J_{1',2'}$ 7.3 Hz, H-1′), 4.99 (dd, 1 H, H-4′), 5.47 (d, 1 H, $J_{1,2}$ 5.2 Hz, H-1), 5.74 (s, 1 H, *endo*-Cl_3C-C*H*), 7.41 (d, 1 H, $J_{NH,CH}$ 7.6 Hz, N-H), 8.24 (s, 1 H, O=C*H*-); ^{13}C NMR (Me_2SO-d_6) δ 24.4, 25.0, 26.0 (4 Me), 24.7, 25.3, 25.9, 32.5, 32.7 (5 cyclohexyl-*C*H_2), 49.9 (cyclohexyl-*C*H), 61.7 (C-6′), 65.9 (C-4′), 67.1 (C-5), 68.2 (C-6), 69.8 (C-2), 70.2 (C-3), 70.7 (C-4), 74.3 (C-5′), 76.3 (C-2′), 76.8 (C-3′), 95.8 (C-1), 99.3 (Cl_3*C*-CH), 99.8 (C-1′), 105.8 (Cl_3C-*C*H), 108.0, 108.7 (2 Me_2C), 154.2 (NH-C=O), 161.9 (O=CH-). Anal. Calcd for $C_{28}H_{40}Cl_3NO_{13}$ (705.0): C, 47.70; H, 5.72; N, 1.99. Found: C, 47.98; H, 5.90; N, 2.10.

Workup procedure B.—To the separated organic phase was added 20:1 MeOH–triethylamine (10 mL). The mixture was refluxed for 1–2 min and then allowed to stand overnight at room temperature to remove the formyl group in the 6-position; TLC then showed only the spot of **6** (R_f 0.17). After column chromatographic purification (eluent: 3:1 toluene–EtOAc), **6** (0.65 g, 46%) was obtained as an *endo*-H/*exo*-H diastereomeric mixture (4.8:1); colorless crystals; mp 226–228 °C (from 1:1 Et_2O–pentane).

6: ^{1}H NMR (Me_2SO-d_6): δ 1.05–1.80 (m, 10 H, cyclohexyl-CH_2), 1.28, 1.36, 1.45 (3 s, 12 H, 2 Me_2C), 3.25 (d, 1 H, cyclohexyl-C*H*), 3.53–3.44 (m, 2 H, H-6′a,6′b), 3.59 (ddd, 1 H, H-5), 3.75–3.99 (m, 3 H, $J_{6a,6b}$ 10.7 Hz, H-5′,6a,6b), 4.29–4.23 (m, 2 H, H-4,2′), 4.34 (dd, 1 H, $J_{2,3}$ 1.8 Hz, H-2), 4.52 (dd, 1 H, $J_{2',3'}$ 1.4 Hz, H-3′), 4.59 (dd, 1 H, $J_{3,4}$ 7.5 Hz, H-3), 4.71 (d, 1 H, $J_{1',2'}$ 7.6 Hz, H-1′), 4.95 (dd, 1 H, H-4′), 5.48 (d, 1 H, $J_{1,2}$ 5.5 Hz, H-1), 5.76 (s, 1 H, *endo*-Cl_3C-CH), 7.33 (d, 1 H, $J_{NH,CH}$ 8.2 Hz, NH); ^{13}C NMR ($CDCl_3$): δ 24.4, 25.0, 26.1 (4 Me), 24.7, 25.3, 25.5, 32.5, 32.7 (5 cyclohexyl-*C*H_2), 49.9 (cyclohexyl-*C*H), 59.4 (C-6′), 65.8 (C-4′), 67.1 (C-5), 68.2 (C-6), 69.8 (C-2), 70.2 (C-3), 70.8 (C-4), 73.1 (C-5′), 76.7 (C-2′), 76.9 (C-3′), 95.8 (C-1), 99.4 (Cl_3C), 99.9 (C-1′), 105.8 (Cl_3C-*C*H), 107.9, 108.4 (2 Me_2C), 154.6 (NH-C=O). Anal. Calcd for $C_{27}H_{40}Cl_3NO_{12}$ (677.0): C, 47.90; H, 5.96. Found: C, 47.74; H, 5.95.

*Phenyl 4-*O*-[4-*O*-cyclohexylcarbamoyl-2,3-*O*-(2,2,2-trichloroethylidene)-β-*D*-gulopyranosyl]-1-thio-β-*D*-glucopyranoside* (**8**).—A suspension of powdered phenyl 4-*O*-β-D-galactopyranosyl-1-thio-β-D-glucopyranoside (**7**) [13] (1.0 g, 2.3 mmol), dicyclohexylcarbodiimide (1.19 g, 5.75 mmol), chloral (2.38 g, 16.1 mmol), and 1,2-dichloroethane (10 mL) was refluxed for 8 h. The reaction mixture was shaken with aq 20% AcOH (25 mL) for 1 h, the dicyclohexylurea separated by filtration, and then 1,2-dichloroethane (20 mL) was added. The separated organic layer was neutralized by shaking with saturated aq $NaHCO_3$ (15 mL), then washed twice with water (10 mL), and dried with Na_2SO_4. To convert some 6-*O*-formylated byproduct of **8** into **8**, the crude product was dissolved in 20 mL of 20:1 MeOH–triethylamine, and the solution was refluxed for 1–2 min. The residue, obtained after evaporation of the solvent, was an *endo*-H/*exo*-H diastereomeric mixture (≈ 5:1) of the chloral acetals **8**. Purification by column chromatography (eluent: 2:1 toluene–EtOAc) allowed the separation of a fraction containing the pure *endo*-H diastereomer (400 mg, R_f 0.28); mp 191–193 °C (from $CHCl_3$); $[\alpha]_D^{22}$ $-75.6°$ (*c* 1.0, MeOH); and of a crystalline *endo*-H/*exo*-H mixture (367 mg, R_f 0.31). Yield: 767 mg (47.4%).

8 (*endo*-H): ^{1}H NMR (CD_3OD): δ 1.10–1.39 (m, 5 H, cyclohexyl-CH_2), 1.57–1.91 (m, 5 H, cyclohexyl-CH_2), 3.29 (m, 1 H, H-2), 3.45 (ddd, $J_{5,6}$ 4.1 Hz, H-5), 3.53 (dd, 1 H, $J_{3,4}$ 8.7 Hz, H-3), 3.61 (dd, 1 H, $J_{4,5}$ 3.4 Hz, H-4), 3.64–3.69 (m, 2 H, H-6a,6b), 3.84 (dd, 2 H, $J_{6'a,6'b}$ 12.2 Hz, H-6′a,6′b), 3.91 (dd, 1 H, $J_{4',5'}$ 2.1 Hz, H-5′), 4.35 (dd, 1 H, $J_{2',3'}$ 5.3 Hz, H-2′), 4.63 (d, 1 H, $J_{1,2}$ 9.8 Hz, H-1), 4.63 (dd, 1 H, H-3′), 4.72 (d, 1 H, $J_{1',2'}$ 7.5 Hz, H-1′), 5.05 (dd, 1 H, H-4′), 5.68 (s, 1 H, Cl_3C-CH); ^{13}C NMR: δ 26.1, 26.6, 30.7, 34.0 (cyclohexyl-CH$_2$), 49.7 (cyclohexyl-CH), 51.5 (C-6), 61.5 (C-6′), 67.9 (C-4′), 73.7 (C-2), 75.6 (C-5′), 77.7 (C-5), 78.4 (C-2′), 78.5 (C-3′), 80.3, 80.6 (C-3, C-4), 89.1 (C-1), 101.9 (C-1′), 107.8 (Cl_3C-CH), 128.4, 129.9, 133.0, 134.8 (Ph-C), 156.6 (NH-C=O). Anal. Calcd for $C_{27}H_{36}Cl_3NO_{11}S$ (688.98): C, 47.15; H, 5.28; S, 4.65. Found: C, 46.95; H, 5.56; S, 4.55.

Acknowledgements

This work was supported by the Deutsche Forschungsgemeinschaft. The authors are grateful to Dr M. Michalik (Institute of Organic Catalysis Research, Rostock) for recording the NMR spectra.

References

[1] R. Miethchen, D. Rentsch, and N. Stoll, *Tetrahedron*, 48 (1992) 8393–8400.
[2] R. Miethchen, D. Rentsch, and M. Michalik, *Liebigs Ann. Chem.*, (1994) 219–222.
[3] E. Vowinkel and P. Gleichenhagen, *Tetrahedron Lett.*, (1974) 139–142.
[4] R. Miethchen and D. Rentsch, *Synthesis*, (1994) 827–831.
[5] R. Miethchen and D. Rentsch, *Liebigs Ann. Chem.*, (1994) 1191–1197.
[6] R. Miethchen, D. Rentsch, and M. Frank, *J. Carbohydr. Chem.*, 15(1) (1996), in press.
[7] R. Miethchen and D. Rentsch, *J. Prakt. Chem./Chem.-Ztg.*, 337 (1995) 422–423.
[8] J. Kopf, G. Sheldrick, D. Rentsch, H. Reinke, and R. Miethchen, *Acta Crystallogr., Sect. C*, 51 (1995) 1198–1201; H. Reinke, D. Rentsch, and R. Miethchen, *Carbohydr. Res.*, accepted for publication.
[9] S. Forsen, B. Lindberg, and B. Silvander, *Acta Chem. Scand.*, 19 (1965) 359–369.
[10] S. Jacobsen and F. Sløk, *Acta Chem. Scand.*, 47 (1993) 1012–1018.
[11] A. Lipták, E. Csik, and P. Nánási, *Acta Chim. Acad. Sci. Hung.*, 88 (1976) 155–159.
[12] C.P.J. Glaudemans, E. Zissis, and M.E. Jolley, *Carbohydr. Res.*, 40 (1975) 129–135.
[13] E. Fischer and K. Delbrück, *Ber.*, 42 (1909) 1476–1482.
[14] H. Lönn, *Carbohydr. Res.*, 139 (1985) 105–113 and 115–121.
[15] P. Fügedi and P.J. Garegg, *Carbohydr. Res.*, 149 (1986) C9–C12.