Synthesis of Monosaccharide-Derived Spirocyclic Cyclopropylamines and Their Evaluation as Glycosidase Inhibitors

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The glucose-, mannose-, and galactose-derived spirocyclic cyclopropylammonium chlorides **1a**–**1d**, **2a**–**2d** and **3a**–**3d** were prepared as potential glycosidase inhibitors. Cyclopropanation of the diazirine **5** with ethyl acrylate led in 71% yield to a 4:5:1:20 mixture of the ethyl cyclopropanecarboxylates **7a**–**7d**, while the Cu-catalysed cycloaddition of ethyl diazoacetate to the *exo*-glycal **6** afforded **7a**–**7d** (6:2:5:3) in 93–98% yield (*Scheme 1*). Saponification, *Curtius* degradation, and subsequent addition of BnOH or *t*-BuOH led in 60–80% overall yield to the Z- or Boc-carbamates **11a**–**11d** and **12a**–**12d**, respectively. Hydrogenolysis of **11a**–**11d** afforded **1a**–**1d**, while **12a**–**12d** was debenzylated to **13a**–**13d** prior to acidic cleavage of the *N*-Boc group. The *manno*- and *galacto*-isomers **2a**–**2d** and **3a**–**3d**, respectively, were similarly obtained in comparable yields (*Schemes 2* and *4*). Also prepared were the differentially protected *manno*-configured esters **24a**–**24d**; they are intermediates for the synthesis of analogous *N*-acetylglucosamine-derived cyclopropanes (*Scheme 3*).

The cyclopropylammonium chlorides **1a**–**1d**, **2a**–**2d** and **3a**–**3d** are very weak inhibitors of several glycosidases (*Tables 1* and *2*). Traces of Pd compounds, however, generated upon catalytic debenzylation, proved to be strong inhibitors. $PdCl_4^{2-}$ is, indeed, a reversible, micromolar inhibitor for the β-glucosidases from *C. saccharolyticum* and sweet almonds (non-competitive), the β-galactosidases from bovine liver and from *E. coli* (both non-competitive), the α-galactosidase from *Aspergillus niger* (competitive), and an irreversible inhibitor of the α-glucosidase from yeast and the α-galactosidase from coffee beans. The cyclopropylamines derived from **1a**–**1d** or **3a**–**3d** significantly enhance the inhibition of the β-glucosidase from *C. saccharolyticum* by $PdCl_4^{2-}$, lowering the K_i value from 40 μM ($PdCl_4^{2-}$) to 0.5 μM for a 1:1 mixture of $PdCl_4^{2-}$ and **1d**. A similar effect is shown by cyclopropylamine, but not by several other amines.

Introduction. – Two classes of glycosidases, *anti*- and *syn*-protonators, have been discerned on the basis of the trajectory of the proton transfer from the catalytic acid to the glycosidic O-atom [1]. The precise position, in individual glycosidases, of the catalytic acid relative to the catalytic nucleophile and the bound substrate has thus become of renewed interest. A couple of complementary inhibitors, one inhibiting *anti*-protonators, and the other *syn*-protonators, would be most useful to specify the position of the catalytic acid. Currently available inhibitors are not satisfactory in this respect [2–4]. The complementary inhibitors should possess a functional group that is oriented in a defined way so as to interact with the catalytic acid of either an *anti*- or a *syn*-protonator. Ideally, this functional group will be attached to a common scaffold to ensure that the complementary inhibitors bind in the same orientation in the active site of a glycosidase of unknown structure. We considered spirocyclic cyclopropylamines of type **1** promising candidates for this purpose and planned to prepare the *gluco*-, *manno*-, and *galacto*-derivatives **1a**–**1d**, **2a**–**2d**, and **3a**–**3d** (*Schemes 1*, *2*, and *4*)[1]).

[1]) Several carbohydrate-derived spirocyclic cyclopropanes are known [5–30]. The cyclopropylamines **1**–**3** are formally *C*-glycosides of ulopyranoses. For the use of cyclopropanes as scaffolds, see *e.g.*, [31–48].

We decided to first synthesise the glucose-derived spirocyclic cyclopropylamines **1a**–**1d**, and to then apply the synthesis to the mannose- and galactose-derived analogues **2a**–**2d** and **3a**–**3d**, respectively. Such cyclopropylamines are expected to possess a pK_{HA} value of *ca.* 8–9 [49–51]. At the acidic pH optimum typical for glycosidases, these amines are protonated and interact with the catalytic nucleophile. We planned to first evaluate this interaction and to prepare less-basic analogues of **1**–**3** at a later stage.

Results and Discussion. – *Molecular Modelling.* To evaluate the possibility of an interaction of the catalytic nucleophile with **1a**–**1d**, we docked the corresponding ammonium ions in the active site of the β-glucosidase from *Sulfolobus solfataricus* [52]. Molecular-modelling studies were restricted to the space defined by a maximal distance of 10 Å from any atom of the glycon moiety of methyl β-D-glucopyranoside that was docked in the active site according to a reported procedure (*Fig. 1,a*) [1]. The structure of the substrate or inhibitor, and the structural domain of the enzyme located in an inner shell (up to 5 Å from the substrate) of the space under consideration were unconstrained, while those in an outer shell (5–10 Å from the substrate) were constrained. The ammonium ions corresponding to **1a**–**1d** were inserted manually at the position of the substrate and in the same orientation. The geometry of the enzyme–inhibitor complex was energy-minimised with the Amber* force field (Macromodel V. 6.0 [53]). In the resulting optimised geometry, one of the isomers, **1b**, showed a geometrically favourable interaction between the ammonium group and the carboxylate corresponding to the catalytic nucleophile, *viz.* a salt bridge with a N ··· O distance of 2.5 Å (*cf. Fig. 1,b*).

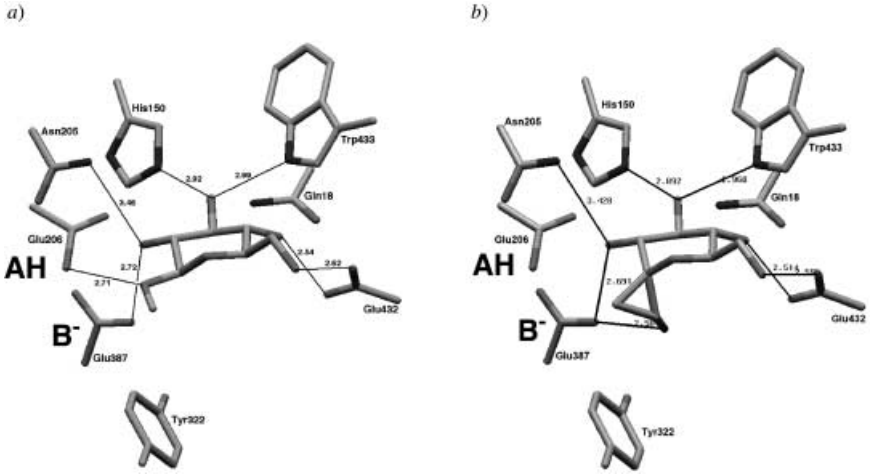

Fig. 1. *Docking of* a) *methyl* β-D-*glucopyranoside* (according to [1]), b) **1b** *in the active site of the* β-*glucosidase from* Sulfolobus solfataricus [52]

Synthesis of the gluco-*Cyclopropylamines.* We planned to prepare the cyclopropylammonium chlorides **1a**–**1d** *via* a *Curtius* rearrangement of the *O*-benzylated cyclopropanecarboxylic acids **8a**–**8d** (*Scheme 1*). The nitriles **30a**–**30d** (*cf. Fig. 2*)

corresponding to these acids had been prepared by cycloaddition to acrylonitrile of a carbene derived from perbenzylated glucono-1,5-lactone tosylhydrazone [16][20], or from the diazirine **5** [54][2]). The diazirine **5** [56][57] reacted with ethyl acrylate to yield 71% of a 4:5:1:20 mixture of the cyclopropane esters **7a**–**7d**. The undesired diastereoselectivity and the lengthy synthesis prompted us to look for an alternative. The esters **7a**–**7d** were obtained much more efficiently by cyclopropanating the readily available enol ether **6** [58] with ethyl diazoacetate. Catalysis of the cyclopropanation with Cu powder in toluene [59] led, in yields of 93–98%, to a 3:1:3:2 mixture of **7a**–**7d**, while $Rh_2(OAc)_4$ required a large excess of diazoacetate to yield 42–69% of **7a**–**7d** (3:2:3:2), depending on the choice of solvent and temperature[3]). The cyclopropanation proceeded best when a toluene solution of excess ethyl diazoacetate at below 25° was slowly added to a suspension of Cu powder in a toluene solution of **6** at 100°. The ester **7c** was isolated by crystallisation from MeOH (28%), while isolation of the other diastereoisomers required repeated purification by HPLC with different solvent systems to give **7a** (36%), **7b** (12%), **7c** (additional 3%), and **7d** (18%). The individual esters were hydrolysed, and the resulting acids **8a**–**8d** were transformed into the corresponding acyl azides **9a**–**9d**. Thermolysis of the azides in toluene at 100°, and treatment of the resulting isocyanates **10a**–**10d** with BnOH or *t*-BuOH led, in overall yields of 60–80%, to the carbamates **11a**–**11d** and **12a**–**12d**, respectively. The acyl azides **9a**–**9d** and the isocyanates **10a**–**10d** were stable enough to be isolated and characterised. Hydrogenolysis of the benzyl carbamates **11a**–**11d** yielded the desired ammonium chlorides **1a**–**1d** in almost quantitative yields, while debenzylation of the *tert*-butyl carbamates **12a**–**12d** led in high yield to the tetrahydroxy *tert*-butyl carbamates **13a**–**13d**. These carbamates were nearly quantitatively deprotected to **1a**–**1d** by treatment with 1N HCl at 50°.

Synthesis of the manno-*Cyclopropylamines.* We had planned to prepare the *O*-benzylated cyclopropanecarboxylates **15a**–**15d** (*Scheme 2*) and the differentially protected analogues **24a**–**24d** (*Scheme 3*), the former as precursors of the *manno*-cyclopropylammonium chlorides **2a**–**2d**, and the latter as precursors of *N*-acetylglucosamine-derived cyclopropylamines[4]). Cyclopropanation of the enol ether **14** [58] yielded 86% of a *ca.* 9:51:11:29 mixture of the corresponding esters **15a**–**15d** (*Scheme 2*), which were readily separated by HPLC. Hydrolysis of the esters **15a**–**15d** and *Curtius* degradation of the resulting acids **16a**–**16d** by using the same procedure as in the *gluco*-series yielded the corresponding *N*-Boc-protected cyclopropylamines **17a**–**17d**. These carbamates were also obtained by treating the acids **16a**–**16d** with diphenylphosphoryl azide in *t*-BuOH [61]. Yields were similar for both procedures (56–74%), but treatment of the acids **16c** and **16d** with diphenylphosphoryl azide gave also *ca.* 15% of the aminocarbonyl azides **19c** and **19d**, respectively (*cf.* [61][62]). Hydrogenation of **17a**–**17d** gave the *N*-Boc-cyclopropylamines **18a**–**18d** (84–99%), which were readily deprotected (1N aq. HCl) to the cyclopropylammonium chlorides **2a**–**2d**. The differentially protected *exo*-glycal **22** (*Scheme 3*) was obtained from the

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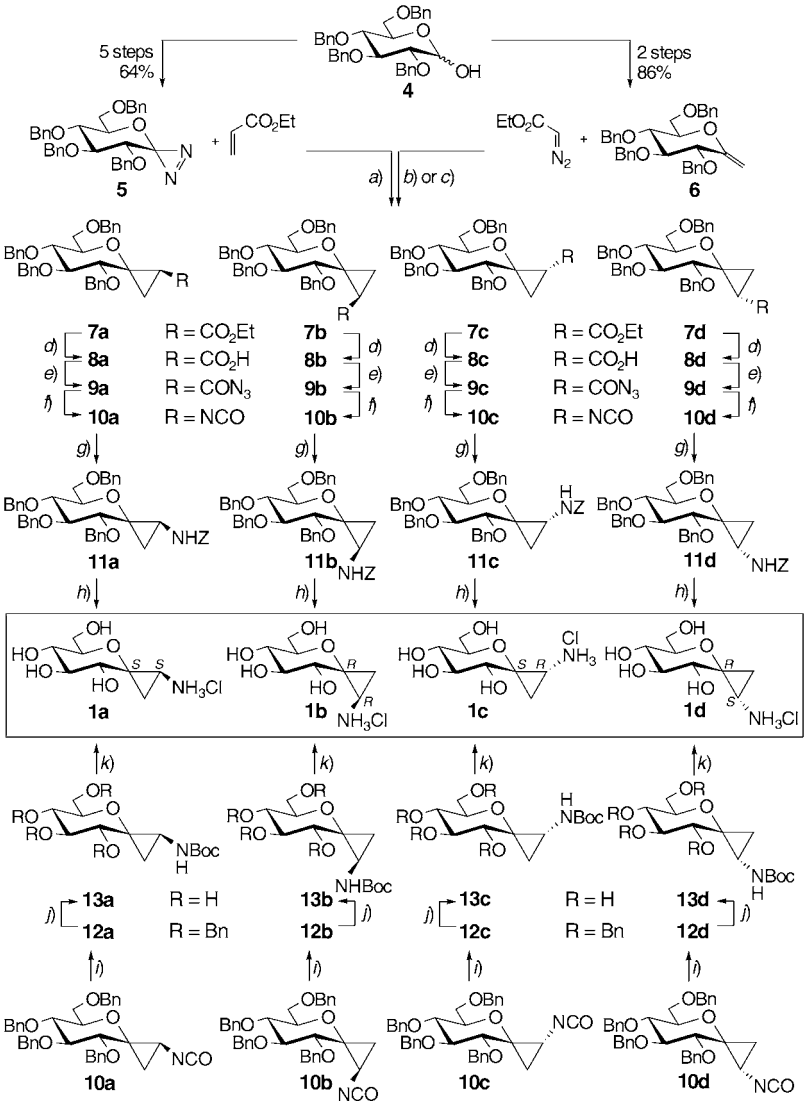
[2]) *O*-Acyl-protected nitriles corresponding to **8a**–**8d** were obtained in low yields by the reaction of acrylonitrile with 2,3,4,6-tetra-*O*-acetyl-1,5-anhydro-1,1-diazido-D-glucitol [15][55].

[3]) Comparable yields were obtained from the $Rh_2(OAc)_4$-catalysed cyclopropanation of glycals [60].

[4]) In view of the results discussed below, we did not pursue the synthesis of the glucosamine derivatives.

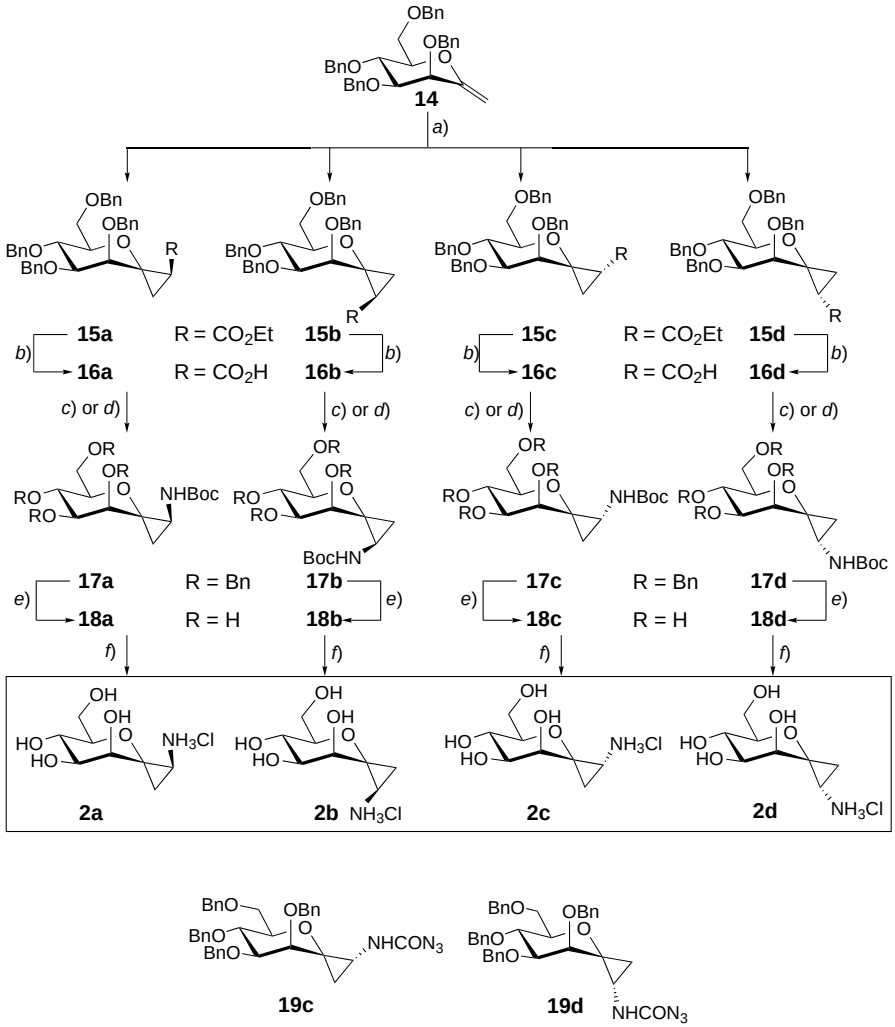
Scheme 1



a) 1,4-Dioxane, 23°; **7a**/**7b**/**7c**/**7d** 4:5:1:20 (71%). *b*) $Rh_2(OAc)_4$, Et_2O, 23°, **7a**/**7b**/**7c**/**7d** 3:2:3:2 (69%). *c*) Cu Powder, toluene, 100°, **7a**/**7b**/**7c**/**7d** 3:1:3:2 (98%). *d*) KOH, EtOH/H_2O, 80°; 95–99%. *e*) 1. $ClCO_2Et$, Et_3N, acetone, 0°, 2. NaN_3, H_2O, 23°. *f*) Toluene, 100°. *g*) BnOH, 100°; **11a** (85%), **11b** (82%), **11c** (77%), **11d** (68%). *h*) H_2, Pd/C, MeOH/HCl; quant. *i*) 1. Toluene, 100°, 2. *t*-BuOH, 90°; **12a** (78%), **12b** (82%), **12c** (85%), **12d** (78%). *j*) H_2, Pd/C, MeOH; **13a** (79%), **13b** (73%), **13c** (84%), **13d** (79%). *k*) 1N HCl; quant.

hemiacetals **20** (α/β 9:1) by oxidation and olefination. Thus, **20** was oxidised with pyridinium chlorochromate (PCC) to the spontaneously crystallising lactone **21** (79%). Treatment of **21** with the reagent of *Petasis* [63][64] gave the *exo*-glycal **22** (75%) besides the bis-enolether **23** (3%). Cyclopropanation of **22** with excess ethyl

Scheme 2

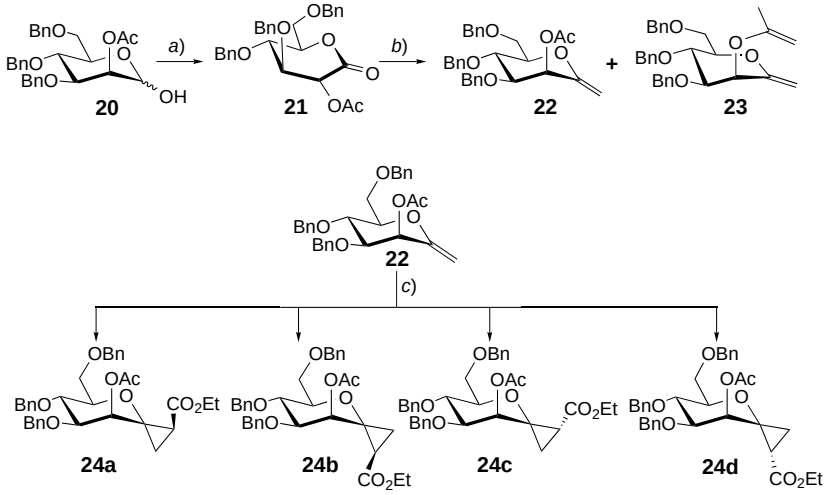


a) Ethyl diazoacetate, Cu powder, toluene, 70°; **14** (9%), **15a**/**15b**/**15c**/**15d** 9:51:11:29 (86%). *b*) KOH, EtOH/H_2O, 60°; 80–99%. *c*) 1. $ClCO_2Et$, Et_3N, acetone, 0°, 2. NaN_3, H_2O, 23°, 3. toluene, 100°. 4. *t*-BuOH, 100°; **17a** (67%), **17b** (74%), **17c** (67%), **17d** (56%). *d*) $(PhO)_2PON_3$, Et_3N, *t*-BuOH, 100°; **17a** (69%), **17b** (74%), **17c** (70%), **17d** (57%), **19c** (16%), **19d** (16%). *e*) H_2, Pd/C, MeOH; **18a** (quant.), **18b** (84%), **18c** (94%), **18d** (90%). *f*) 1N HCl; 90% – quant.

diazoacetate in the presence of Cu powder (0.2 equiv.) gave 91% of a *ca.* 18:42:17:23 mixture of the diastereoisomeric ethyl cyclopropanecarboxylates **24a**–**24d**, which were separated by HPLC (*Scheme 3*).

Synthesis of the galacto-*Cyclopropylamines.* Similarly as for the *gluco*-configured derivatives, Cu-catalysed cyclopropanation of the *exo*-galactal **25** [58] with ethyl diazoacetate yielded 71% of a 3:2:2:3 mixture of the cyclopropanecarboxylates **26a**–

Scheme 3



a) PCC, CH_2Cl_2, 23°; 79%. *b*) Cp_2TiMe_2, toluene, 60°; **22** (75%), **23** (3%). *c*) Ethyl diazoacetate, Cu powder, toluene, 60°, **24a**/**24b**/**24c**/**24d** 18:42:17:23 (91%).

26d (*Scheme 4*). This mixture was subjected to ester hydrolysis and *Curtius* degradation, providing the *tert*-butyl carbamates **28a**–**28d** in an overall yield of 68%. At this stage, the isomers were readily separated by flash chromatography into two groups of two isomers each, *viz.* **28a**/**28c** and **28b**/**28d**. Hydrogenolytic debenzylation of the carbamate mixtures, followed by chromatography, yielded 86–90% of the pure, debenzylated carbamates **29a**–**29d**. The desired cyclopropylammonium chlorides **3a**–**3d** were obtained in a nearly quantitative yield by treatment of the individual carbamates with 1N aq. HCl.

Structure Analysis. The structure determination of the isomeric *gluco*-, *manno*-, and *galacto*-cyclopropanes requires essentially the identification of the position of the cyclopropyl ring substituents X relative to C(2) and C(5)–O, and relative to the plane determined by C(2), C(1), and C(5)–O. To this end, the four positions are labelled A–D (*Fig. 2*,*a*), A being *anti* to O–C(5) and on top of the above-mentioned plane, B *anti* and below the plane, C *syn* and above the plane, and D *syn* and below the plane. The cyclopropane H-atoms were identified by their positions relative to the substituents X as H_{gem}, H_{cis}, and H_{trans}. H_{gem}, characterised by J_{cis} (*ca.* 9 Hz) and J_{trans} (*ca.* 7 Hz)[5]), is expected to be the most strongly deshielded cyclopropane H. H_{cis} and H_{trans} are further characterised by J_{gem} (*ca.* 6 Hz). The crystal structure of the *gluco*-configured derivatives **7c**, **11a**, and **13d** (*Fig. 3*)[6]), and the chemical correlation of the derivatives

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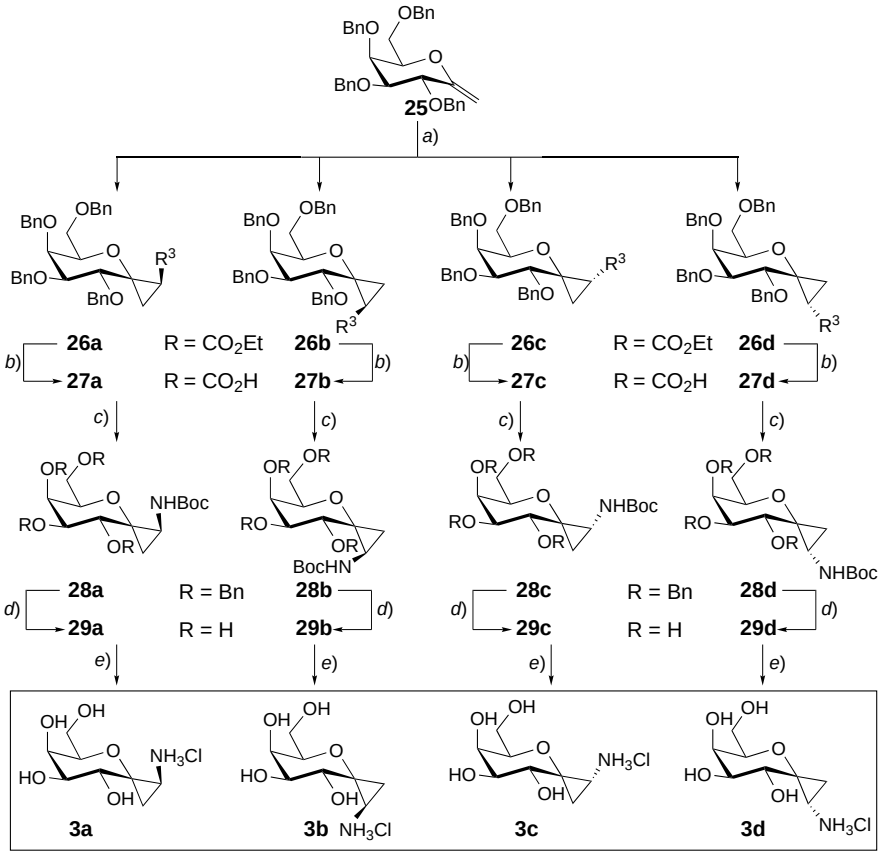
[5]) H_{gem}, H_{cis}, and H_{trans} refer to the positions of the H-atoms relative to the one of the substituents X, while J_{gem}, J_{cis} and J_{trans} mean the coupling constants between gem-, *cis*-, and *trans*-oriented H-atoms.

[6]) The crystallographic data have been deposited with the *Cambridge Crystallographic Data Centre* as supplementary publication No. CCDC-158320 (**11a**), 158321 (**7c**), 158322 (**13d**) and CCDC-207349 (**29d**). Copies of the data can be obtained, free of charge, on application to the CCDC, 12 Union Road, Cambridge CB2 1EZ (fax: +44(1223)336033; e-mail: deposit@ccdc.cam.ac.uk).

Scheme 4



a) Ethyl diazoacetate, Cu powder, toluene, 100°, **26a**/**26b**/**26c**/**26d** 29:17:21:33 (71%). *b*) KOH, EtOH/H_2O, 80°, 94%. *c*) 1. $ClCO_2Et$, Et_3N, acetone, 0°, 2. NaN_3, H_2O, 23°, 3. toluene, 100°, 4. *t*-BuOH, 100°; **28a**/**28c** 1:1 (40%), **28b**/**28d** 3:2 (33%). *d*) H_2, Pd/C, MeOH; **29a** (45%) and **29c** (41%) from the mixture **28a**/**28c**, **29b** (51%) and **29d** (36%) from the mixture **28b**/**28d**. *e*) 1N HCl; quant.

possessing the same configuration and differing by the nature of X allowed determination of the structures of all *gluco*-cyclopropanes. The NMR data of these compounds and those of the cyclopropane nitriles **30a**–**30d** provided a critical set of coupling constants and chemical shifts. The structure determination of the *manno*-cyclopropanes, as based on a comparison with these data and NOEs, was rather straightforward, while that of the *galacto*-cyclopropanes, although facilitated by the crystal structure of **29d** (*cf. Fig. 3*), proved more difficult.

Depending on their relative arrangement, the substituents X on the cyclopropane ring interact with substituents of the pyranose ring. Substituents in position A and B (*anti* to O–C(5)) should interact most strongly with the C(2) group, and substituents in position C and D most strongly with O–C(5) (*Fig. 2*). In the $^4C_1$ conformation, the equatorial nonbonding, doubly occupied orbital of O–C(5) bisects the plane of the

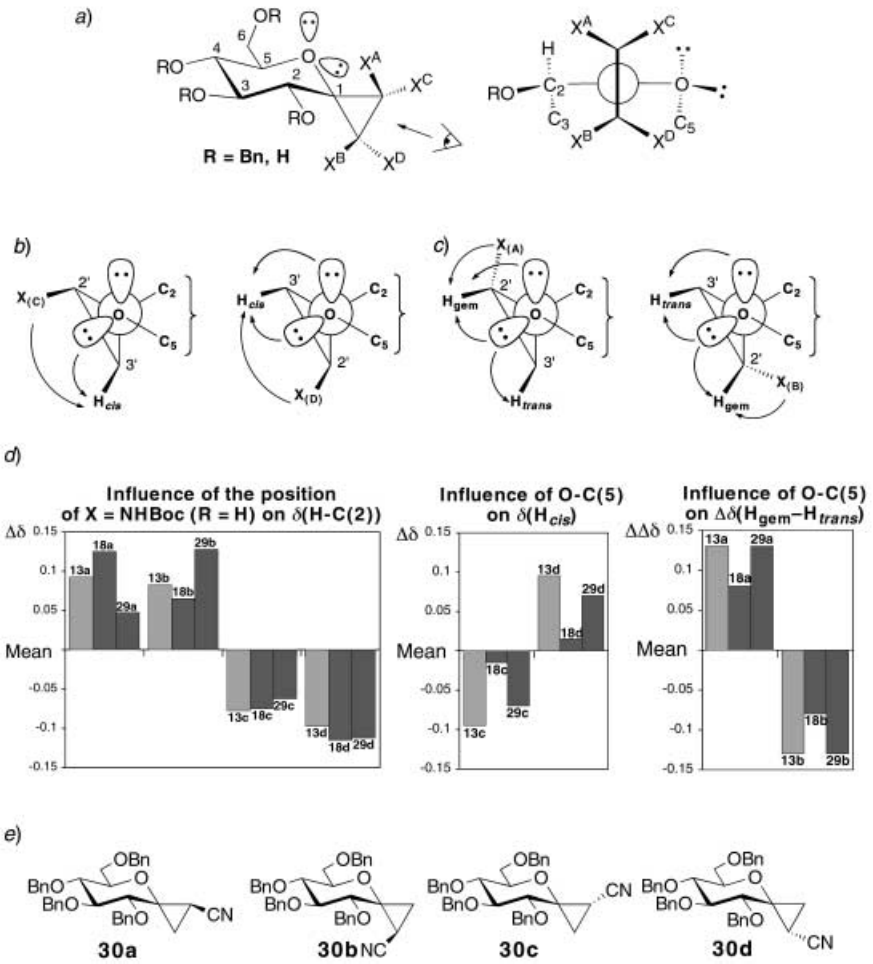


Fig. 2. a) *Positions A – D on the spirocyclic cyclopropane scaffold.* b) *Influence of the O – C(5) lone-pairs on* $\delta(H_{cis})$ *for X in positions C or D.* c) *Influence of the O – C(5) lone-pairs on* $\Delta\delta(H_{gem} - H_{trans})$ *for X in positions A or B.* d) *Graphical representation of the influence of X in positions A – D on* $\delta(H-C(2))$, $\delta(H_{cis})$, *and* $\Delta\delta(H_{gem} - H_{trans})$, *relative to the mean-values, for the* tert-*butyl carbamates* **13a** – **13d**, **18a** – **18d**, *and* **29a** – **29d**. e) *Structures of the nitriles* **30a** – **30d**.

cyclopropane ring and should have a similar deshielding effect on H in position C and D (H^C and H^D), while the axial nonbonding, doubly occupied orbital should influence H^C more strongly than H^D[7]; H^C_{cis} should then be more strongly deshielded than H^D_{cis} (*Fig. 2*, *b*) and $\Delta(\delta H^C_{gem} - \delta H^D_{trans})$ should be larger than $\Delta(\delta H^D_{gem} - \delta H^C_{trans})$ (*Fig. 2*, *c*). The influence of the C(2) group on H^A and H^B depends on the configuration of C(2). The axial RO substituent at C(2) in the *manno*-configured derivatives should mainly

7) For related observations and calculations, see, *e.g.*, [65 – 68].

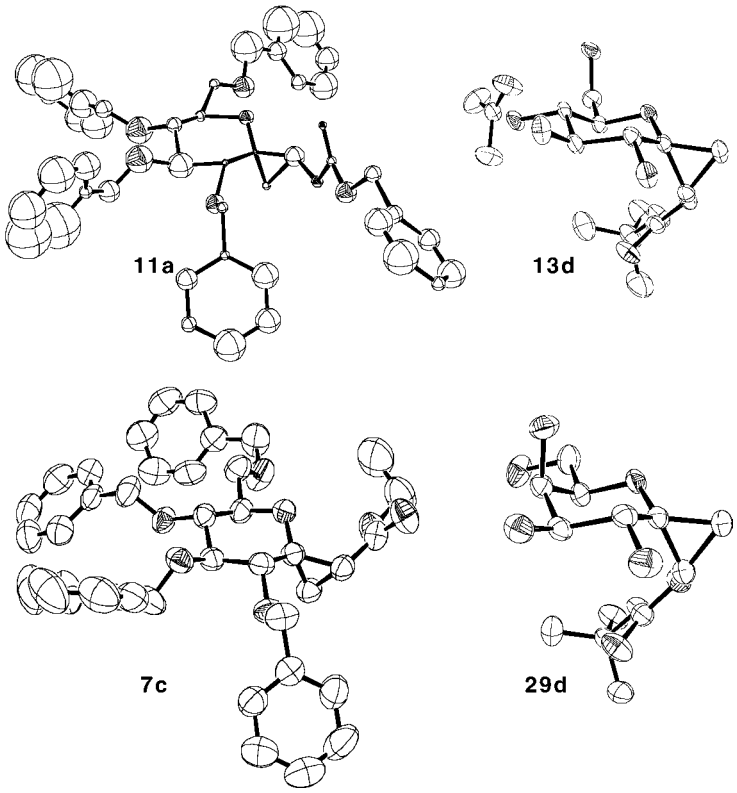


Fig. 3. *ORTEP Representations of the crystal structures of the carbamates* **11a**, **13d**, *and* **29d**, *and of the ester* **7c**. Parts of the structures of **11a** and **13d** were found on a *Fourier* map. The non-H-atoms of **7c**, **13d**, and **29d** were refined anisotropically. Structural refinement for **11a** was not possible (low crystal quality; *cf. Exper. Part*).

deshield H^A. In the *gluco*- and *galacto*-series, the equatorial RO substituent at C(2) bisects the plane of the cyclopropane ring and should deshield H^A and H^B to about the same extent. Conversely, the substituents X^A and X^B (*anti* to O–C(5)) should have an effect on δ(H–C(2)). In the *manno*-series, this effect should be similar for X^A and X^B and allow to distinguish isomers with X^A or X^B from isomers with X^C and X^D. In the *gluco*- and *galacto*-series the effect should be stronger for X^A than for X^B. One also expects an effect of X^B on δ(H–C(3)), and of X^D on δ(H–C(5)). The donor (O–C(5)) and acceptor (X) substituents of the cyclopropane ring may give rise to through-bond effects that will strengthen or weaken the through-space effects discussed above, and complicate the structure determination. We compared the chemical shifts of the ^{1}H and ^{13}C signals of each of the four diastereoisomers with the same X in the *gluco*-, *manno*-, and *galacto*-series, relative to the mean value for each one of these series, and compared the results in the three series with each other.

Configuration of the gluco-*Isomers.* The pyranose ring of the *gluco*-configured cyclopropanes **7b**–**7d**, **8b**–**8d**, **9b**–**9d**, **10b**–**10d**, **11b**–**11d**, **12b**–**12d**, **13b**–**13d**, **1a**–**1d**, and **30b**–**30d** [16][17] adopts the $^4C_1$ conformation, as evidenced by the coupling constants in *Tables 3* and *5*–*7* (*Exper. Part*), while *J*(2,3) values between 5.0 and 7.8 Hz

evidence a flattened chair conformation of **7a**, **8a**, **9a, 10a**, **11a**, **12a**, **13a**, and **30a**. The flattening of the pyranose ring correlates with the position A for X, suggesting that it is due to an interaction between X^A and C(2)–OR. In accordance with the above-mentioned considerations, isomers possessing X^A (with the exception of **8a** and **9a**) show a deshielding of H–C(2) relative to the mean values. Surprisingly, the deshielding effect of substituents X^B is even stronger, possibly reflecting the pyranose deformation caused by X^A[8]). As expected, H^C_{cis} (for isomers with X^D) resonates at lower field than H^D_{cis} (for isomers with X^C), and $\Delta(\delta H^C_{gem} - \delta H^D_{trans})$ (for isomers with X^A) is always larger than $\Delta(\delta H^D_{gem} - \delta H^C_{trans})$ (for isomers with X^B). CN, NCO, and carbonyl substituents in position B have a deshielding effect on H–C(3), evidencing their spatial proximity. Similarly, CN in position D has a deshielding effect on H–C(5), while carbonyl substituents in position D have a shielding effect ($\Delta\delta = 0.27 - 0.37$ ppm relative to the mean values). The chemical shift of the ethyl ester methylene group in **7a** is shifted upfield by 0.23 ppm, indicating a shielding effect of the adjacent C(2)–OBn group. The ^{13}C-NMR spectra of all *gluco*-cyclopropanes show an upfield shift of the resonance for the C-atom bearing X in the *anti*-isomers (possessing X^A or X^B) relative to the *syn*-isomers (possessing X^C or X^D) (*cf. Table 4* in *Exper. Part*). This may be a consequence of the different electronic structures resulting from the *trans*- or *cis*-arrangement of donor (O–C(5)) and acceptor (X) substituents.

Relatively weak NOEs were found between H in position A and H–C(2), H in position B and H–C(3), and H in position D and H–C(5) for **1a**, **7a**, **7c**, **7d**, and **8b**, in agreement with the assigned configurations. There was also a weak NOE between H in position B and H–C(5) of **7d**[9]).

Configuration of the manno-*Isomers.* The observed small $J(3,4)$ (1.6 Hz) and medium $J(4,5)$ (7.0 Hz) values of the lactone **21** in $CDCl_3$ solution evidence its $B_{2,5}$ conformation, and are similar to $J(3,4)$ and $J(4,5)$ values of 2,3,4,6-tetra-*O*-benzyl-D-mannono-1,5-lactone [69] and of D-mannono-1,5-lactone [70]. The dominant conformation of the *exo*-glycal **22** ($^4C_1$) and the bis-enolether **23** (flattened $^4C_1$) was deduced from a small $J(2,3)$, and large and similar $J(3,4)$ and $J(4,5)$ values ($J(3,4) \approx J(4,5) = 9.0$ and 7.6 Hz for **22** and **23**, resp.). The pyranose ring of all *manno*-configured cyclopropanes adopts a $^4C_1$ conformation (*cf. Tables 8*, *10*, and *11* in *Exper. Part*). On the basis of the considerations above, the *manno*-configured esters **15a** and **15b** (δ(H–C(2)) = 4.13 and 4.17 ppm, resp.) possess an *anti*-configuration, and the esters **15c** and **15d** (δ(H–C(2)) = 3.13 and 3.11 ppm, resp.) a *syn*-configuration. The same assignment results from the analysis of the δ(H–C(2)) values of the acids, carbamates, and amines derived from the esters **15a**–**15d**, and also for the esters **24a**–**24d** (*Tables 8*, *10*, and *11* in *Exper. Part*). The position of X in the *anti*-isomers **15a** and **15b** was deduced from $\Delta(\delta H^C_{gem} - \delta H^D_{trans}) = 0.99$ ppm (**15a**) and $\Delta(\delta H^D_{gem} - \delta H^C_{trans}) = 0.17$ ppm (**15b**). Analogous $\Delta\delta$ values were found for all products derived from **15a** and **15b**, respectively, and for **24a** and **24b**. The structure of the *syn*-isomers **15c** and **15d** was

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[8]) In keeping with this hypothesis, the weaker deformation of the pyranose ring in the nitrile **30a** and in the Boc-carbamate **13a** correlates with an almost equal influence on δ(H–C(2)) of the CN and NHBoc groups in position A or B.

[9]) Unexpected intensity enhancements were observed for the signals of H–C(2) and H–C(4) of **8a** upon irradiation of H_{gem} in position C, and for the signal of H–C(2) upon irradiation of H_{cis} in position B. They correlate with the deformation of the pyranose ring.

further evidenced by $\delta(H^{D}_{cis}) = 1.44$ ppm (**15c**) and by $\delta(H^{C}_{cis}) = 1.93$ ppm (**15d**). Similar chemical-shift differences for H_{cis} were observed for the *O*-benzylated products derived from either **15c** or **15d**, and for **24c** and **24d**. The spectra of the *manno*-esters and *manno*-acids show shielding of H–C(3) by C=O substituents in position C (**15c** and **16c**), and similarly of H–C(5) by C=O substituents in position D (**15d** and **16d**). These effects evidence the spatial proximity of these groups. The ^{13}C chemical shifts for C(2′) in the *manno*-configured derivatives (*cf. Table 9* in *Exper. Part*) do not differ as clearly as is observed in the *gluco*-analogues. The C(2′) signals of **15c**, **16c**, and **17c** are significantly shifted downfield relative to the corresponding signals in the *gluco*-cyclopropanes.

The proposed configuration for the *manno*-cyclopropanes is further evidenced by (relatively weak) NOEs between H^{A} and H–C(2) in **15d** and **24b**, between H^{B} and H–C(2) in **15d** and **24a**, and between H^{D} and H–C(5) in **24a** and **24b**.

Configuration of the galacto-*Isomers.* Similar to what was found in the *gluco*-series, all isomers of the debenzylated *galacto*-cyclopropanes **29a**–**29d** and **3a**–**3d**, but only three isomers each of the *O*-benzylated esters (**26b**–**26d**) and *O*-benzylated Boc-carbamates (**28b**–**28d**) adopt a $^{4}C_{1}$ conformation (*cf. Tables 12* and *14* in *Exper. Part*). The isomers **26a** and **28a** adopt a flattened chair conformation, evidencing interaction between X^{A} and C(2)–OBn. Surprisingly, δ(H–C(2)) of **26a** and **28a** is not shifted downfield as expected from the observations in the *gluco*-series. δ(H–C(2)) appears to be influenced by the axial C(4)–OBn group. In agreement with this hypothesis, H–C(2) of the debenzylated carbamates **29a** (δ 4.20) and **29b** (δ 4.28) is deshielded relative to H–C(2) of **29c** (δ 4.09) and **29d** (δ 4.04), allowing to deduce that the NHBoc group is *anti* to O–C(5) in **29a** and **29b**, and *syn* to O–C(5) in **29c** and **29d**. The orientation as above or below the reference plane defined above was deduced on the basis of $\Delta(\delta H^{C}_{gem} - \delta H^{D}_{trans}) \approx 1.72 - 1.83$ ppm (**29a**) and $\Delta(\delta H^{D}_{gem} - \delta H^{C}_{trans}) = 1.51$ ppm (**29b**) for the *anti*-isomers **29a** and **29b**, and of $H^{D}_{cis} = 0.65$ ppm (**29c**) and $H^{C}_{cis} = 0.79$ ppm (**29d**) for the *syn*-isomers **29c** and **29d**. A similar analysis of the ammonium chlorides **3a**–**3d** derived from the NBoc-carbamates leads to the same configurational assignment. Similar to **7b** and **7d**, δ(H–C(3)) is shifted downfield by the proximal C=O substituent in **26b**, while δ(H–C(5)) is shifted upfield by the C=O substituent in **26d**. Similarly as in **7a**, the ethyl ester CH_2 group of **26a** is shielded relative to **26b**–**26d**, indicating its proximity to the C(2)–OBn group. The ^{13}C-NMR spectra of all *galacto*-cyclopropanes (*cf. Table 13* in *Exper. Part*) show an upfield shift for C(2′) in the *anti*-isomers (with X^{A} or X^{B}) relative to the *syn*-isomers (with X^{C} or X^{D}), as apparent in the *gluco*-compounds.

Inhibition Studies. The *gluco*-, *manno*-, and *galacto*-cyclopropylammonium chlorides **1a**–**1d**, **2a**–**2d**, and **3a**–**3d** were tested against the β-glucosidases from *Caldocellum saccharolyticum* and from sweet almonds, the α-glucosidase from brewer's yeast, the α-mannosidases from jack beans and from almonds, the β-mannosidase from snails, the α-galactosidases from *Aspergillus niger* and from coffee beans, and the β-galactosidases from bovine liver and from *E. coli*. The ammonium salts **1a**–**1d** and **3a**–**3d** proved to be millimolar inhibitors of these enzymes (*Tables 1* and *2*)[10]), while **2a**–**2d** showed no inhibition even at a concentration of 1.5 mM. Although differences

[10]) For a discussion of the discrepancy with data reported earlier [71], see below.

between the isomers were apparent, they were not significant in view of the weak binding. Unambiguous determination of the inhibition type was problematic. This unsatisfactory result may be attributed to the fact that the ammonium group in **1a**–**1d**, **2a**–**2d,** and **3a**–**3d** is not at the position corresponding to the glycosidic O-atom in the natural substrate, but shifted by one C–C bond. Although small changes in the binding geometry resulting from this shift were apparent in our modelling studies, the resulting loss of binding energy seemed to be compensated by the interaction between the ammonium group and the carboxylate corresponding to the catalytic nucleophile. That this was not observed may mean that a conformation closer to the transition state (*e.g.*, one deformed towards a half-chair or a $^{1,4}B$; *cf.* [72]) is essential for strong binding.

Table 1. *Inhibition of α-Glucosidase from Yeast and β-Glucosidases from Almonds and* Caldocellum saccharolyticum *at pH 6.8 by the* gluco-*Cyclopropylamines* **1a**–**1d**, $PdCl_4^{2-}$, *and 1:1 Mixtures of* **1a**–**1d** *and* PdC_4^{2-}: K_i *and* IC_{50} *values* [μM]

	α-Glucosidase (Brewer's yeast)	β-Glucosidase (Sweet almonds)	β-Glucosidase (*C. saccharolyticum*)
$PdCl_4^{2-}$	19[a])	400[e])	40[d])
1a	6800[b])	10000[e])	12000[b])
1a/$PdCl_4^{2-}$	0.43[a])	45[d])	1.5[d])
1b	12000[c])	59000[e])	25000 [d])
1b/$PdCl_4^{2-}$	0.46[a])	52[d])	3.0[d])
1c	1800[d])	17000[e])	11000[b])
1c/$PdCl_4^{2-}$	1.5[a])	38[d])	2.0[d])
1d	7600[d])	71000[e])	8000[c])
1d/$PdCl_4^{2-}$	0.20[a])	52[d])	0.5[d])

[a]) Non-competitive, irreversible. [b]) Mixed, reversible. [c]) Competitive, reversible. [d]) Non-competitive, reversible. [e]) IC_{50}.

Table 2. *Inhibition of α-Galactosidase from* Aspergillus niger *at pH 4.0, α-Galactosidase from Coffee Beans at pH 6.0, β-Galactosidase from Bovine Liver at pH 7.0, and β-Galactosidase from* Escherichia coli *and β-glucosidase from* Caldocellum saccharolyticum *at pH 6.8 by the* galacto-*Cyclopropylamines* **3a**–**3d**, $PdCl_4^{2-}$, *and 1:1 Mixtures of* **3a**–**3d** *and* $PdCl_4^{2-}$: K_i *and* IC_{50} *values* [μM]

	α-Galactosidase (*A. niger*)	α-Galactosidase (Coffee beans)	β-Galactosidase (Bovine liver)	β-Galactosidase (*E. coli*)	β-Glucosidase (*C. saccharolyticum*)
$PdCl_4^{2-}$	5.8[a])	4.8[d])	36[b])	1.2[b])	40[b])
3a	11000[c])	1900[c])	22000[c])	43000[c])	n.d.
3a/$PdCl_4^{2-}$	8.1[a])	1.7[c])	45[b])	1.1[b])	2.0[b])
3b	5100[c])	11000[c])	17000[c])	5500[c])	n.d.
3b/$PdCl_4^{2-}$	8.2[a])	0.3[c])	48[b])	0.9[b])	0.6[b])
3c	13000[c])	5600[c])	18000[c])	29000 [c])	n.d.
3c/$PdCl_4^{2-}$	7.3[a])	3.0[c])	41[b])	2.0[b])	2.3[b])
3d	8600[c])	15000[c])	64000[c])	5300[c])	n.d.
3d/$PdCl_4^{2-}$	17[a])	0.7[c])	35[b])	0.9[b])	0.8[b])

[a]) Competitive, reversible. [b]) Non-competitive, reversible. [c]) IC_{50}. [d]) Uncompetitive, irreversible.

Our initial observations with samples of **1a**–**1d** obtained by hydrogenolysis of the corresponding benzyl carbamates **11a**–**11d** differed considerably from this result.

Unlike the samples prepared by acidic deprotection of the *tert*-butyl carbamates **13a**–**13d**, those resulting from hydrogenolysis were micromolar inhibitors of the α-glucosidase from yeast and the β-glucosidase from *C. saccharolyticum*. Investigation of these conflicting results led to the identification of traces of Pd compounds contaminating the products of the hydrogenolytic debenzylation as a possible origin of the strong inhibition. In contact with air and acid, Pd^0 on the heterogeneous catalyst was readily oxidised in the reaction mixtures to soluble Pd^{II} compounds[11]).

The debenzylation of **11a** was examined by drawing aliquots from the reaction mixture, and measuring their effect on the activity of the *C. saccharolyticum* β-glucosidase as a function of time and reaction conditions. Remarkably, a mixture of **11a**, 10% Pd on charcoal, MeOH, and aqueous HCl already inhibited the enzyme more strongly than samples prepared by cleaving the Boc-protected analogues. Upon exposure to H_2 (1 bar), this inhibition decreased rapidly and remained low until the end of the reaction (8 h), when H_2 was displaced by air. Within minutes after the first contact with air, the reaction mixture inhibited the β-glucosidase strongly. This effect was reversed by replacing air with H_2. Obviously then, filtration through the acidic ion exchanger that was initially used to purify **1a**–**1d** did not remove the Pd^{II} contamination. All samples of **1a**–**1d**, **2a**–**2d**, and **3a**–**3d** were thus purified by flash chromatography prior to enzyme testing.

To learn more about the inhibition by Pd^{II}, solutions of $PdCl_4^{2-}$, prepared from $PdCl_2$ and aqueous HCl, were tested against the β-glucosidases from *C. saccharolyticum* and sweet almonds, the α-glucosidase from brewer's yeast, the α-galactosidases from *A. niger* and from coffee beans, and the β-galactosidases from bovine liver and from *E. coli* (*Tables 1* and *2*). The yeast α-glucosidase and the coffee-bean α-galactosidase were irreversibly inhibited. The other enzymes were inhibited reversibly, with K_i values in the micromolar range. The α-galactosidase from *A. niger* was the only enzyme to be inhibited competitively, while the β-glucosidases from *C. saccharolyticum* and sweet almonds, and the β-galactosidases from bovine liver and from *E. coli* were inhibited non-competitively. Addition of **1a**–**1d** or **3a**–**3d** to these Pd^{II} solutions strongly enhanced the inhibition of some of these glycosidases (*Tables 1* and *2*). The addition of 1 equiv. of **1d**, for example, lowered K_i for the inhibition of the β-glucosidase from *C. saccharolyticum* by $PdCl_4^{2-}$ from 40 to 0.5 μM. It is significant that different isomers enhanced the inhibition by Pd^{II} to a different extent, and that even the *galacto*-configured **3a**–**3d** had a strong effect on the inhibition of the β-glucosidase from *C. saccharolyticum* by $PdCl_4^{2-}$. Ethanolamine, tris(hydroxymethyl)aminomethane (*Tris*), glucosamine, or galactosamine had no effect. Cyclopropylamine, however, enhanced the inhibition of the β-glucosidase from *C. saccharolyticum* by $PdCl_4^{2-}$ significantly. This effect is under scrutiny; it evidences that the effect of added amines on the inhibition by Pd^{2+} is not simply due to solubilisation.

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[11]) Evidenced on TLC by the typical greenish-brown colour developing upon spraying with $SnCl_2$ and heating [73].

Experimental Part

General. Solvents were distilled before use. TLC: *Merck* silica gel *60F-254* plates; detection by heating with mostain (400 ml of 10% H_2SO_4 soln., 20 g of $(NH_4)_6Mo_7O_{24}\cdot 6\,H_2O$, 0.4 g of $Ce(SO_4)_2$); detection of Pd^{2+} by spraying with a soln. of 8 g of $SnCl_2$ in 80 ml of 37% HCl, and heating. Flash chromatography (FC): silica gel *Fluka 60* (0.04–0.063 mm). Anal. HPLC: *Spherisorb*, 5 μm (4 × 250 mm), Prep. HPLC: *Kromasil* 100 Å, 5 μm, with a self-packed silica-gel column (20 × 250 mm). MPLC: self-packed column with 2 kg of silica gel *Fluka 60*. Molecular sieves 4 Å (*Fluka*): powder, activated by drying at 0.05 mbar for 12 h at 250°. M.p. uncorrected. Optical rotations: 1-dm cell. IR Spectra: KBr, or 2% $CHCl_3$ soln. ^{1}H- and ^{13}C-NMR spectra: at 300 and 75 MHz, resp., if not indicated otherwise; chemical shifts δ in ppm, coupling constants J in Hz. α-Glucosidase from brewer's yeast (maltase, 3.2.1.20, Type VI, G-4634, as lyophilised powder), β-glucosidases from sweet almonds (3.2.1.21, as lyophilised powder), β-glucosidase from *C. saccharolyticum* (3.2.1.21, as lyophilised powder), α-mannosidase from jack beans (EC 3.2.1.24, as suspension in 3.0M $(NH_4)_2SO_4$ and 0.1 mM zinc acetate, pH 7.5), α-mannosidase from almonds (EC 3.2.1.24, as soln. in 10 mM potassium phosphate buffer and 0.1% NaN_3, pH 6.0), β-mannosidase from snails (EC 3.2.1.25, as suspension in 3.0M $(NH_4)_2SO_4$ and 10 mM NaOAc, pH around 4.0), α-galactosidase from *A. niger* (EC 3.2.1.22, as suspension in 3.5M $(NH_4)_2SO_4$ and 50 mM NaOAc, pH 5.5), α-galactosidase from green coffee beans (EC 3.2.1.22, as suspension in 3.2M $(NH_4)_2SO_4$ containing BSA, pH 6.0), β-galactosidase from bovine liver (3.2.1.23, as lyophilised powder), β-galactosidase from *E. coli* (3.2.1.23, as lyophilised powder), and all nitrophenyl glycopyranosides were purchased from *Sigma* and used without any further purification.

Preparation of **7a**–**7d**. a) *By Cyclopropanation of* **5**. A soln. of ethyl acrylate (5 ml, 46.0 mmol) in dry 1,4-dioxane (5 ml) was treated with 0.5 g of activated, powdered 4-Å molecular sieves, stirred for 30 min at 23°, treated with 4.7 ml of a 0.15M soln. of **5** (0.71 mmol) in CH_2Cl_2, and stirred for an additional 8 h. The mixture was diluted with CH_2Cl_2 (5 ml), filtered through *Celite*, and the residue was washed with CH_2Cl_2. Evaporation of the combined filtrate and washings gave crude **7a**–**7d** (0.45 g) as a colourless oil. MPLC (hexane/Et_2O/CH_2Cl_2 8:1:1) gave **7d** (211.5 mg, 48%) and a mixture of **7a**–**7c**. Prep. HPLC (hexane/Et_2O 4:1) of this mixture afforded **7a** (47.6 mg, 11%), **7b** (39.3 mg, 9%), and **7c** (13.7 mg, 3%).

b) *By $Rh_2(OAc)_4$-Catalysed Cyclopropanation of* **6**. Under exclusion of air, a soln. of **6** (0.30 g, 0.56 mmol) [58] and $Rh_2(OAc)_4$ (2.7 mg, 5.6 μmol) in dry Et_2O (2 ml) at 23° was treated with a soln. of ethyl diazoacetate (1.6 g, 14 mmol) in dry Et_2O (15 ml) *via* syringe pump (1 equiv./h). Filtration over Al_2O_3 and evaporation gave crude **7a**–**7d** (540 mg). FC (hexane/Et_2O 5:1 → 1:1) yielded a 26:30:20:23 mixture **7a**–**7d** (241 mg, 69%), which was separated as described above.

c) *By Cu-Catalysed Cyclopropanation of* **6**. A suspension of Cu powder (0.25 g, 3.9 mmol) in a soln. of **6** (3.44 g, 6.41 mmol) in toluene (15 ml) in a 100-ml long-necked flask was heated to 100° and treated dropwise with a soln. of ethyl diazoacetate (1.83 g, 16.0 mmol) in dry toluene (15 ml) *via* syringe pump (1 equiv./h), in such a way that the injection needle resided only in the cooler upper part of the flask (*ca.* r.t.). After completed addition, the soln. was stirred for an additional 30 min at 100°. Evaporation and crystallisation from MeOH yielded pure **7c** (1.10 g, 28%). FC (hexane/Et_2O 5:1 → 1:1) of the mother liquor gave a mixture of **7a**–**7d** (2.83 g, 70%), which was separated as described above.

*Ethyl (1*S*,2′*S*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-carboxylate* (**7a**). Colourless oil. R_f (hexane/Et_2O 3:2) 0.34. Anal. HPLC: t_R (hexane/Et_2O 7:1, 2 ml/min) 6.7 min. Prep. HPLC: t_R (hexane/Et_2O 4:1, 10 ml/min) 20 min. $[\alpha]_D^{25} = +23.3$ ($c = 1.00$, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3068*m*, 2906*m*, 2870*m*, 1714*s*, 1603*w*, 1497*m*, 1454*m*, 1379*w*, 1358*w*, 1326*w*, 1262*m*, 1093*s*, 1028*m*, 871*w*. ^{1}H-NMR (500 MHz, $CDCl_3$; assignment based on a DQFC.GRASP spectrum): see *Table 3*; additionally, 7.36–7.16 (*m*, 20 arom. H); 4.80 (*d*, $J = 11.7$, PhC*H*); 4.78 (*d*, $J = 11.1$, PhC*H*); 4.63 (*d*, $J = 11.2$, PhC*H*); 4.61 (*d*, $J = 12.1$, PhC*H*); 4.59 (*d*, $J = 11.8$, PhC*H*); 4.59 (*d*, $J = 11.8$, PhC*H*); 4.56 (*d*, $J = 11.1$, PhC*H*); 4.52 (*d*, $J = 12.2$, PhC*H*); 3.96 (irrad. at 1.48 → NOE of 1.7%, irrad. at 2.10 → NOE of 0.7%); 3.88 (irrad. at 2.10 → NOE of 1.3%); 3.79 (*qd*, $J = 7.1$, 10.7, MeC*H*O); 3.79 (irrad. at 1.48 → NOE of 0.8%); 3.75 (irrad. at 1.19 → NOE of 1.0%); 3.74 (*qd*, $J = 7.1$, 10.7, MeC*H*O); 2.10 (irrad. at 3.96 → NOE of 1.0%, irrad. at 3.88 → NOE of 1.5%); 1.48 (irrad. at 3.96 → NOE of 2.0%); 1.06 (*t*, $J = 7.1$, *Me*CH_2O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 170.04 (*s*, C=O); 138.50 (*s*); 137.82 (*s*, 2 C); 137.69 (*s*); 128.52–127.22 (several *d*); 74.43, 73.86, 73.51, 72.81 (4*t*, 4 Ph*C*H_2); 60.78 (*t*, Me*C*H_2O); 14.11 (*q*, *Me*CH_2O). Anal. calc. for $C_{39}H_{42}O_7$ (622.76): C 75.22, H 6.80; found: C 75.08, H 6.84.

*Ethyl (1*R*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-carboxylate* (**7b**). Colourless oil. R_f (hexane/Et_2O 3:2) 0.28. Anal. HPLC: t_R (hexane/Et_2O 7:1, 2 ml/min) 6.0 min. Prep. HPLC: t_R (hexane/Et_2O 4:1, 10 ml/min) 26 min. $[\alpha]_D^{25} = +14.0$ ($c = 1.55$, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3067*w*, 2871*m*, 1726*s*, 1586*w*, 1497*m*, 1454*m*, 1375*m*, 1360*m*, 1322*m*, 1159*w*, 1093*s*, 1028*w*, 911*w*. ^{1}H-NMR (500 MHz, $CDCl_3$,

Table 3. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the* gluco-*Cyclopropanes* **7a**–**7d** *and* **8a**–**8d** *in $CDCl_3$*

Compound	**7a**[a])	**7b**[a])	**7c**	**7d**	**8a**	**8b**	**8c**	**8d**
H–C(2′)	2.10	1.80	2.01	2.11	2.04	1.83	2.07	2.12
H_{cis}–C(3′)	1.48	1.49	1.37	1.73	1.43	1.49	1.39	1.73
H_{trans}–C(3′)	1.19	1.29	1.26	1.26	1.19	1.41	1.43	1.34
H–C(2)	3.96	3.99	3.92	3.91	3.95	4.05	3.98	3.93
H–C(3)	3.79	3.99	3.69	3.74	3.77	3.95	3.73	3.74
H–C(4)	3.88	3.81–3.74	3.85	3.87	3.85	3.80	3.82	3.89
H–C(5)	3.75	3.72–3.68	3.51	3.17	3.72	3.66	3.61	3.30
H_a–C(6)	3.75	3.72–3.68	3.73	3.72	3.72	3.68	3.73	3.73
H_b–C(6)	3.61	3.63–3.60	3.66	3.60	3.59	3.59	3.67	3.61
$J(2',3'_{cis})$	7.7	7.7	6.2	6.9	7.8	7.8	7.2	6.6
$J(2',3'_{trans})$	10.0	10.1	9.0	9.1	10.0	10.3	9.0	9.1
$J(3'_{cis},3'_{trans})$	5.9	6.3	5.4	5.8	5.9	6.5	5.6	5.8
$J(2,3)$	5.8	8.8	9.0	9.2	5.9	8.7	8.7	9.1
$J(3,4)$	7.7	9.3	9.0	9.1	7.8	8.4	9.0	9.1
$J(4,5)$	9.0	[b])	9.7	9.7	7.8	9.3	9.3	9.1
$J(5,6_a)$	4.4	[b])	3.5	3.1	4.4	3.4	2.2	3.3
$J(5,6_b)$	[b])	[b])	1.9	1.9	4.4	[b])	4.4	2.1
$J(6_a,6_b)$	11.9	[b])	11.1	10.8	12.5	11.8	10.9	10.8

[a]) Assignment based on DQFC·COSY spectrum. [b]) Not assigned.

assignment based on a DQFC.GRASP spectrum): see *Table 3*; additionally, 7.34–7.16 (*m*, 20 arom. H); 4.83 (*d*, *J* = 10.9, PhC*H*); 4.78 (*s*, PhCH_2); 4.66 (*d*, *J* = 11.8, PhC*H*); 4.63 (*d*, *J* = 11.2, PhC*H*); 4.59 (*d*, *J* = 12.1, PhC*H*); 4.53 (*d*, *J* = 10.9, PhC*H*); 4.48 (*d*, *J* = 12.1, PhC*H*); 4.09 (*qd*, *J* = 7.1, 10.8, MeC*H*O); 3.87 (*qd*, *J* = 7.1, 10.8, MeC*H*O); 1.12 (*t*, *J* = 7.1, *Me*CH_2O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 169.37 (*s*, C=O); 138.67, 138.42, 138.13, 137.98 (4*s*); 128.52–126.91 (several *d*); 75.32 (*t*, 2 PhCH_2); 74.87, 73.54 (2*t*, 2 PhCH_2); 60.68 (*t*, MeCH_2O); 14.15 (*q*, *Me*CH_2O). Anal. calc. for $C_{39}H_{42}O_7$ (622.76): C 75.22, H 6.80, O 17.98; found: C 75.35, H 6.91.

*Ethyl (1S,2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carboxylate* (**7c**). Colourless solid. R_f (hexane/Et_2O 3:2) 0.30. M.p. 89° (MeOH). Anal. HPLC: t_R (hexane/Et_2O 7:1, 2 ml/min) 5.5 min. Prep. HPLC: t_R (hexane/Et_2O 4:1, 10 ml/min) 25 min. $[\alpha]_D^{25} = -6.1$ ($c = 0.68$, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3067*w*, 2926*m*, 2855*m*, 1729*s*, 1497*w*, 1454*m*, 1380*m*, 1360*m*, 1280*m*, 1154*m*, 1092*s*, 1028*s*, 917*w*, 818*w*. ^{1}H-NMR (500 MHz, $CDCl_3$): see *Table 3*; additionally, 7.35–7.23 (*m*, 18 arom. H); 7.19–7.17 (*m*, 2 arom. H); 4.88 (*d*, *J* = 11.3, 2 PhC*H*); 4.85 (*d*, *J* = 11.2, 2 PhC*H*); 4.66 (*d*, *J* = 11.3, PhC*H*); 4.60 (*d*, *J* = 12.2, PhC*H*); 4.59 (*d*, *J* = 10.7, PhC*H*); 4.49 (*d*, *J* = 12.2, PhC*H*); 4.18 (*qd*, *J* = 7.1, 10.8, MeC*H*O); 4.10 (*qd*, *J* = 7.1, 10.8, MeC*H*O); 2.01 (irrad. at 3.92 → NOE of 2.3%); 1.37 (irrad. at 3.51 → NOE of 4.6%); 1.26 (irrad. at 3.69 → NOE of 3.1%); 1.24 (*t*, *J* = 7.1, *Me*CH_2O). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 169.50 (*s*, C=O); 138.71, 138.43, 138.36, 138.08 (4*s*); 128.65–127.73 (several *d*); 75.77, 75.39, 75.17, 73.58 (4*t*, 4 PhCH_2); 60.79 (*t*, MeCH_2O); 12.82 (*q*, *Me*CH_2O). Anal. calc. for $C_{39}H_{42}O_7$ (622.76): C 75.22, H 6.80, O 17.98; found: C 75.25, H 6.92, O 18.02.

X-Ray Analysis of **7c**. Monoclinic $P2_1$; $a = 12.654(7)$, $b = 9.329(1)$, $c = 15.295(5)$, $\beta = 107.62(2)$; $V = 1720.8(7)$ Å^3, $D_{calc} = 1.202$ Mg/m^3, $Z = 2$. The reflections were measured on an *Enraf-Nonius-CAD4* diffractometer (graphite monochromator, CuK_α radiation, $\lambda = 1.54184$) at 293(2) K. $R = 0.0432$, $R_w = 0.1047$. The structure was solved with the direct-methods routine SIR97 [74]. The non-H-atoms were refined anisotropically with SHELXL-97 [75]. H-Atoms were calculated at idealised positions and included in the structure-factor calculation with fixed isotropic displacement parameters.

*Ethyl (1*R*,2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carboxylate* (**7d**). Colourless oil. R_f (hexane/Et_2O 3:2) 0.31. Anal. HPLC: t_R (hexane/Et_2O 7:1, 2 ml/min) 7.2 min. Prep. MPLC: t_R (hexane/Et_2O/CH_2Cl_2 8:1:1, 10 ml/min) 5.8 h. Prep. HPLC: t_R (hexane/Et_2O 4:1, 10 ml/min) 20 min. $[\alpha]_D^{25} =$

Table 4. *Selected ^{13}C-NMR Chemical Shifts* [ppm] *of the* gluco-*Spirocyclopropanes* **7**–**12** *in $CDCl_3$, and of* **13a**–**13d** *and* **1a**–**1d** *in D_2O*

	C(2′)	C(3′)	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)
7a	26.55	14.11	63.57	75.51	85.12	76.33	77.16	68.90
7b	25.61	14.25	64.91	77.89	84.59	78.33	78.62	68.68
7c[a])	23.33	14.32	65.39	77.99	86.94	78.47	78.88	68.37
7d	21.03	15.93	66.92	77.92	86.59	78.00	78.60	68.22
8a	26.29	14.48	64.28	75.36	84.76	76.49	77.17	68.79
8b	26.01	15.51	65.88	78.16	84.49	78.20	78.47	68.54
8c	22.92	14.12	65.71	77.63	86.77	78.45	78.92	68.39
8d	20.62	17.03	67.94	77.82	86.54	77.82	78.67	68.20
9a	28.82	16.06	65.16	74.84	84.24	75.98	76.68	68.68
9b	28.12	15.58	68.66	78.15	84.15	78.15	78.40	67.10
9c	25.44	14.23	67.16	77.34	86.75	77.94	78.63	67.76
9d	23.61	17.78	69.62	77.35	86.35	77.35	78.97	67.66
10c	31.16	15.67	61.41	76.90	86.55	78.33	78.93	68.48
10d	30.17	17.65	61.55	77.86	86.74	78.09	78.77	68.56
11a	34.87	13.61	61.71	76.48	87.69	76.74	78.50	68.68
11b	34.36	15.75	61.37	78.04	86.06	78.94	79.14	68.49
11c	30.00	14.65	60.77	77.35	86.36	78.30	78.37	68.49
11d	29.55	14.51	60.72	77.90	86.67	78.16	78.28	68.80
12a	34.57	13.38	61.88	76.51	87.77	76.85	78.58	68.76
12b	34.03	15.63	61.50	77.87	86.09	78.99	79.23	68.50
12c	29.73	14.47	60.78	77.51	86.39	78.43	78.43	68.55
12d	29.23	14.41	60.75	77.80	86.62	78.40	78.40	68.94
13a	35.63	15.08	65.44	71.72	80.60	72.80	80.70	63.71
13b	33.68	13.27	62.43	70.12	76.34	71.23	79.45	61.01
13c	28.95	12.38	61.83	69.07	76.78	70.56	79.64	61.16
13d[a])	31.00	14.59	64.29	72.33	79.47	72.77	81.85	63.57
1a	34.14	13.92	62.73	71.23	80.30	72.47	81.21	63.43
1b	34.57	15.75	63.02	72.93	79.88	72.93	82.64	63.62
1c	30.31	13.46	63.28	70.89	79.28	72.99	82.75	63.82
1d	29.55	14.37	63.88	71.40	78.86	72.08	82.71	63.43

[a]) Assignments based on HSQC-GRASP spectrum.

+98.5 ($c = 0.68$, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3067*w*, 2907*m*, 2870*m*, 1723*s*, 1497*m*, 1454*s*, 1397*m*, 1382*m*, 1360*m*, 1325*w*, 1289*s*, 1160*s*, 1126*s*, 1091*s*, 1028*s*, 1016*m*, 911*w*, 867*w*. ^{1}H-NMR (500 MHz, $CDCl_3$): see *Table 3*; additionally, 7.35–7.12 (*m*, 20 arom. H); 4.90 (*d*, $J = 11.3$, PhC*H*); 4.88 (*d*, $J = 11.2$, PhC*H*); 4.85 (*d*, $J = 11.3$, PhC*H*); 4.83 (*d*, $J = 10.6$, PhC*H*); 4.66 (*d*, $J = 12.1$, PhC*H*); 4.58 (*d*, $J = 11.3$, PhC*H*); 4.55 (*d*, $J = 10.6$, PhC*H*); 4.46 (*d*, $J = 12.1$, PhC*H*); 4.16 (*qd*, $J = 7.1$, 10.8, MeC*H*O); 4.07 (*qd*, $J = 7.1$, 10.8, MeC*H*O); 3.91 (irrad. at 1.26 → NOE of 0.8%); 3.74 (irrad. at 3.17 → NOE of 3.5%, irrad. at 2.11 → NOE of 1.8%); 3.17 (irrad. at 2.11 → NOE of 1.0%); 2.11 (irrad. at 3.17 → NOE of 1.8%); 1.24 (*t*, $J = 7.1$, *Me*CH_2O). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 170.58 (*s*, C=O); 138.75, 138.26, 138.16, 137.96 (4*s*); 128.59–27.77 (several *d*); 75.76, 75.44, 75.27, 73.65 (4*t*, 4 PhCH_2); 60.70 (*t*, MeCH_2O); 14.23 (*q*, *Me*CH_2O). CI-MS: 623 (1, $[M+1]^+$), 285 (19), 263 (12), 181 (16), 108 (10), 92 (12), 91 (100). Anal. calc. for $C_{39}H_{42}O_7$ (622.76): C 75.22, H 6.80, O 17.98; found: C 75.27, H 6.94.

*(1*S*,2′*S*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**8a**). A soln. of KOH (440 mg, 7.85 mmol) and **7a** (646 mg, 1.04 mmol) in EtOH/H_2O 1:4 (20 ml) was stirred at 80° in a closed flask, until TLC indicated complete conversion of the ester (*ca.* 2 h). After concentration to 1/3 of the volume *in vacuo* at 50°, the residue was diluted with H_2O (50 ml) and extracted once with Et_2O (30 ml). The aq. phase was acidified with 1N HCl to pH *ca.* 1 and extracted with Et_2O (4 × 30 ml). The combined org. phases were

dried (Na_2SO_4) and evaporated to yield crude **8a** (600 mg, 97%), which was sufficiently clean for the following reaction. FC (hexane/Et_2O 2:1 → 0:1, then AcOEt/AcOH 99:1) gave pure **8a** (586 mg, 95%). Colourless oil. R_f (hexane/Et_2O 1:20) 0.42. $[\alpha]_D^{25} = +23.4$ ($c = 1.00$, $CHCl_3$). IR ($CHCl_3$): 3516*w*, 3400–2400*m* (br.), 3089*w*, 3066*w*, 2924*m*, 2867*m*, 1728*m*, 1702*s*, 1497*m*, 1454*s*, 1361*m*, 1324*w*, 1092*s*, 1028*m*, 947*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 3*; additionally, 7.35–7.13 (*m*, 20 arom. H); 4.78 (*d*, $J = 11.8$, PhC*H*); 4.75 (*d*, $J = 10.9$, PhC*H*); 4.65 (*d*, $J = 11.5$, PhC*H*); 4.61 (*d*, $J = 11.5$, PhC*H*); 4.58 (*d*, $J = 12.1$, PhC*H*); 4.56 (*d*, $J = 11.5$, PhC*H*); 4.53 (*d*, $J = 11.2$, PhC*H*); 4.50 (*d*, $J = 12.1$, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 175.97 (*s*, C=O); 138.41 (*s*); 138.33 (*s*, 2 C); 138.24 (*s*); 130.40–127.40 (several *d*); 74.44, 73.84, 73.55, 73.06 (4*t*, 4 Ph*C*H_2).

*(1*R*,2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**8b**). As described above, the reaction of KOH (220 mg, 3.92 mmol) and **7b** (189 mg, 0.304 mmol) in EtOH/H_2O 1:4 (10 ml) gave crude **8b** (172 mg, 95%), which was sufficiently clean for the following reaction. FC (hexane/Et_2O 2:1 → 0:1, then AcOEt/AcOH 99:1) gave pure **8b** (157 mg, 87%). Colourless oil. R_f (hexane/Et_2O 1:20) 0.56. $[\alpha]_D^{25} = +18.2$ ($c = 1.00$, $CHCl_3$). IR ($CHCl_3$): 3520*w*, 3400–2400*m* (br.), 3089*w*, 3066*w*, 2926*m*, 2869*m*, 1729*s*, 1705*s*, 1497*m*, 1454*s*, 1400*m*, 1362*m*, 1320*m*, 1262*w*, 1126*w*, 1091*s*, 1028*m*, 947*w*, 911*w*, 864*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 3*; additionally, 7.35–7.13 (*m*, 20 arom. H); 4.81 (*d*, $J = 10.9$, PhC*H*); 4.75 (*s*, PhCH_2); 4.74 (*d*, $J = 11.2$, PhC*H*); 4.67 (*d*, $J = 11.2$, PhC*H*); 4.58 (*d*, $J = 12.1$, PhC*H*); 4.51 (*d*, $J = 10.9$, PhC*H*); 4.56 (*d*, $J = 12.1$, PhC*H*); 4.05 (irrad. at 1.49 → NOE of 1.1%); 3.66 (irrad. at 1.83 → NOE of 3.7%); 1.49 (irrad. at 4.05 → NOE of 1.4%). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 174.03 (*s*, C=O); 138.36, 138.24, 137.95, 137.21 (4*s*); 128.51–127.78 (several *d*); 75.59, 75.41, 74.88, 73.58 (4*t*, 4 Ph*C*H_2).

*(1*S*,2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**8c**). As described above, the reaction of KOH (220 mg, 3.92 mmol) and **7c** (120 mg, 0.193 mmol) in EtOH/H_2O 1:4 (10 ml) gave crude **8c** (117 mg, quant.), which was sufficiently clean for the following reaction. FC (hexane/Et_2O 2:1 → 0:1, then AcOEt/AcOH 99:1) gave pure **8c** (109 mg, 95%). Colourless oil. R_f (hexane/Et_2O 1:20) 0.18. $[\alpha]_D^{25} = +3.6$ ($c = 2.00$, $CHCl_3$). IR ($CHCl_3$): 3522*w*, 3400–2400*m* (br.), 3090*m*, 3066*m*, 2911*m*, 2869*m*, 1740*s*, 1709*m*, 1497*m*, 1454*s*, 1360*s*, 1261*m*, 1126*s*, 1090*s*, 1028*s*, 1007*m*, 916*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 3*; additionally, 9.60–7.80 (br. *s*, CO_2H); 7.38–7.21 (*m*, 20 arom. H); 4.91 (*s*, PhCH_2); 4.91 (*d*, $J = 11.2$, PhC*H*); 4.89 (*d*, $J = 11.8$, PhC*H*); 4.67 (*d*, $J = 11.2$, PhC*H*); 4.62 (*d*, $J = 12.1$, PhC*H*); 4.62 (*d*, $J = 11.8$, PhC*H*); 4.53 (*d*, $J = 12.1$, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 174.27 (*s*, C=O); 138.42, 138.05, 138.02, 137.68 (4*s*); 128.62–127.71 (several *d*); 75.80, 75.49, 75.23, 73.50 (4*t*, 4 Ph*C*H_2).

*(1*R*,2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**8d**). As described above, the reaction of KOH (220 mg, 3.92 mmol) and **7d** (74.1 mg, 0.119 mmol) in EtOH/H_2O 1:4 (10 ml) gave crude **8d** (70.2 mg, 99%), which was sufficiently clean for the following reaction. FC (hexane/Et_2O 2:1 → 0:1, then AcOEt/AcOH 99:1) gave pure **8d** (61.5 mg, 87%). Colourless oil. R_f (hexane/Et_2O 1:20) 0.30. $[\alpha]_D^{25} = +114.4$ ($c = 2.00$, $CHCl_3$). IR ($CHCl_3$): 3519*w*, 3400–2400*m* (br.), 3090*m*, 3066*m*, 2908*m*, 2869*m*, 1728*m* (sh.), 1698*s*, 1497*m*, 1454*s*, 1400*w*, 1361*m*, 1290*m*, 1155*m*, 1127*m*, 1091*s*, 1028*m*, 954*w*, 911*w*, 867*w*. ^{1}H-NMR (200 MHz, $CDCl_3$): see *Table 3*; additionally, 7.36–7.20 (*m*, 18 arom. H); 7.15–7.10 (*m*, 2 arom. H); 4.89 (*s*, PhCH_2); 4.86 (*d*, $J = 11.2$, PhC*H*); 4.84 (*d*, $J = 10.4$, PhC*H*); 4.66 (*d*, $J = 12.0$, PhC*H*); 4.58 (*d*, $J = 11.2$, PhC*H*); 4.52 (*d*, $J = 10.8$, PhC*H*); 4.43 (*d*, $J = 12.0$, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 176.87 (*s*, C=O); 138.70, 138.25, 138.22, 137.91 (4*s*); 128.69–127.83 (several *d*); 75.83, 75.50, 75.30, 73.57 (4*t*, 4 Ph*C*H_2).

*(1*S*,2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carbonyl Azide* (**9a**). A soln. of **8a** (12.9 mg, 21.7 μmol) in dry acetone (1 ml) was cooled to 0°, treated with Et_3N (54 μl of a 0.5M soln. in acetone, 27.1 μmol) and $ClCO_2Et$ (61 μl of a 0.5M soln. in acetone, 30.5 μmol), stirred for 1 h at 0°, treated with a soln. of NaN_3 (0.35 ml of a 0.1M soln. in H_2O, 35 μmol), and stirred for another 30 min at 0° and for 2 h at 23°. After concentration to 1/3 of the volume *in vacuo* at 23°, the residue was diluted with 5 ml of H_2O and extracted with Et_2O (3 × 2 ml). The combined org. phases were washed with H_2O (1 ml), dried (Na_2SO_4), and evaporated at 23°. The residue was dried in high vacuum at 23° for 12 h to give crude **9a** (13.4 mg, quant.). Colourless oil. Rapid FC (hexane/Et_2O 2:1) yielded pure **9a** (11.4 mg, 85%). Colourless oil. R_f (hexane/Et_2O 1:1) 0.58, R_f (hexane/AcOEt 1:1) 0.47. $[\alpha]_D^{25} = +49.8$ ($c = 0.55$, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3066*m*, 2909*m*, 2867*m*, 2139*s*, 1696*s*, 1497*m*, 1454*s*, 1363*s*, 1324*m*, 1172*s*, 1092*s*, 1028*s*, 1003*m*, 883*w*, 854*m*, 599*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.36–7.17 (*m*, 20 arom. H); 4.79 (*d*, $J = 11.8$, PhC*H*); 4.77 (*d*, $J = 11.2$, PhC*H*); 4.60 (*d*, $J = 11.8$, PhC*H*); 4.58 (*s*, PhCH_2); 4.58 (*d*, $J = 12.1$, PhC*H*); 4.57 (*d*, $J = 11.2$, PhC*H*); 4.52 (*d*, $J = 12.1$, PhC*H*). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 176.86 (*s*, C=O); 138.33 (*s*, 2 C), 138.09, 138.02 (2*s*); 128.64–127.56 (several *d*); 74.24, 73.48, 73.41, 72.75 (4*t*, 4 Ph*C*H_2).

Table 5. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the Acyl Azides* **9a**–**9d** *and of the Isocyanates* **10a**–**10d** *in $CDCl_3$*

Compound	**9a**	**9b**	**9c**	**9d**	**10a**	**10b**	**10c**	**10d**
H–C(2′)	2.07	1.80	2.05	2.18	3.21	2.51	2.67	2.82
H_{cis}–C(3′)	1.56	1.56	1.53	1.90	1.32	1.14	0.70	0.97
H_{trans}–C(3′)	1.33	1.36	1.41	1.41	1.04	1.28	1.32	1.20
H–C(2)	3.91	3.99–3.93	3.97	3.95	4.01–3.99	4.06	3.94	3.90
H–C(3)	3.79	3.99–3.93	3.73	3.74	3.78–3.71	3.91	3.74	3.68
H–C(4)	3.90	3.80–3.74	3.90	3.91	3.78–3.71	3.79	3.95	3.90
H–C(5)	3.84	3.71–3.64	3.55	3.20	3.38	3.53	3.60	3.59
H_a–C(6)	3.74	3.71–3.64	3.77	3.76	3.66	3.65	3.84	3.83
H_b–C(6)	3.59	3.63–3.57	3.72	3.65	3.55	3.55	3.74	3.76
$J(2',3'_{cis})$	7.5	7.8	6.5	6.5	5.9	5.9	4.7	5.0
$J(2',3'_{trans})$	9.7	9.7	8.7	8.7	9.3	9.3	8.4	8.1
$J(3'_{cis},3'_{trans})$	6.2	6.5	5.3	5.9	6.5	7.2	6.3	7.2
$J(2,3)$	5.0	[a])	9.0	9.0	[a])	9.3	8.7	9.0
$J(3,4)$	6.8	[a])	9.0	9.3	[a])	8.7	9.0	9.0
$J(4,5)$	9.0	[a])	9.7	9.6	9.1	9.7	9.7	9.7
$J(5,6_a)$	4.4	[a])	3.1	≤ 1.5	3.7	4.0	3.4	2.5
$J(5,6_b)$	2.5	[a])	1.9	≤ 1.5	1.9	1.9	1.9	≤ 1.5
$J(6_a,6_b)$	10.6	[a])	11.2	10.9	10.9	10.9	11.2	10.9

[a]) Not assigned.

*(1*R*,2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carbonyl Azide* (**9b**). As described above, a soln. of **8b** (22.4 mg, 37.7 μmol) in dry acetone (1 ml) was treated with Et_3N (0.94 ml of a 0.5M soln. in acetone, 47 μmol), $ClCO_2Et$ (0.106 ml of a 0.5M soln. in acetone, 53.1 μmol), and NaN_3 (0.60 ml of a 0.1M soln. in H_2O, 60 μmol). Usual workup gave crude **9b** (23.5 mg, quant). Rapid FC (hexane/Et_2O 2:1) yielded pure **9b** (11.2 mg, 48%). Colourless oil. R_f (hexane/Et_2O 1:1) 0.53, R_f (hexane/AcOEt 1:1) 0.44. $[\alpha]_D^{25} = +31.8$ ($c = 0.11$, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3066*w*, 2912*m*, 2868*m*, 2138*s*, 1707*m*, 1497*m*, 1454*s*, 1362*s*, 1319*m*, 1168*s*, 1091*s*, 1028*s*, 861*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.32–7.25 (*m*, 18 arom. H); 7.18–7.15 (*m*, 2 arom. H); 4.81 (*d*, $J = 10.9$, PhC*H*); 4.81 (*s*, PhCH_2); 4.70 (*d*, $J = 11.2$, PhC*H*); 4.58 (*d*, $J = 10.9$, PhC*H*); 4.58 (*d*, $J = 12.5$, PhC*H*); 4.52 (*d*, $J = 11.2$, PhC*H*); 4.47 (*d*, $J = 12.5$, PhC*H*). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 176.13 (*s*, C=O); 138.58, 138.39, 138.14, 137.73 (4*s*); 128.62–127.95 (several *d*); 75.36, 74.23, 74.85, 73.64 (4*t*, 4 PhCH_2).

*(1*S*,2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carbonyl Azide* (**9c**). As described above, a soln. of **8c** (94.4 mg, 0.159 mmol) in dry acetone (3 ml) was treated with Et_3N (20.0 mg, 0.198 mmol), $ClCO_2Et$ (24.2 mg, 0.223 mmol), and NaN_3 (2.54 ml of a 0.1M soln. in H_2O, 0.254 mmol). Usual workup gave crude **9c** (98 mg, quant). Colourless oil. R_f (hexane/Et_2O 1:1) 0.64, R_f (hexane/AcOEt 1:1) 0.55. $[\alpha]_D^{25} = -44.7$ ($c = 2.00$, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3066*w*, 2910*m*, 2869*m*, 2146*m*, 1712*m*, 1497*m*, 1454*m*, 1362*m*, 1262*m*, 1090*s*, 1028*m*, 1009*m*, 916*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.40–7.21 (*m*, 20 arom. H); 4.94 (*d*, $J = 10.9$, PhC*H*); 4.92 (*d*, $J = 11.2$, PhC*H*); 4.90 (*d*, $J = 10.6$, PhC*H*); 4.90 (*d*, $J = 10.9$, PhC*H*); 4.67 (*d*, $J = 11.5$, PhC*H*); 4.66 (*d*, $J = 12.1$, PhC*H*); 4.64 (*d*, $J = 10.9$, PhC*H*); 4.55 (*d*, $J = 12.1$, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 175.70 (*s*, C=O); 138.31, 138.01, 137.88, 137.62 (4*s*); 128.70–127.85 (several *d*); 75.82, 75.24, 75.19, 73.36 (4*t*, 4 PhCH_2).

*(1*R*,2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-carbonyl Azide* (**9d**). As described above, a soln. of **8d** (57.5 mg, 96.7 μmol) in dry acetone (2 ml) was treated with Et_3N (12.2 mg, 0.121 mmol), $ClCO_2Et$ (14.8 mg, 0.136 mmol), and NaN_3 (1.55 ml of a 0.1M soln. in H_2O, 0.155 mmol). Usual workup gave crude **9d** (57 mg, quant). Colourless oil. R_f (hexane/Et_2O 1:1) 0.61, R_f (hexane/AcOEt 1:1) 0.53. $[\alpha]_D^{25} = +163.9$ ($c = 2.00$, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3067*w*, 2907*w*, 2869*w*, 2148*m*, 1808*w*, 1704*m*, 1497*w*, 1454*m*, 1381*w*, 1362*m*, 1327*w*, 1283*m*, 1162*s*, 1129*s*, 1093*s*, 1028*m*, 911*w*, 864*w*, 598*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.40–7.15 (*m*, 20 arom. H); 4.95 (*d*, $J = 11.2$, PhC*H*); 4.91 (*d*, $J = 11.2$, PhC*H*); 4.87 (br. *d*, $J = 10.9$, 2 PhC*H*); 4.70 (*d*, $J = 12.1$, PhC*H*); 4.60 (br. *d*, $J = 10.0$, PhC*H*); 4.57 (br. *d*, $J = 10.6$,

PhC*H*); 4.50 (*d*, *J* = 12.1, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 176.59 (*s*, C=O); 138.41, 137.81, 137.76, 137.53 (4*s*); 128.68 – 127.94 (several *d*); 75.83, 75.43, 75.36, 73.55 (4*t*, 4 PhCH_2).

*(1*S*,2′*S*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-yl Isocyanate* (**10a**). A soln. of **9a** (11.4 mg, 18.4 μmol) in dry toluene (1 ml) was kept at 100° until TLC showed complete consumption of **9a** (*ca.* 2 h). Evaporation gave **10a** (11.0 mg, quant.). Colourless oil. R_f (hexane/AcOEt 1:1) 0.75. $[\alpha]_D^{25} = +27.4$ (*c* = 0.50, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3066*w*, 2925*s*, 2865*m*, 2268*s*, 1497*m*, 1454*s*, 1359*m*, 1258*w*, 1152*m*, 1122*s*, 1092*s*, 1028*s*, 1007*m*, 948*w*, 602*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.35 – 7.11 (*m*, 20 arom. H); 4.87 (*s*, PhCH_2); 4.86 (*d*, *J* = 10.3, PhC*H*); 4.83 (*d*, *J* = 10.9, PhC*H*); 4.73 (*d*, *J* = 10.6, PhC*H*); 4.59 (*d*, *J* = 12.1, PhC*H*); 4.53 (*d*, *J* = 10.9, PhC*H*); 4.47 (*d*, *J* = 12.1, PhC*H*); 4.01 – 3.99 (irrad. at 3.76 → br. *s*); 3.78 – 3.71 (irrad. at 4.00 → changed *m*, irrad. at 3.38 → changed *m*); 3.38 (irrad. at 3.76 → br. *s*).

*(1*R*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-yl Isocyanate* (**10b**). As described above, thermolysis of **9b** (11.2 mg, 18.1 μmol) in dry toluene (1 ml), and evaporation yielded **10b** (11.0 mg, quant.). Colourless oil. R_f (hexane/AcOEt 1:1) 0.72. $[\alpha]_D^{25} = -32.6$ (*c* = 0.50, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3066*w*, 2925*s*, 2865*m*, 2284*s*, 1497*m*, 1454*m*, 1361*m*, 1262*w*, 1152*m*, 1090*s*, 1028*s*, 1003*m*, 950*w*, 861*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.35 – 7.23 (*m*, 18 arom. H); 7.15 – 7.09 (*m*, 2 arom. H); 4.98 (*d*, *J* = 11.2, PhC*H*); 4.90 (*d*, *J* = 11.2, 2 PhC*H*); 4.88 (*d*, *J* = 10.6, PhC*H*); 4.69 (*d*, *J* = 11.5, PhC*H*); 4.58 (*d*, *J* = 12.1, PhC*H*); 4.50 (*d*, *J* = 10.6, PhC*H*); 4.44 (*d*, *J* = 12.1, PhC*H*); 4.06 (irrad. at 3.91 → *m*); 3.91 (irrad. at 4.06 → *d*, *J* = 8.7, irrad. at 3.79 → *d*, *J* = 9.3); 3.79 (irrad. at 3.91 → *d*, *J* = 9.7); 3.53 (irrad. at 3.79 → *m*).

*(1*S*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-yl Isocyanate* (**10c**). As described above, thermolysis of **9c** (101 mg, 0.163 mmol) in dry toluene (10 ml), and evaporation yielded **10c** (96.2 mg, quant.). Colourless oil. R_f (hexane/AcOEt 1:1) 0.71. $[\alpha]_D^{25} = -7.6$ (*c* = 2.00, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3066*w*, 2911*m*, 2869*m*, 2254*s*, 1497*m*, 1454*m*, 1360*m*, 1264*m*, 1151*m*, 1091*s*, 1028*s*, 914*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.40 – 7.23 (*m*, 20 arom. H); 4.95 (*d*, *J* = 10.9, PhC*H*); 4.93 (*d*, *J* = 10.9, PhC*H*); 4.90 (*d*, *J* = 10.6, PhC*H*); 4.88 (*d*, *J* = 10.6, PhC*H*); 4.71 (*d*, *J* = 12.1, PhC*H*); 4.69 (*d*, *J* = 10.6, PhC*H*); 4.61 (*d*, *J* = 11.5, PhC*H*); 4.60 (*d*, *J* = 12.5, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 138.46 (*s*); 138.17 (*s*, 2 C); 137.76 (*s*); 128.61 – 127.64 (several *d*); 123.03 (*s*, N=*C*=O); 75.74, 75.24, 75.17, 73.82 (4*t*, 4 PhCH_2).

*(1*R*,2′*S*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-yl Isocyanate* (**10d**). As described above, thermolysis of **9d** (57.0 mg, 96.0 μmol) in dry toluene (5 ml), and evaporation yielded **10d** (57.0 mg, quant.). Colourless oil. R_f (hexane/AcOEt 1:1) 0.69. $[\alpha]_D^{25} = +101.7$ (*c* = 2.00, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3067*w*, 2925*s*, 2868*m*, 2273*s*, 1496*m*, 1454*m*, 1360*m*, 1263*m*, 1154*m*, 1090*s*, 1028*s*, 910*w*, 862*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 5*; additionally, 7.35 – 7.12 (*m*, 20 arom. H); 4.90 (*d*, *J* = 11.2, PhC*H*); 4.84 (br. *d*, *J* = 11.2, 2 PhC*H*); 4.81 (*d*, *J* = 10.6, PhC*H*); 4.71 (*d*, *J* = 12.1, PhC*H*); 4.56 (*d*, *J* = 10.3, PhC*H*); 4.53 (*d*, *J* = 11.2, PhC*H*); 4.47 (*d*, *J* = 12.1, PhC*H*). ^{13}C-NMR (75 MHz, C_6D_6): see *Table 4*; additionally, 139.32, 139.19, 138.80, 138.36 (4*s*); 128.58 – 127.82 (several *d*); 122.91 (*s*, N=*C*=O); 75.55, 75.26, 75.06, 73.72 (4*t*, 4 PhCH_2).

*Benzyl [(1*S*,2′*S*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**11a**). As described above, the reaction of **8a** (106 mg, 0.175 mmol) in dry acetone (3 ml) with Et_3N (22.7 mg, 0.224 mmol), $ClCO_2Et$ (27.1 mg, 0.250 mmol), and NaN_3 (18.6 mg, 0.280 mmol) in H_2O (1 ml), and usual workup gave crude **9a** (111 mg, 0.179 mmol), which was dissolved in dry toluene (10 ml) and kept at 100° until TLC showed complete consumption of **9a** (*ca.* 2 h). After the addition of dry BnOH (10 ml), heating was continued for another 18 h. Evaporation yielded crude **11a** (148 mg). Crystallisation from Et_2O and FC (hexane/Et_2O 4:1 → 1:1) of the mother liquors afforded pure **11a** (106 mg, 85%). Colourless solid. R_f (hexane/AcOEt 1:1) 0.57. Prep. HPLC: t_R (hexane/Et_2O 5:1, 10 ml/min) 40 min. M.p. 138 – 139° (MeOH). $[\alpha]_D^{25} = +13.0$ (*c* = 1.70, $CHCl_3$). IR ($CHCl_3$): 3443*m*, 3090*w*, 3067*w*, 2906*m*, 2867*m*, 1718*s*, 1522*m*, 1497*m*, 1454*s*, 1401*w*, 1558*m*, 1326*m*, 1151*m*, 1123*m*, 1090*s*, 1060*s*, 1028*s*, 910*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 6*; additionally, 7.36 – 7.17 (*m*, 25 arom. H); 5.1 – 4.8 (br. *s*, NH); 5.11 (*d*, *J* = 12.8, PhC*H*); 5.03 (*d*, *J* = 12.8, PhC*H*); 4.98 (*d*, *J* = 10.9, PhC*H*); 4.98 (*d*, *J* ≈ 10, PhC*H*); 4.89 (*d*, *J* = 11.2, PhC*H*); 4.84 (*d*, *J* = 10.9, PhC*H*); 4.63 (*d*, *J* = 12.1, PhC*H*); 4.61 (*d*, *J* = 10.9, PhC*H*); 4.52 (*d*, *J* ≈ 10, PhC*H*); 4.52 (*d*, *J* = 12.5, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 156.63 (*s*, C=O); 138.54, 138.31, 138.27, 137.54, 136.66 (5*s*); 128.74 – 127.75 (several *d*); 75.58, 75.04, 74.49, 73.63 (4*t*, 4 PhCH_2); 66.84 (*t*, PhCH_2–O–C(O)–N). FAB-MS: 700 (6, $[M+1]^+$), 699 (6, M^+), 698 (8, $[M-1]^+$), 564 (5, $[M-\text{Cbz}]^+$), 485 (12), 484 (31), 253 (10), 155 (13), 154 (37), 152 (12), 147 (16), 138 (11), 137 (20), 136 (35), 133 (100), 107 (14), 91 (69). Anal. calc. for $C_{44}H_{45}NO_7$ (699.85): C 75.51, H 6.48, N 2.00, O 16.00; found: C 75.43, H 6.68, N 2.13.

X-Ray Analysis of **11a**. Monoclinic *P*1; *a* = 5.106(3), *b* = 17.819(11), *c* = 20.635(9), *α* = 94.74(4), *β* = 89.77(4), *γ* = 93.49(5); *V* = 1867.6(18) Å^3, D_{calc} = 1.244 Mg/m^3, *Z* = 1. The reflections were measured on an

Table 6. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the* O*-Benzylated Carbamates* **11a**–**11d**, *and* **12a**–**12d** *in* $CDCl_3$

Compound	**11a**	**11b**	**11c**	**11d**	**12a**	**12b**	**12c**	**12d**
H–C(2′)	3.43–3.32	3.14	3.13	3.37–3.10	3.33–3.22	3.09–2.98	3.14–2.84	3.32–2.95
H_{cis}–C(3′)	1.07–0.97	0.92	0.54	0.74	1.01–0.92	0.92	0.48	0.72
H_{trans}–C(3′)	1.07–0.97	1.29	1.32	1.14	1.01–0.92	1.29	1.28	1.13
H–C(2)	4.07–3.95	4.06	3.88	3.89–3.78	4.07–3.98	4.08	3.86	3.91–3.78
H–C(3)	3.86–3.75	3.76	3.74	3.89–3.78	3.80	3.83	3.71	3.91–3.78
H–C(4)	3.86–3.75	3.81	3.84	3.70–3.45	3.78	3.88	3.83	3.72–3.55
H–C(5)	3.51–3.43	3.58	3.56	3.70–3.45	3.44	3.64–3.57	3.55	3.72–3.55
H_a–C(6)	3.71	3.71–3.64	3.75	3.70–3.45	3.69	3.77–3.68	3.75	3.72–3.55
H_b–C(6)	3.62	3.71–3.64	3.67	3.70–3.45	3.61	3.77–3.68	3.72–3.65	3.72–3.55
$J(2',3'_{cis})$	[a])	6.5	≤ 1.5	5.6	[a])	6.5	5.3	5.6
$J(2',3'_{trans})$	[a])	8.7	≤ 1.5	8.7	[a])	8.7	7.8	8.7
$J(3'_{cis},3'_{trans})$	[a])	6.9	≤ 1.5	7.2	[a])	7.0	5.9	6.9
$J(2,3)$	[a])	8.7	8.4	[a])	6.5	8.7	8.7	[a])
$J(3,4)$	[a])	8.7	9.3	[a])	9.0	8.4	9.3	[a])
$J(4,5)$	[a])	≤ 1.5	9.0	[a])	8.7	8.4	9.0	[a])
$J(5,6_a)$	4.0	≤ 1.5	3.4	[a])	4.0	[a])	3.7	[a])
$J(5,6_b)$	1.9	≤ 1.5	1.9	[a])	1.9	[a])	[a])	[a])
$J(6_a,6_b)$	10.9	[a])	10.9	[a])	10.9	[a])	10.9	[a])

[a]) Not assigned.

Enraf-Nonius-CAD4 diffractometer (graphite monochromator, CuK_α radiation, $\lambda = 1.54184$) at 230(2) K. $R = 0.1764$, $R_w = 0.3897$. Part of the structure was solved by direct methods with SIR97 [74], the remaining non-H-atoms were found from a difference *Fourier* map. Poor crystal quality did not allow anisotropic refinement. The Ph rings were refined with fixed geometry. Some of the isotropic ADPs were also fixed. The non-H-atoms were refined isotropically with SHELXL-97 [75].

*Benzyl [(1*R*,2′*R*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**11b**). As described above, the reaction of **8b** (35 mg, 59 μmol) in dry acetone (3 ml) with Et_3N (148 μl of a 0.5M soln. in acetone, 74 μmol), $ClCO_2Et$ (166 μl of a 0.5M soln. in acetone, 83 μmol), and NaN_3 (0.94 ml of a 0.1M soln. in H_2O, 94 μmol), and usual workup gave crude **9b** (34.9 mg, 56 μmol), which was heated in dry toluene (10 ml) for 2 h, then treated with dry BnOH (10 ml), and heated for 18 h. FC (hexane/Et_2O 4:1 → 1:1) afforded pure **11b** (32.1 mg, 82%). Colourless oil. R_f (hexane/AcOEt 1:1) 0.61. Prep. HPLC: t_R (hexane/Et_2O 5:1, 10 ml/min) 33 min. $[\alpha]_D^{25} = +65.2$ ($c = 0.42$, $CHCl_3$). IR ($CHCl_3$): 3416*m*, 3090*w*, 3067*w*, 2914*m*, 2868*m*, 1715*s*, 1519*s*, 1497*s*, 1454*s*, 1404*w*, 1354*m*, 1324*m*, 1152*m*, 1090*s*, 1063*s*, 1028*s*, 1004*m*, 910*w*. ^{1}H-NMR (500 MHz, $CDCl_3$): see *Table 6*; additionally, 7.33–7.13 (*m*, 25 arom. H); 5.53 (*d*, $J = 7.8$, NH); 5.14 (*d*, $J = 12.5$, PhC*H*); 5.09 (*d*, $J = 12.5$, PhC*H*); 4.85 (*d*, $J = 11.2$, PhC*H*); 4.83 (*d*, $J = 10.6$, PhC*H*); 4.81 (*d*, $J = 10.6$, PhC*H*); 4.76 (*d*, $J = 11.2$, PhC*H*); 4.64 (*d*, $J = 11.2$, PhC*H*); 4.60 (*d*, $J = 11.5$, PhC*H*); 4.53 (*d*, $J = 10.9$, PhC*H*); 4.44 (*d*, $J = 12.1$, PhC*H*). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 156.89 (*s*, C=O); 138.59, 138.49, 138.14, 137.72, 136.92 (5*s*); 128.80–127.93 (several *d*); 75.79 (*t*, 2 Ph*C*H$_2$); 75.04, 73.60 (2*t*, 2 Ph*C*H$_2$); 66.74 (*t*, Ph*C*H$_2$–O–C(O)–N). Anal. calc. for $C_{44}H_{45}NO_7$ (699.85): C 75.51, H 6.48, N 2.00, O 16.00; found: C 75.61, H 6.60, N 2.11.

*Benzyl [(1*S*,2′*R*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-glucitol-1,1′-cyclopropane]-2′yl]carbamate* (**11c**). As described above, the reaction of **8c** (117.0 mg, 0.197 mmol) in dry acetone (3 ml) with Et_3N (24.9 mg, 0.246 mmol), $ClCO_2Et$ (29.7 mg, 0.274 mmol), and NaN_3 (20.4 mg, 0.314 mmol) in H_2O (1 ml), and usual workup gave crude **9c** (122.8 mg, 0.198 mmol), which was heated in dry toluene (10 ml) for 2 h, then treated with dry BnOH (10 ml), and heated for 18 h. FC (hexane/Et_2O 4:1 → 1:1) gave pure **11c** (107 mg, 77%), which was recrystallised from hexane/Et_2O 10:1. Colourless solid. R_f (hexane/AcOEt 1:1) 0.58. Prep. HPLC: t_R (hexane/Et_2O 5:1, 10 ml/min) 46 min M.p. 100–101° (hexane/Et_2O). $[\alpha]_D^{25} = +0.1$ ($c = 2.00$, $CHCl_3$). IR ($CHCl_3$): 3438*m*, 3090*w*, 3067*w*, 2904*m*, 2869*m*, 1717*s*, 1511*m*, 1498*w*, 1454*m*, 1402*m*, 1361*m*, 1271*m*, 1152*w*, 1126*w*, 1091*s*, 1028*m*, 914*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 6*; additionally, 7.42–7.18 (*m*, 25 arom. H);

5.29 (br. *d*, *J* = 5.3, NH); 5.19 (*d*, *J* = 12.1, PhC*H*); 5.15 (*d*, *J* = 12.1, PhC*H*); 4.90 (*d*, *J* = 10.6, PhC*H*); 4.89 (*s*, PhCH_2); 4.84 (*d*, *J* = 11.2, PhC*H*); 4.67 (*d*, *J* = 11.5, PhC*H*); 4.62 (*d*, *J* = 12.1, PhC*H*); 4.60 (*d*, *J* = 10.9, PhC*H*); 4.52 (*d*, *J* = 12.1, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 157.03 (*s*, C=O); 138.55, 138.21, 137.95, 137.82, 136.63 (5*s*); 128.62–127.78 (several *d*); 75.59, 75.19, 75.14, 73.45 (4*t*, 4 PhCH_2); 66.94 (*t*, PhCH_2–O–C(O)–N). Anal. calc. for $C_{44}H_{45}NO_7$ (699.85): C 75.51, H 6.48, N 2.00; found: C 75.69, H 6.58, N 2.13.

*Benzyl [(1*R,*2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**11d**). As described above, the reaction of **8d** (55.1 mg, 93 μmol) in dry acetone (3 ml) with Et_3N (0.116 ml of a 0.5M soln. in acetone, 58 μmol), $ClCO_2Et$ (0.129 ml of a 0.5M soln. in acetone, 65 μmol), and NaN_3 (9.60 mg, 0.148 mmol) in H_2O (0.5 ml), and usual workup gave crude **9d** (61.6 mg, 99.0 μmol), which was heated in dry toluene (10 ml) for 2 h, then treated with dry BnOH (10 ml), and heated for 18 h. FC (hexane/Et_2O 4:1 → 1:1) gave pure **11d** (44.4 mg, 68%), which was recrystallised from hexane. Colourless solid. R_f (hexane/AcOEt 1:1) 0.58. Prep. HPLC: t_R (hexane/Et_2O 5:1, 10 ml/min) 37 min. M.p. 84–85° (hexane). $[\alpha]_D^{25} = +60.0$ (*c* = 2.00, $CHCl_3$). IR ($CHCl_3$): 3447*m*, 3089*w*, 3067*w*, 2905*m*, 2867*m*, 1717*s*, 1513*m*, 1498*s*, 1454*s*, 1402*w*, 1361*m*, 1271*m*, 1155*m*, 1127*m*, 1090*s*, 1075*s*, 1028*s*, 911*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 6*; additionally, 7.36–7.17 (*m*, 25 arom. H); 5.12 (*s*, PhCH_2); 4.97 (*d*, *J* = 6.2, NH); 4.89 (*s*, PhCH_2); 4.87 (*d*, *J* = 11.2, PhC*H*); 4.86 (*d*, *J* = 11.8, PhC*H*); 4.57 (*d*, *J* = 12.1, PhC*H*); 4.57 (*d*, *J* = 11.8, PhC*H*); 4.53 (*d*, *J* = 11.2, PhC*H*); 4.45 (*d*, *J* = 12.1, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 156.95 (*s*, C=O); 138.65, 138.28, 138.07, 138.00, 136.71 (5*s*); 128.62–127.65 (several *d*); 75.83, 75.28, 75.01, 73.50 (4*t*, 4 PhCH_2); 66.90 (*t*, PhCH_2–O–C(O)–N). Anal. calc. for $C_{44}H_{45}NO_7$ (699.85): C 75.51, H 6.48, N 2.00; found: C 75.68, H 6.58, N 2.15.

tert-*Butyl [(1*S,*2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**12a**). As described above, the reaction of **8a** (760 mg, 1.28 mmol) in dry acetone (20 ml) with Et_3N (165 mg, 1.63 mmol), $ClCO_2Et$ (197 mg, 1.82 mmol), and NaN_3 (133 mg, 2.05 mmol) in H_2O (6 ml), and usual workup gave crude **9a** (798 mg, quant), which was dissolved in dry toluene (60 ml) and kept at 100° until TLC showed complete consumption of **9a** (*ca.* 2 h). After the addition of dry *t*-BuOH (60 ml), heating was continued for another 24 h at 90°. Evaporation and FC (hexane/AcOEt 4:1 → 1:1) gave **12a** (668 mg, 78%), which was recrystallized from hexane/Et_2O. Colourless solid. R_f (hexane/AcOEt 1:1) 0.65. Prep. HPLC: t_R (hexane/AcOEt 4:1, 10 ml/min) 14 min. M.p. 92° (hexane/Et_2O). $[\alpha]_D^{25} = +12.4$ (*c* = 1.00, $CHCl_3$). IR ($CHCl_3$): 3448*m*, 3065*w*, 2909*m*, 2871*m*, 1708*s*, 1500*s*, 1455*m*, 1364*s*, 1327*w*, 1165*s*, 1089*s*, 910*w*, 850*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 6*; additionally, 7.35–7.16 (*m*, 20 arom. H); 4.97 (*d*, *J* = 10.9, PhC*H*); 4.97 (*d*, *J* = 11.2, PhC*H*); 4.90 (*d*, *J* = 11.2, PhC*H*); 4.87–4.78 (*m*, NH); 4.83 (*d*, *J* = 10.9, PhC*H*); 4.61 (*d*, *J* = 12.1, PhC*H*); 4.60 (*d*, *J* = 10.9, PhC*H*); 4.57 (*d*, *J* = 10.9, PhC*H*); 4.50 (*d*, *J* = 12.1, PhC*H*); 1.43 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 156.18 (*s*, C=O); 138.67 (*s*); 138.37 (*s*, 2 C); 137.75 (*s*); 128.74–127.74 (several *d*); 79.52 (*s*, Me_3C); 75.62, 75.07, 74.54, 73.63 (4*t*, 4 PhCH_2); 28.41 (*q*, *Me*$_3$C). Anal. calc. for $C_{41}H_{47}NO_7$ (665.81): C 73.96, H 7.12, N 2.10; found: C 73.94, H 7.30, N 2.10.

tert-*Butyl [(1*R,*2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**12b**). As described above, the reaction of **8b** (230 mg, 0.388 mmol) in dry acetone (6 ml) with Et_3N (49.0 mg, 0.484 mmol), $ClCO_2Et$ (59.2 mg, 0.546 mmol), and NaN_3 (40.3 mg, 0.620 mmol) in H_2O (2.5 ml), and usual workup gave crude **9b** (240 mg, quant), which was heated in dry toluene (20 ml) for 2 h, then treated with dry *t*-BuOH (20 ml) and heated for 24 h. FC (hexane/AcOEt 4:1 → 1:1) gave pure **12b** (212 mg, 82%). Colourless oil. R_f (hexane/AcOEt 1:1) 0.67. Prep. HPLC: t_R (hexane/AcOEt 4:1, 10 ml/min) 13 min. $[\alpha]_D^{25} = +58.7$ (*c* = 2.00, $CHCl_3$). IR ($CHCl_3$): 3428*m*, 3065*w*, 2911*m*, 2870*m*, 1705*s*, 1503*s*, 1453*m*, 1363*s*, 1325*w*, 1166*s*, 1090*s*, 910*w*, 861*w*, 603*w*, 536*w*. ^{1}H-NMR (500 MHz, $CDCl_3$): see *Table 6*; additionally, 7.38–7.17 (*m*, 20 arom. H); 5.22 (br. *d*, *J* = 6.2, NH); 4.92 (*d*, *J* = 11.5, PhC*H*); 4.87 (*s*, PhCH_2); 4.87 (*d*, *J* = 12.1, PhC*H*); 4.68 (*d*, *J* = 11.5, PhC*H*); 4.61 (*d*, *J* = 12.1, PhC*H*); 4.57 (*d*, *J* = 12.1, PhC*H*); 4.46 (*d*, *J* = 12.1, PhC*H*); 1.48 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 4*; additionally, 156.54 (*s*, C=O); 138.62, 138.59, 138.16, 138.04 (4*s*); 128.70–127.41 (several *d*); 78.99 (*s*, Me_3C); 75.78, 75.56, 74.91, 73.55 (4*t*, 4 PhCH_2); 28.48 (*q*, *Me*$_3$C). Anal. calc. for $C_{41}H_{47}NO_7$ (665.81): C 73.96, H 7.12, N 2.10; found: C 74.10, H 7.22, N 2.18.

tert-*Butyl [(1*S,*2′*R*)-2,3,4,6-Tetra*-O-*benz ylspiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**12c**). As described above, the reaction of **8c** (190 mg, 0.319 mmol) in dry acetone (5 ml) with Et_3N (40.5 mg, 0.400 mmol), $ClCO_2Et$ (48.7 mg, 0.449 mmol), and NaN_3 (33.1 mg, 0.510 mmol) in H_2O (1.5 ml), and usual workup gave crude **9c** (205 mg, quant), which was heated in dry toluene (25 ml) for 2 h, then treated with dry *t*-BuOH (25 ml) and heated for 24 h. FC (hexane/AcOEt 4:1 → 1:1) gave pure **12c** (180 mg, 85%). Colourless oil. R_f (hexane/AcOEt 1:1) 0.66. Prep. HPLC: t_R (hexane/AcOEt 4:1, 10 ml/min) 17 min. $[\alpha]_D^{25} = +3.6$ (*c* = 2.00, $CHCl_3$). IR ($CHCl_3$): 3444*m*, 3065*w*, 2909*m*, 2872*m*, 1707*s*, 1501*s*, 1453*m*, 1366*s*, 1161*s*, 1092*s*, 1026*s*, 915*m*, 853*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 6*; additionally, 7.37–7.18 (*m*, 20 arom. H); 5.02

(*d*, *J* = 4.7, NH); 4.89 (*d*, *J* = 12.1, PhC*H*); 4.87 (*s*, PhCH_2); 4.82 (*d*, *J* = 11.2, PhC*H*); 4.67 (*d*, *J* = 11.2, PhC*H*); 4.64 (*d*, *J* = 12.1, PhC*H*); 4.60 (*d*, *J* = 12.1, PhC*H*); 4.54 (*d*, *J* = 12.1, PhC*H*); 1.49 (*s*, Me_3C). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 156.70 (*s*, C=O); 138.70, 138.35, 138.16, 138.01 (4*s*); 128.61 – 127.78 (several *d*); 79.57 (*s*, Me_3C); 75.60, (*t*, PhCH$_2$); 75.19 (*t*, 2 PhCH$_2$); 73.44 (*t*, PhCH$_2$); 28.46 (*q*, Me_3C). Anal. calc. for $C_{41}H_{47}NO_7$ (665.81): C 73.96, H 7.12, N 2.10; found: C 74.01, H 7.28, N 2.14.

tert-*Butyl [(1*R,*2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro-*D*-glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**12d**). As described above, the reaction of **8d** (380 mg, 0.639 mmol) in dry acetone (10 ml) with Et_3N (82.3 mg, 0.813 mmol), $ClCO_2Et$ (98.7 mg, 0.910 mmol), and NaN_3 (66.5 mg, 1.02 mmol) in H_2O (3 ml), and usual workup gave crude **9d** (395 mg, quant), which was heated in dry toluene (30 ml) for 2 h, then treated with dry *t*-BuOH (30 ml) and heated for 24 h. FC (hexane/AcOEt 4 : 1 → 1 : 1) gave pure **12d** (330 mg, 78%), which was recrystallised from hexane. Colourless solid. R_f (hexane/AcOEt 1 : 1) 0.66. Prep. HPLC: t_R (hexane/AcOEt 4 : 1, 10 ml/min) 15 min. M.p. 69 – 70° (hexane). $[\alpha]_D^{25} = +56.5$ (*c* = 2.00, $CHCl_3$). IR ($CHCl_3$): 3449*m*, 3065*w*, 2909*m*, 2870*m*, 1707*s*, 1500*s*, 1454*m*, 1366*s*, 1163*s*, 1090*s*, 910*w*, 837*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 6*; additionally, 7.34 – 7.17 (*m*, 20 arom. H); 4.88 (*s*, PhCH_2); 4.88 (*d*, *J* = 11.2, PhC*H*); 4.86 (*d*, *J* = 11.8, PhC*H*); 4.76 (br. *d*, *J* = 5.3, NH); 4.61 (*d*, *J* = 11.8, PhC*H*); 4.58 (*d*, *J* = 11.2, PhC*H*); 4.56 (*d*, *J* = 11.5, PhC*H*); 4.51 (*d*, *J* = 11.8, PhC*H*); 1.45 (*s*, Me_3C). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 156.65 (*s*, C=O); 138.78 (*s*, 2 C); 138.27 (*s*, 2 C); 128.59 – 127.63 (several *d*); 86.62 (*s*, Me_3C); 75.80, 75.26, 74.88, 73.48 (4*t*, 4 PhCH$_2$); 28.44 (*q*, Me_3C). Anal. calc. for $C_{41}H_{47}NO_7$ (665.81): C 73.96, H 7.12, N 2.10; found: C 73.97, H 7.31, N 2.14.

tert-*Butyl [(1*S,*2′*S*)-Spiro[1,5-anhydro-*D*-glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**13a**). Hydrogenation of **12a** (108 mg, 0.162 mmol) in MeOH (5 ml) containing 10% Pd/C (200 mg) at 4 bar for 18 h, filtration through *Celite*, washing the residue with MeOH (5 ml), and evaporation of the combined filtrates and washings gave crude **13a** (47.5 mg, quant.). FC ($CHCl_3$/EtOH/20% aq. NH_3 15 : 15 : 2) gave pure **13a** (39.3 mg, 79%), which was recrystallised from MeOH or acetone. Colourless solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 9 : 5 : 1) 0.42. M.p. 173 – 174° (acetone). $[\alpha]_D^{25} = +18.5$ (*c* = 2.00, H_2O). IR (KBr): 3700 – 3000*s* (br.), 2978*m*, 2931*m*, 1690*s*, 1527*m*, 1394*m*, 1367*m*, 1254*w*, 1171*s*, 1078*s*, 1024*m*, 847*w*. ^{1}H-NMR (300 MHz, D_2O): see *Table 7*; additionally, 1.47 (*s*, Me_3C). ^{13}C-NMR (75 MHz, D_2O): see *Table 4*; additionally, 161.65 (*s*, C=O); 84.37 (*s*, Me_3C); 30.51 (*q*, Me_3C). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 51.09, H 7.34, N 4.48.

Table 7. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the Debenzylated Boc-Carbamates* **13a** – **13d** *and of the Ammonium Chlorides* **1a** – **1d** *in D_2O*

Compound	**13a**	**13b**	**13c**	**13d**	**1a**	**1b**	**1c**	**1d**
H–C(2′)	2.94	2.89	2.88	2.94	2.99	2.91	2.90	2.93
H_{cis}–C(3′)	1.22 – 1.04	1.26	0.68	0.87	1.39	1.52 – 1.48	1.03	1.14
H_{trans}–C(3′)	1.22 – 1.04	1.34	1.24	1.27	1.34	1.52 – 1.48	1.38	1.41
H–C(2)	4.00	3.99	3.83	3.81	4.09	4.11	3.92 – 3.84	3.87
H–C(3)	3.52	3.63	3.52 – 3.40	3.59	3.55	3.63	3.55 – 3.47	3.59 – 3.49
H–C(4)	3.47	3.48	3.52 – 3.40	3.47	3.46	3.53	3.55 – 3.47	3.59 – 3.49
H–C(5)	3.43 – 3.35	3.77 – 3.58	3.52 – 3.40	3.41 – 3.28	3.39	3.53 – 3.45	3.55 – 3.47	3.44 – 3.37
H_a–C(6)	3.85	3.88	3.88	3.82	3.80	3.83	3.92	3.90
H_b–C(6)	3.67	3.77 – 3.58	3.70	3.69	3.65	3.68	3.73	3.75
J(2′,3′$_{cis}$)	7.1	6.5 – 6.9	5.6	5.6	5.8	≤ 1.5	5.3	5.0
J(2′,3′$_{trans}$)	8.4	8.7 – 10.0	8.7	8.6	9.6	≤ 1.5	8.7	8.7
J(3′$_{cis}$,3′$_{trans}$)	[a])	7.2 – 7.5;	6.5	7.5 – 8.1	8.1	[a])	8.1	8.1
J(2,3)	7.8	9.7	8.7	9.0	9.0	9.3	[a])	8.1
J(3,4)	8.7	9.0	≤ 1.5	8.7	8.9	8.4	[a])	[a])
J(4,5)	8.7	9.3	≤ 1.5	9.6	9.8	9.6	[a])	[a])
J(5,6$_a$)	≤ 1.5	≤ 1.5	≤ 1.5	1.4	2.2	≤ 1.5	≤ 1.5	2.2
J(5,6$_b$)	6.2	≤ 1.5	4.7	5.3	6.0	5.3	3.4	5.3
J(6$_a$,6$_b$)	12.5	10.6	12.8	12.1	12.4	11.8	12.8	12.5

[a]) Not assigned.

tert-*Butyl [(1*R,*2′*R*)-Spiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**13b**). As described above, hydrogenation of **12b** (41.7 mg, 62.6 μmol) in MeOH (5 ml) containing 10% Pd/C (60 mg) gave crude **13b** (21.1 mg, quant.). FC ($CHCl_3$/EtOH/20% aq. NH_3 15:15:2) gave pure **13b** (13.9 mg, 73%), which was recrystallised from hexane/AcOEt. Colourless solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 9:5:1) 0.47. M.p. 195–196° (hexane/AcOEt). $[\alpha]_D^{25} = +75.7$ ($c = 0.90$, H_2O). IR (KBr): 3700–3000*s* (br.), 2978*m*, 2935*w*, 1688*s*, 1521*m*, 1448*w*, 1394*m*, 1367*m*, 1248*m*, 1169*s*, 1100*m*, 1077*m*, 1057*m*, 1024*m*, 970*w*. ^{1}H-NMR (300 MHz, D_2O): see *Table 7*; additionally, 1.49 (*s*, Me_3C). ^{13}C-NMR (50 MHz, D_2O): see *Table 4*; additionally, 158.61 (*s*, C=O); 81.90 (*s*, Me_3C); 27.77 (*q*, Me_3C). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 50.87, H 7.39, N 4.43.

tert-*Butyl [(1*S,*2′*R*)-Spiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**13c**). As described above, hydrogenation of **12c** (74.4 mg, 0.112 mmol) in MeOH (5 ml) containing 10% Pd/C (100 mg) gave crude **13c** (34.6 mg, quant.). FC ($CHCl_3$/EtOH/20% aq. NH_3 15:15:2) gave pure **13c** (28.6 mg, 84%). Colourless oil. R_f ($CHCl_3$/EtOH/20% aq. NH_3 9:5:1) 0.40. $[\alpha]_D^{25} = +41.0$ ($c = 2.00$, H_2O). IR (KBr): 3700–3000*s* (br.), 2977*m*, 2929*m*, 1685*s*, 1522*m*, 1394*m*, 1367*m*, 1252*m*, 1169*s*, 1103*m*, 1079*m*, 1053*m*, 1026*m*, 909*w*, 851*w*, 774*w*. ^{1}H-NMR (300 MHz, D_2O): see *Table 7*; additionally, 1.45 (*s*, Me_3C). ^{13}C-NMR (50 MHz, D_2O): see *Table 4*; additionally, 159.44 (*s*, C=O); 81.61 (*s*, Me_3C); 27.71 (*q*, Me_3C). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 51.13, H 7.65, N 4.47.

tert-*Butyl [(1*R,*2′*S*)-Spiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-yl]carbamate* (**13d**). As described above, hydrogenation of **12d** (153.0 mg, 0.230 mmol) in MeOH (10 ml) containing 10% Pd/C (200 mg) gave crude **13d** (77.4 mg, quant.). FC ($CHCl_3$/EtOH/20% aq. NH_3 15:15:2) gave pure **13d** (55.8 mg, 79%), which was recrystallised from acetone. Colourless solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 9:5:1) 0.36. M.p. 177–178° (acetone). $[\alpha]_D^{25} = -5.4$ ($c = 2.00$, MeOH). IR (KBr): 3700–3000*s* (br.), 2979*m*, 2929*m*, 1689*s*, 1523*s*, 1393*m*, 1367*m*, 1279*m*, 1253*m*, 1169*s*, 1099*s*, 1077*s*, 1029*m*, 974*w*, 945*w*, 855*w*. ^{1}H-NMR (300 MHz, D_2O): see *Table 7*; additionally, 1.45 (*s*, Me_3C). ^{13}C-NMR (75 MHz, D_2O): see *Table 4*; additionally, 161.70 (*s*, C=O); 84.19 (*s*, Me_3C); 30.55 (*q*, Me_3C). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 51.14, H 7.55, N 4.42.

X-Ray Analysis of **13d**. Orthorhombic $P2_12_12_1$; $a = 5.357(3)$, $b = 12.810(3)$, $c = 28.362(14)$; $V = 1946.3(15)$ Å^3, $D_{calc} = 1.240$ Mg/m^3, $Z = 4$. The reflections were measured on an *Enraf-Nonius-CAD4* diffractometer (graphite monochromator, CuK_α radiation, $\lambda = 1.54184$) at 200(2) K. $R = 0.0680$, $R_w = 0.1837$. Part of the structure was solved by direct methods with SIR97 [74], the remaining non-H-atoms were found from a difference *Fourier* map. The non-H-atoms were refined anisotropically with SHELXL-97 [75]. H-Atoms were calculated at idealised positions and included in the structure-factor calculation with fixed isotropic displacement parameters.

*(1*S,*2′*S*)-Spiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**1a**). a) *Hydrogenolysis of* **11a**. Hydrogenation of **11a** (68.2 mg, 97.4 μmol) in MeOH (10 ml) containing 37% aq. HCl (0.3 ml) and 10% Pd/C (100 mg) at 4 bar for 2 h, filtration through *Celite*, washing the residue with H_2O (5 ml) and MeOH (5 ml), and evaporation of the combined filtrates and washings gave a colourless oil. Dissolution of the oil in H_2O (5 ml) and lyophilisation gave **1a** (24.0 mg, quant.).

b) *Hydrolysis of* **13a**. Compound **13a** (39.3 mg, 0.129 mmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **1a** (31.1 mg, quant.). Slightly yellow, hygroscopic solid. p$K_{HA} = 7.79$ (H_2O). R_f ($CHCl_3$/MeOH/20% aq. NH_3 2:3:1) 0.53. $[\alpha]_D^{25} = +49.5$ ($c = 1.00$, MeOH). ^{1}H-NMR (500 MHz, D_2O): see *Table 7*; additionally, 3.55 (irrad. at 1.37 → NOE of 1.2%); 3.39 (irrad. at 1.37 → NOE of 3.2%). ^{13}C-NMR (75 MHz, D_2O): see *Table 4*. ESI-MS (negative mode): 240 (100, $[M-1]^-$). HR-MALDI-MS: 228.0844 ($[M - HCl + Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848), 206.1025 ($[M - Cl]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028).

*(1*R,*2′*R*)-Spiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**1b**). a) *Hydrogenolysis of* **11b**. As described above, hydrogenation of **11b** (48.6 mg, 69.4 μmol) in MeOH (10 ml) containing 37% HCl (0.3 ml) and 10% Pd/C (80 mg), followed by the usual workup, gave **1b** (17.0 mg, quant.).

b) *Hydrolysis of* **13b**. Compound **13b** (9.6 mg, 31.4 μmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **1b** (7.60 mg, quant.). Slightly yellow, hygroscopic solid. p$K_{HA} = 7.88$ (H_2O). R_f ($CHCl_3$/MeOH/20% aq. NH_3 2:3:1) 0.51. $[\alpha]_D^{25} = +37.3$ ($c = 1.00$, MeOH). ^{1}H-NMR (300 MHz, D_2O): see *Table 7*. ^{13}C-NMR (50 MHz, D_2O): see *Table 4*. HR-MALDI-MS: 228.0844 ($[M - HCl + Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848), 206.1025 ($[M - Cl]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028).

*(1*S,*2′*R*)-Spiro[1,5-anhydro*-D-*glucitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**1c**). a) *Hydrogenolysis of* **11c**. As described above, hydrogenation of **11c** (43.9 mg, 62.7 μmol) in MeOH (10 ml) containing 37% HCl (0.3 ml) and 10% Pd/C (80 mg), followed by the usual workup, gave **1c** (16.0 mg, quant.).

b) *Hydrolysis of* **13c**. Compound **13c** (28.6 mg, 93.7 μmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **1c** (23.3 mg, quant.). Colourless, hygroscopic solid. $pK_{HA} = 8.16$ (H_2O). R_f ($CHCl_3$/MeOH/20% aq. NH_3 2:3:1) 0.45. $[\alpha]_D^{25} = +37.0$ ($c = 1.00$, MeOH). ^{1}H-NMR (300 MHz, D_2O): see *Table 7*. ^{13}C-NMR (75 MHz, D_2O): see *Table 4*. HR-MALDI-MS: 228.0844 ($[M - HCl + Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848), 206.1024 ($[M - Cl]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028).

*(1*R*,2′*S*)-Spiro[1,5-anhydro-*D*-glucitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**1d**). a) *Hydrogenolysis of* **11d**. As described above, hydrogenation of **11d** (74.6 mg, 0.107 mmol) in MeOH (10 ml) containing 37% HCl (0.3 ml) and 10% Pd/C (100 mg), followed by the usual workup, gave **1d** (26.1 mg, quant.).

b) *Hydrolysis of* **13d**. Compound **13d** (55.8 mg, 0.183 mmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **1d** (44.2 mg, quant.). Slightly yellow, hygroscopic solid. $pK_{HA} = 7.68$ (H_2O). R_f ($CHCl_3$/MeOH/20% aq. NH_3 2:3:1) 0.42. $[\alpha]_D^{25} = +84.6$ ($c = 1.00$, MeOH). ^{1}H-NMR (300 MHz, D_2O): see *Table 7*. ^{13}C-NMR (75 MHz, D_2O): see *Table 4*. HR-MALDI-MS: 228.0844 ($[M - HCl + Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848), 206.1024 ($[M - Cl]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028).

Cyclopropanation of **14**. At 70°, a soln. of **14** (4.74 g, 8.8 mmol) [58] in dry toluene (20 ml) was treated with Cu powder (250 mg, 3.9 mmol) and with a soln. of ethyl diazoacetate (4.03 g, 35 mmol) in dry toluene (15 ml) over a period of 8 h (using a syringe pump) and stirred for an additional 30 min at 70°. Evaporation and FC (AcOEt/hexane 1:50 → 1:10) gave **14** (450 mg, 9%) and a *ca.* 9:51:11:29 mixture of **15a**–**15d** (4.7 g, 86%). Prep. HPLC (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) afforded pure samples of **15a**–**15d**.

*Ethyl (1*S*,2′*S*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-carboxylate* (**15a**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.61. Prep. HPLC: t_R (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) 16.6 min. $[\alpha]_D^{25} = 5.6$ ($c = 1.5$, $CHCl_3$). IR ($CHCl_3$): 3007*m*, 2908*m*, 2871*m*, 1747*s*, 1602*w*, 1450*m*, 1373*m*, 1327*m*, 1272*w*, 1177*s*, 1095*s*, 1045*m*, 968*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.39–7.15 (*m*, 20 arom. H); 4.91 (*d*, *J* = 10.9, PhC*H*); 4.78 (*d*, *J* = 11.5, PhC*H*); 4.73 (*d*, *J* = 11.5, PhC*H*); 4.66 (*d*, *J* = 11.8, PhC*H*); 4.61 (*d*, *J* = 12.5, PhC*H*); 4.59 (*d*, *J* = 11.5, PhC*H*); 4.53 (*d*, *J* = 10.6, PhC*H*); 4.51 (*d*, *J* = 12.1, PhC*H*); 4.14, 4.03 (2*qd*, *J* = 7.2, 10.9, MeCH_2O); 1.21 (*t*, *J* = 7.2, Me). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 171.95 (*s*, C=O); 139.65, 139.44, 138.61, 138.55 (4*s*); 128.63–127.37 (sevaral *d*); 75.42, 73.59, 72.86, 71.86 (4*t*, 4 PhCH_2); 61.16 (*t*, MeCH_2O); 14.18 (*q*, Me). HR-MALDI-MS: 645.3131 ($[M + Na]^+$, $C_{39}H_{42}NaO_7^+$; calc. 645.2828).

Table 8. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the* manno-*Cyclopropyl Esters* **15a**–**15d** *and* **24a**–**24d** *in $CDCl_3$*

Compound	**15a**	**15b**	**15c**	**15d**	**24a**	**24b**	**24c**	**24d**
H–C(2′)	2.25	1.81	1.86	1.43	2.23	1.92	2.06	1.83
H_{cis}–C(3′)	1.13	1.44	1.44	1.93	1.37	1.56–1.62	1.61	1.80
H_{trans}–C(3′)	1.26	1.64	0.59	1.11	1.27	1.56–1.62	1.03	1.32
H–C(2)	4.13	4.17	3.13	3.11	5.54	5.86	4.88	4.86
H–C(3)	3.81	3.51	3.76	3.85	3.83	3.59	3.84	3.91
H–C(4)	4.07	4.11	4.17	4.21	3.91	3.98	4.00	4.05
H–C(5)	3.53	3.56	3.55	3.24	3.54	3.56	3.57	3.27
H_a–C(6)	3.68	3.70	3.73	3.67	3.66	3.66	3.71	3.62
H_b–C(6)	3.71	3.76	3.78	3.78	3.74	3.76	3.79	3.77
$J(2',3'_{cis})$	6.7	7.0	6.9	6.5	6.9	8.4	6.9	6.7
$J(2',3'_{trans})$	9.3	9.5	9.0	9.0	9.3	8.4	9.0	10.6
$J(3'_{cis},3'_{trans})$	5.6	5.9	5.9	6.2	5.6	[a])	5.9	6.7
J(2,3)	3.1	3.1	3.1	3.1	3.4	3.4	3.7	3.4
J(3,4)	9.2	9.3	9.5	9.5	9.2	9.3	9.3	9.5
J(4,5)	9.7	9.5	9.7	9.7	9.3	9.7	9.7	9.7
$J(5,6_a)$	4.7	5.3	4.4	4.4	4.7	4.7	4.1	3.7
$J(5,6_b)$	2.5	3.2	1.9	1.9	1.9	1.9	1.9	1.9
$J(6_a,6_b)$	11.2	10.9	11.5	11.2	10.9	10.8	11.2	10.9

[a]) Not assigned.

Table 9. *Selected ^{13}C-NMR Chemical Shifts* [ppm] *of the* manno-*Spirocyclopropanes* **15a**–**15d**, **16a**–**16d**, **17a**–**17d**, **19c**, **19d**, *and* **24a**–**24d** *in $CDCl_3$ and of* **18a**–**18d** *and* **2a**–**2d** *in D_2O Solution.*

	C(2′)	C(3′)	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)
15a	25.83	17.85	66.05	73.74	83.87	75.08	78.77	69.58
15b	24.43	20.49	65.09	71.85	82.50	74.79	79.11	69.42
15c	27.70	13.60	62.92	75.19	82.73	76.10	80.08	69.19
15d[a])	23.27	19.39	65.09	74.57	83.00	77.76	79.52	69.09
24a	26.85	17.94	65.22	67.95	81.59	74.38	78.42	69.04
24b[a])	26.56	19.88	65.59	67.38	80.58	74.29	78.88	68.93
24c	26.38	16.66	64.50	72.35	80.86	74.58	79.59	68.79
24d	25.42	18.03	65.68	72.64	80.89	74.04	79.09	68.56
16a	25.73	18.52	66.60	73.48	83.87	74.94	78.77	69.39
16b	24.20	21.26	66.00	72.36	82.52	74.71	79.27	69.39
16c	26.73	15.04	63.15	75.11	82.5	75.69	79.67	68.95
16d	22.74	20.22	65.84	74.45	82.78	77.62	79.47	68.95
17a	33.81	18.52	63.32	75.23	84.25	77.99	79.92	69.35
17b	32.87	18.38	62.17	75.29	83.56	75.29	78.31	69.58
17c	33.53	15.99	59.17	75.30	82.12	76.60	79.27	69.42
17d	31.43	17.79	60.36	74.76	83.48	76.81	78.74	69.76
18a	34.83	19.46	66.82	70.15	76.22	73.31	81.38	63.73
18b	35.34	16.82	65.20	69.21	75.39	71.66	80.83	62.97
18c[a])	34.41	19.27	65.07	70.18	75.83	75.59	82.68	64.04
18d	34.65	16.89	65.00	69.00	75.83	75.75	82.09	63.71
19c	33.73	15.83	59.28	75.20	81.94	76.60	79.05	69.47
19d	31.54	17.83	60.43	74.60	83.34	76.59	79.16	69.55
2a	34.25	18.37	64.51	69.95	76.05	72.91	81.55	63.73
2b	34.88	18.32	63.55	69.36	75.90	71.75	82.48	64.68
2c	32.62	17.49	64.12	70.04	75.46	74.92	83.21	63.79
2d[a])	32.94	16.89	64.43	68.77	75.56	75.09	83.23	63.94

[a]) Assignments based on HSQC-GRASP spectrum.

*Ethyl (1*R*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-mannitol-1,1′-cyclopropane]-2′-carboxylate* (**15b**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.61. Prep. HPLC: t_R (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) 14.2 min. $[\alpha]_D^{25} = -2.0$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3066*w*, 3007*m*, 2870*m*, 1713*s*, 1602*w*, 1555*w*, 1496*w*, 1452*m*, 1369*w*, 1272*w*, 1176*s*, 1090*s*, 1027*m*, 961*w*, 910*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.48–7.17 (*m*, 20 arom. H); 4.96 (*d*, $J = 10.6$, PhC*H*); 4.88 (*d*, $J = 12.5$, PhC*H*); 4.79 (*d*, $J = 12.1$, PhC*H*); 4.63 (*d*, $J = 12.1$, 2 PhC*H*); 4.56–4.52 (*m*, 2 PhC*H*); 4.46 (*d*, $J = 12.1$, PhC*H*); 4.04, 3.90 (2*qd*, $J = 7.2$, 10.9, MeCH_2O); 1.17 (*t*, $J = 7.2$, Me). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 171.30 (*s*, C=O); 138.91 (*s*); 138.58 (2*s*); 138.45 (*s*); 128.65–127.81 (several *d*); 75.64, 73.53, 72.06, 71.03 (4*t*, 4 PhCH_2); 60.99 (*t*, MeCH_2O); 14.21 (*q*, Me). HR-MALDI-MS: 645.3100 ($[M + Na]^+$, $C_{39}H_{42}NaO_7^+$; calc. 645.2828). Anal. calc. for $C_{39}H_{42}O_7$ (622.75): C 75.22, H 6.80; found: C 75.32, H 6.79.

*Ethyl (1*S*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-mannitol-1,1′-cyclopropane]-2′-carboxylate* (**15c**). Colourless solid. R_f (AcOEt/hexane 1:3) 0.46. Prep. HPLC: t_R (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) 26.4 min. $[\alpha]_D^{25} = -28.5$ ($c = 1$, $CHCl_3$). M.p. 103–105° (AcOEt/hexane). IR ($CHCl_3$): 3007*m*, 2873*m*, 1732*s*, 1602*w*, 1496*w*, 1452*s*, 1370*m*, 1262*s*, 1177*s*, 1095*s*, 913*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.49–7.23 (*m*, 20 arom. H); 4.97 (*d*, $J = 12.8$, PhC*H*); 4.96 (*d*, $J = 10.9$, PhC*H*); 4.83 (*d*, $J = 12.8$, PhC*H*); 4.69 (*d*, $J = 11.8$, PhC*H*); 4.63 (*d*, $J = 12.1$, 2 PhC*H*); 4.62 (*d*, $J = 10.6$, PhC*H*); 4.53 (*d*, $J = 12.1$, PhC*H*); 4.21, 4.17 (2*qd*, $J = 7.2$, 10.9, MeCH_2O); 1.28 (*t*, $J = 7.2$, Me). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 168.35 (*s*, C=O); 138.98, 138.82, 138.53, 138.47 (4*s*); 128.71–127.64 (several *d*); 75.50, 73.56, 72.10, 70.28 (4*t*, 4 PhCH_2); 61.12 (*t*, MeCH_2O); 14.38 (*q*, Me). HR-MALDI-MS: 645.2980 ($[M + Na]^+$, $C_{39}H_{42}NaO_7^+$; calc. 645.2828). Anal. calc. for $C_{39}H_{42}O_7$ (622.75): C 75.22, H 6.80; found: C 74.97, H 6.64.

*Ethyl (1*R*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-mannitol-1,1′-cyclopropane]-2′-carboxylate* (**15d**). Colourless solid. M.p. 83.5–84.5° (CH_2Cl_2/hexane). R_f (AcOEt/hexane 1:3) 0.46. Prep. HPLC: t_R (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) 22.2 min. $[\alpha]_D^{25} = 70.5$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3007*m*, 2872*m*, 1725*s*, 1602*w*, 1496*w*, 1453*m*, 1358*m*, 1259*m*, 1174*w*, 1092*s*, 913*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.41–7.17 (*m*, 20 arom. H); 4.92 (*d*, $J = 10.6$, PhC*H*); 4.87 (*d*, $J = 12.5$, irrad. at 1.11 → NOE of 1.4%, PhC*H*); 4.73 (*d*, $J = 12.1$, PhC*H*); 4.72 (*d*, $J = 11.8$, PhC*H*); 4.69 (*d*, $J = 11.8$, PhC*H*); 4.60 (*d*, $J = 11.5$, PhC*H*); 4.57 (*d*, $J = 10.6$, PhC*H*); 4.51 (*d*, $J = 11.8$, PhC*H*); 4.21 (irrad. at 3.24 → *d*, $J = 9.7$); 4.14, 4.07 (2*qd*, $J = 7.2$, 10.9, MeCH_2O); 3.85 (irrad. at 3.11 → *d*, $J = 9.3$, irrad. at 1.43 → NOE of 3.2%, irrad. at 3.11 → NOE of 6.7%, irrad. at 3.24 → NOE of 6.2%); 3.78 (irrad. at 3.24 → *d*, $J = 11.3$, irrad. at 3.24 → NOE of 3.2%); 3.67 (irrad. at 3.24 → *d*, $J = 10.9$, irrad. at 3.24 → NOE of 3.1%); 3.24 (irrad. at 3.67 → br. *dd*, $J = 3.4$, 9.3, irrad. at 4.21 → *dd*, $J \approx 1.8$, 4.1); 3.11 (irrad. at 1.43 → NOE of 8.4%, irrad. at 1.11 → NOE of 5%); 1.93 (irrad. at 1.11 → NOE of 32%); 1.43 (irrad. at 1.11 → NOE of 8.4%, irrad. at 1.93 → NOE of 1.6%, irrad. at 3.11 → NOE of 8.1%); 1.22 (*t*, $J = 7.2$, Me); 1.11 (irrad. at 1.43 → NOE of 3.1%, irrad. at 1.93 → NOE of 18%, irrad. at 3.11 → NOE of 3.1%). ^{13}C-NMR (75 MHz, $CDCl_3$; assignments based on a HSQC-GRASP spectrum): see *Table 9*; additionally, 169.54 (*s*, C=O); 138.78, 138.72, 138.62, 138.54 (4*s*); 128.71–127.69 (several *d*); 75.56, 73.59, 72.47, 71.48 (4*t*, 4 PhCH_2); 61.07 (*t*, MeCH_2O); 14.23 (*q*, Me). HR-MALDI-MS: 645.3119 ($[M + Na]^+$, $C_{39}H_{42}NaO_7^+$; calc. 645.2828). Anal. calc. for $C_{39}H_{42}O_7$ (622.75): C 75.22, H 6.80; found: C 75.20, H 6.94.

*(1*S*,2′*S*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-mannitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**16a**). A soln. of **15a** (250 mg, 0.40 mmol) in EtOH (10 ml) was heated to 60°, treated with 1N KOH (3 ml), stirred for 3 h, cooled to r.t., concentrated to 1/3 of its volume, treated with 3N HCl (6 ml), and extracted with CH_2Cl_2. The combined org. layers were dried and evaporated to yield crude **16a** (214 mg). FC (AcOEt/hexane 3:2) gave pure **16a** (190 mg, 80%). Colourless solid. R_f (AcOH/AcOEt/hexane 1:25:75) 0.19. $[\alpha]_D^{25} = 4.6$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3510*w*, 3400–2400*w* (br.), 3066*w*, 3007*m*, 2871*m*, 1698*s*, 1603*w*, 1496*m*, 1363*m*, 1318*w*, 1269*w*, 1178*m*, 1091*s*, 1041*m*, 1028*s*, 924*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 10*; additionally, 7.40–7.16 (*m*, 20 arom. H); 4.92 (*d*, $J = 10.6$, PhC*H*); 4.77 (*d*, $J = 11.8$, PhC*H*); 4.68 (*d*, $J = 11.8$, PhC*H*); 4.67 (*d*, $J = 11.2$, PhC*H*); 4.61 (*d*, $J = 12.5$, PhC*H*); 4.59 (*d*, $J = 11.2$, PhC*H*); 4.54 (*d*, $J = 10.6$, PhC*H*); 4.52 (*d*, $J = 12.2$, PhC*H*); 3.74–3.67 (irrad. at 3.54 → *s*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 176.95 (*s*, C=O); 138.91, 138.51, 138.41, 138.36 (4*s*); 128.65–127.54 (sevaral *d*); 75.39, 73.50, 72.82, 72.09 (4*t*, 4 PhCH_2). HR-MALDI-MS: 617.2516 ($[M + Na]^+$, $C_{37}H_{38}NaO_7^+$; calc. 617.2515). Anal. calc. for $C_{37}H_{38}O_7 \cdot 1.9\ H_2O$ (630.72): C 70.86, H 6.69; found: C 70.86, H 6.63.

*(1*R*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-mannitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**16b**). A soln. of **15b** (1.78 g, 2.86 mmol) and 1N KOH (15 ml) in EtOH (50 ml) was stirred at 60° for 3 h. Workup as described above gave crude **16b** (1.667 g, quantitative). Colourless oil. R_f (AcOH/AcOEt/hexane 1:25:75) 0.21. $[\alpha]_D^{25} = -14.0$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3511*w*, 3400–2400*m* (br.), 3511*w*, 3089*m*, 3065*s*, 3007*s*, 2866*s*, 1688*s*, 1606*w*, 1494*m*, 1454*s*, 1362*s*, 1318*m*, 1279*s*, 1177*s*, 1090*s*, 1041*s*, 1027*s*, 953*m*, 913*m*, 839*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 10*; additionally, 7.44–7.14 (*m*, 20 arom. H); 4.92 (*d*, $J = 10.9$, PhC*H*); 4.82 (*d*, $J = 12.1$, PhC*H*); 4.75 (*d*, $J = 12.1$, PhC*H*); 4.61 (*d*, $J = 12.1$, PhC*H*); 4.58 (*d*, $J = 11.8$, PhC*H*); 4.52 (*d*, $J = 10.6$, PhC*H*); 4.51 (*d*, $J = 11.5$, PhC*H*); 4.47 (*d*, $J = 11.8$, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 175.46 (*s*, C=O); 138.79, 138.59, 138.51, 138.37 (4*s*); 128.61–127.84 (several *d*); 75.53, 73.56, 72.30, 71.55 (4*t*, 4 PhCH_2). HR-MALDI-MS: 617.2504 ($[M + Na]^+$, $C_{37}H_{38}NaO_7^+$; calc. 617.2515). Anal. calc. for $C_{37}H_{38}NaO_7 \cdot 0.5\ H_2O$ (603.69): C 73.61, H 6.51; found: C 73.51, H 6.58.

*(1*S*,2′*R*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-mannitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**16c**). A soln. of **15c** (290 mg, 0.47 mmol) in EtOH (12 ml) was heated to 60°, treated with 1N KOH (3 ml) and stirred for 3 h. Usual workup gave crude **16c** (280 mg, quantitative). Colourless solid. M.p. 145–146° (CH_2Cl_2/hexane). R_f (AcOH/AcOEt/hexane 1:25:75) 0.14. $[\alpha]_D^{25} = 2.5$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3520*w*, 3400–2400*w* (br.), 3212*w*, 3088*m*, 3066*m*, 3007*s*, 2873*m*, 1742*s*, 1713*s*, 1603*w*, 1496*m*, 1454*s*, 1402*m*, 1361*m*, 1309*w*, 1263*m*, 1089*s*, 1027*s*, 913*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 10*; additionally, 7.43–7.21 (*m*, 20 arom. H); 4.97 (*d*, $J = 10.9$, PhC*H*); 4.91 (*d*, $J = 13.1$, PhC*H*); 4.79 (*d*, $J = 12.8$, PhC*H*); 4.68 (*d*, $J = 11.8$, PhC*H*); 4.63 (*d*, $J = 12.1$, PhC*H*); 4.57 (*d*, $J = 12.1$, PhC*H*); 4.55 (*d*, $J = 12.5$, PhC*H*); 4.51 (*d*, $J = 11.8$, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 171.87 (*s*, C=O); 138.47, 138.29, 138.18, 138.05 (4*s*); 128.81–127.87 (several *d*); 75.58, 73.48, 72.20, 70.74 (4*t*, 4 PhCH_2). HR-MALDI-MS: 617.2502 ($[M + Na]^+$, $C_{37}H_{38}NaO_7^+$; calc. 617.2515). Anal. calc. for $C_{37}H_{38}O_7$ (594.69): C 74.73, H 6.44; found: C 74.70, H 6.45.

*(1*R*,2′*S*)-2,3,4,6-Tetra*-O*-benzylspiro[1,5-anhydro*-D*-mannitol-1,1′-cyclopropane]-2′-carboxylic Acid* (**16d**). A soln. of **15d** (270 mg, 0.43 mmol) and 1N KOH (3 ml) in EtOH (10 ml) was heated at 60° for 3 h. Workup as described above gave crude **16d** (250 mg, 97%). Colourless oil. R_f (AcOH/AcOEt/hexane 1:25:75) 0.12. $[\alpha]_D^{25} = 98.6$ ($c = 2$, $CHCl_3$). IR ($CHCl_3$): 3510*w*, 3400–2400*w* (br.), 3088*m*, 3066*m*, 3007*s*, 2871*m*, 1702*s*, 1603*w*,

Table 10. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the Cyclopropanecarboxylic Acids* **16a**–**16d** *and of the Protected Cyclopropylamine* **17a** *in $CDCl_3$, and of the Protected Cyclopropylamines* **17b**, **17d**, *and* **17c** *in CD_3OD* (**16a**–**16d**, **17a**, and **17c** at 25°; **17b** and **17d** at 50°)

Compound	**16a**	**16b**	**16c**	**16d**	**17a**	**17b**	**17c**	**17d**
H–C(2′)	2.27	1.81	1.84	1.42	2.93	2.68	2.92	2.54
H_{cis}–C(3′)	1.15	1.42	1.38	1.93	0.60	0.97	0.63	0.99
H_{trans}–C(3′)	1.34	1.68	0.76	1.14	1.17	1.31	0.73	1.05
H–C(2)	4.07	4.10	3.14	3.08	3.58	3.69	3.30	3.33
H–C(3)	3.81	3.57	3.75	3.83	3.85	3.95–3.97	3.77	4.09
H–C(4)	4.08	4.08	4.11	4.18	4.13	3.95–3.97	3.97	3.93
H–C(5)	3.54	3.54	3.62	3.35	3.49	3.84	3.49	3.59–3.68
H_a–C(6)	3.67–3.74	3.67	3.68	3.66	3.67	3.62–3.68	3.67	3.59–3.68
H_b–C(6)	3.67–3.74	3.73	3.77	3.67	3.74	3.62–3.68	3.72	3.59–3.68
J(2′,3′$_{cis}$)	6.7	6.8	6.7	6.5	5.0	5.6	5.5	5.5
J(2′,3′$_{trans}$)	9.5	9.3	9.3	9.0	8.4	9.7	8.3	9.2
J(3′$_{cis}$,3′$_{trans}$)	5.5	5.9	6.2	6.2	6.8	7.2	7.0	7.2
J(2,3)	3.1	3.1	3.1	2.8	2.8	2.8	3.1	3.2
J(3,4)	9.3	9.3	9.3	9.2	9.3	[a])	9.3	9.1
J(4,5)	9.7	9.8	9.3	9.7	9.7	9.7	9.5	9.3
J(5,6$_a$)	4.4	5.0	5.9	4.4	5.0	7.2	4.5	[a])
J(5,6$_b$)	2.8	1.9	1.6	1.6	2.2	3.7	3.1	[a])
J(6$_a$,6$_b$)	[a])	10.9	10.3	11.2	11.4	[a])	11.2	[a])

[a]) Not assigned.

1496*m*, 1454*s*, 1410*w*, 1359*m*, 1309*w*, 1261*m*, 1090*s*, 1041*m*, 1027*s*, 980*m*, 912*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 10*; additionally, 7.39–7.16 (*m*, 20 arom. H); 4.91 (*d*, *J* = 10.6, PhC*H*); 4.82 (d, *J* = 12.5, PhC*H*); 4.72 (*d*, *J* = 12.5, PhC*H*); 4.70 (*d*, *J* = 11.5, PhC*H*); 4.66 (*d*, *J* = 12.5, PhC*H*); 4.64 (*d*, *J* = 11.8, PhC*H*); 4.55 (*d*, *J* = 10.9, PhC*H*); 4.47 (*d*, *J* = 11.8, PhC*H*). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 174.28 (*s*, C=O); 138.69, 138.57, 138.48, 138.39 (4*s*); 128.75–127.70 (several *d*); 75.54, 73.47, 72.66, 71.72 (4*t*, 4 Ph*C*H$_2$). HR-MALDI-MS: 617.2512 ([*M* + Na]$^+$, $C_{37}H_{38}NaO_7^+$; calc. 617.2515). Anal. calc. for $C_{37}H_{38}O_7 \cdot 0.5\ H_2O$ (603.69): C 73.61, H 6.51; found: C 73.95, H 6.80.

tert-*Butyl [(1*S*,2′*S*) 2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro-*D-*mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**17a**). *a*) A soln. of crude **16a** (190 mg, 0.32 mmol) in acetone (5 ml) was cooled to 0°, treated with Et_3N (59 mg, 0.57 mmol) and $ClCO_2Et$ (73 mg, 0.67 mmol), stirred for 1 h, treated with a soln. of NaN_3 (50 mg, 0.77 mmol) in H_2O (1.6 ml), and stirred for 2 h. The mixture was diluted with CH_2Cl_2, washed with H_2O, dried ($MgSO_4$), evaporated, and dried under high vacuum overnight. The crude carbonyl azide was dissolved in dry toluene (10 ml) and kept at 100° until TLC showed complete consumption of the azide (*ca.* 2 h). After addition of dry *t*-BuOH (10 ml), heating was continued for another 12 h. Evaporation and FC (AcOEt/hexane 1:9 → 1:4) gave **17a** (164 mg, 67%).

b) A soln. of **16a** (212 mg, 0.36 mmol) in *t*-BuOH (12 ml) was treated with Et_3N (163 mg, 1.6 mmol) and $(PhO)_2PON_3$ (293 mg, 1.1 mmol) and stirred at r.t. for 15 min and at 100° for 12 h. Evaporation and FC (AcOEt/hexane 1:9 → 1:4) gave **17a** (165 mg, 69%). Colourless glassy solid forming a gel in AcOEt/hexane mixtures. R_f (AcOEt/hexane 1:3) 0.21. $[\alpha]_D^{25} = 66.0$ (*c* = 1, $CHCl_3$). IR ($CHCl_3$): 3411*w*, 3089*w*, 3068*w*, 3007*s*, 2912*w*, 2869*w*, 1714*s*, 1602*w*, 1495*s*, 1453*s*, 1392*m*, 1367*s*, 1163*s*, 1098*s*, 1051*m*, 1027*s*, 913*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 10*; additionally, 7.43–7.17 (*m*, 20 arom. H); 4.97 (*d*, *J* = 11.8, PhC*H*); 4.90 (*d*, *J* = 10.9, PhC*H*); 4.79 (*d*, *J* = 11.8, PhC*H*); 4.76 (*d*, *J* = 11.8, PhC*H*); 4.74 (*d*, *J* = 11.8, PhC*H*); 4.63 (*d*, *J* = 12.5, PhC*H*); 4.54 (br. *d*, *J* ≈ 1.9, NH), 4.57 (*d*, *J* = 10.9, PhC*H*); 4.49 (*d*, *J* = 12.1, PhC*H*); 1.42 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 156.35 (*s*, C=O); 138.96 (*s*); 138.63 (2*s*); 138.47 (*s*); 128.83–127.75 (several *d*); 79.92 (*s*, Me_3C); 75.34, 73.58, 72.80, 72.75 (4*t*, 4 Ph*C*H$_2$); 28.43 (*q*, *Me*$_3$C). HR-MALDI-MS: 688.3252 ([*M* + Na]$^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250).

tert-*Butyl [(1*R*,2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro-*D-*mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**17b**). *a*) As described above, treatment of crude **16b** (525 mg, 0.88 mmol) in acetone (18 ml) at 0° with Et_3N (126 mg, 1.24 mmol), $ClCO_2Et$ (160 mg, 1.47 mmol), and a soln. of NaN_3 (104 mg, 1.6 mmol) in H_2O

(6 ml), and usual workup gave the crude carbonyl azide. Heating of the carbonyl azide in dry toluene (20 ml) at 100° (2 h), treatment with dry *t*-BuOH (20 ml), heating for another 12 h, evaporation, and FC (AcOEt/hexane 1:9 → 1:4) gave **17b** (435 mg, 74%).

b) Treatment of crude **16b** (1.670 g, 2.85 mmol) in *t*-BuOH (60 ml), with Et_3N (1.275 g, 12.5 mmol) and $(PhO)_2PON_3$ (2.31 g, 8.4 mmol), stirring at r.t. for 15 min and at 100° for 18 h, evaporation, and FC (AcOEt/hexane 1:9 → 1:4) gave **17b** (1.39 g, 74%). Colourless oil. R_f (AcOEt/hexane 1:3) 0.22. $[\alpha]_D^{25} = 48.8$ ($c = 2$, $CHCl_3$). IR ($CHCl_3$): 3477*m*, 3088*m*, 3066*w*, 3007*s*, 2912*w*, 2866*w*, 1711*s*, 1603*w*, 1495*s*, 1453*s*, 1392*m*, 1367*s*, 1162*s*, 1098*s*, 1027*m*, 912*w*, 834*w*. ^{1}H-NMR (CD_3OD, 50°): see *Table 10*; additionally, 7.43 – 7.15 (*m*, 20 arom. H); 4.85 (*d*, $J = 11.2$, PhC*H*); 4.75 (*d*, $J = 11.8$, PhC*H*); 4.67 (*d*, $J = 11.8$, PhC*H*); 4.61 (*d*, $J = 11.5$, PhC*H*); 4.56 (*d*, $J = 11.5$, PhC*H*); 4.54 (*d*, $J = 11.2$, 2 PhC*H*); 4.45 (*d*, $J = 12.1$, PhC*H*); 1.44 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 156.51 (*s*, C=O); 139.18, 139.04, 138.95, 138.73 (4*s*); 128.68 – 127.58 (several *d*); 77.24 (*s*, Me_3C); 75.29, 73.43, 72.55, 72.07 (4*t*, 4 PhCH_2); 28.35 (*q*, Me_3C). HR-MALDI-MS: 688.3242 ($[M + Na]^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250). Anal. calc. for $C_{41}H_{47}NO_7$ (665.81): C 73.96, H 7.12, N 2.10; found: C 73.82, H 7.17, N 2.21.

tert-*Butyl [(1*S*,2′*R*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**17c**). *a*) As described above, treatment of crude **16c** (280 mg, 0.47 mmol) in acetone (12 ml) at 0° with Et_3N (68 mg, 0.66 mmol), $ClCO_2Et$ (85 mg, 0.78 mmol), and a soln. of NaN_3 (38 mg, 0.58 mmol) in H_2O (1.5 ml), and usual workup gave the crude carbonyl azide. Heating the crude carbonyl azide in dry toluene (10 ml) at 100° (2 h), treatment with dry *t*-BuOH (10 ml), heating for another 12 h, evaporation, and FC (AcOEt/hexane 1:9 → 1:4) gave **17c** (208 mg, 67%).

b) Treatment of **16c** (269 mg, 0.45 mmol) in *t*-BuOH (20 ml) with Et_3N (218 mg, 2.15 mmol) and $(PhO)_2PON_3$ (340 mg, 1.39 mmol), heating at 100° for 6 h, evaporation, and FC (AcOEt/hexane 1:9 → 1:4) gave **17c** (214 mg, 70%) and **19c** (39 mg, 16%). Colourless solid. R_f (AcOEt/hexane 1:3) 0.33. $[\alpha]_D^{25} = -21.6$ ($c = 1$, $CHCl_3$). M.p. 92.5 – 93° (CH_2Cl_2/hexane). IR ($CHCl_3$): 3440*m*, 3089*w*, 3066*s*, 3006*s*, 2871*s*, 1708*s*, 1604*w*, 1585*w*, 1496*s*, 1454*s*, 1392*m*, 1367*s*, 1342*m*, 1165*s*, 1108*s*, 1027*s*, 913*m*, 850*w*. ^{1}H-NMR (CD_3OD, 50°): see *Table 10*; additionally, 7.43 – 7.18 (*m*, 20 arom. H); 4.86 (*d*, $J = 11.2$, 2 PhC*H*); 4.71 – 4.48 (several *d*, 6 PhC*H*); 1.44 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 156.62 (*s*, C=O); 138.76 (*s*); 138.65 (2*s*); 138.42 (*s*); 128.68 – 127.82 (several *d*); 79.82 (*s*, Me_3C); 75.50, 73.44, 71.97, 71.10 (4*t*, 4 PhCH_2); 28.48 (*q*, Me_3C). HR-MALDI-MS: 688.3241 ($[M + Na]^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250). Anal. calc. for $C_{41}H_{47}NO_7$ (665.81): C 73.96, H 7.12, N 2.10; found: C 73.80, H 7.23, N 2.16.

*(1*S*,2′*R*)-2′-[(Azidocarbonyl)amino]-2,3,4,6-tetra*-O-*benzylspiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]* (**19c**). Colourless solid. R_f (AcOEt/hexane 1:3) 0.33. IR ($CHCl_3$): 3422*w*, 3089*w*, 3066*w*, 3006*m*, 2924*w*, 2143*s*, 1704*s*, 1602*w*, 1507*m*, 1498*m*, 1454*m*, 1365*s*, 1262*m*, 1090*s*, 1027*m*, 911*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 11*; additionally, 7.35 – 7.11 (*m*, 20 arom. H); 5.78 (*d*, $J = 5.9$, irrad. at 2.88 → *s*, NH); 4.89 (*d*, $J = 12.8$, PhC*H*); 4.72 (*d*, $J \approx 12.8$, 2 PhC*H*); 4.58 – 4.55 (*m*, 2 PhC*H*); 4.50 (*d*, $J = 11.8$, PhC*H*); 4.49 (*d*, $J = 10.6$, PhC*H*); 4.43 (*d*, $J = 12.1$, PhC*H*); 3.97 (*t*, $J \approx 9.3$, H–C(4)); 3.66 (*dd*, $J \approx 3.1$, 9.3, irrad. at 3.00 → *d*, $J = 9.3$, H–C(3)); 3.65 – 3.60 (*AB*, 2 H–C(6)); 3.45 (*ddd*, $J \approx 3.0$, 4.8, 9.7, H–C(5)); 3.00 (*d*, $J = 3.1$, H–C(2)); 2.88 (*td*, $J \approx 7.5$, 5.7, irrad. at 5.78 → *dd*, $J = 7.5$, 5.9, H–C(2′)); 0.56 (*t*, $J \approx 7.8$, H_{trans}–C(3′)); 0.53 (*dd*, $J \approx 5.6$, 7.2, H_{cis}–C(3′)). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 157.30 (*s*, C=O); 138.37, 138.26, 138.06, 138.02 (4*s*); 128.60 – 127.91 (several *d*); 75.52, 73.43, 72.92, 71.21 (4*t*, 4 PhCH_2). HR-MALDI-MS: 564.2755 ($[M - CON_3 + H]^+$, $C_{36}H_{38}NO_5^+$; calc. 564.2750), 586.2581 ($[M - CON_3 + Na]^+$, $C_{36}H_{37}NNaO_5^+$; calc. 586.2569), 629.2621 ($[M - N_2 + Na]^+$, $C_{37}H_{38}N_2NaO_6^+$; calc. 629.2628), 657.2686 ($[M + Na]^+$, $C_{37}H_{38}N_4NaO_6^+$; calc. 657.2689).

tert-*Butyl [(1*R*,2′*S*)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**17d**). *a*) As described above, treatment of **16d** (190 mg, 0.32 mmol) in acetone (5 ml) at 0° with Et_3N (46 mg, 0.45 mmol), $ClCO_2Et$ (58 mg, 0.53 mmol), and a soln. of NaN_3 (38 mg, 0.58 mmol) in H_2O (1.5 ml), and usual workup gave crude carbonyl azide. Heating the crude carbonyl azide in dry toluene (10 ml) at 100° (2 h), treatment with dry *t*-BuOH (10 ml), heating for another 18 h, evaporation, and FC (AcOEt/hexane 1:9 → 1:4) gave **17d** (121 mg, 56%).

b) Treatment of **16d** (492 mg, 0.82 mmol) in *t*-BuOH (40 ml), with Et_3N (377 mg, 3.7 mmol) and $(PhO)_2PON_3$ (683 mg, 2.48 mmol), stirring at r.t. for 15 min and at 100° for 18 h, evaporation, and FC (AcOEt/hexane 1:9 → 1:4) gave **17d** (316 mg, 57%) and **19d** (83 mg, 16%). Colourless oil. R_f (AcOEt/hexane 1:3) 0.20. $[\alpha]_D^{25} = 39.4$ ($c = 2$, $CHCl_3$). IR ($CHCl_3$): 3448*m*, 3088*w*, 3066*w*, 3007*s*, 2931*m*, 2868*m*, 1707*s*, 1603*w*, 1497*s*, 1453*s*, 1392*m*, 1367*s*, 1306*w*, 1164*s*, 1102*s*, 1027*s*, 942*w*, 914*w*. ^{1}H-NMR (CD_3OD, 50°): see *Table 10*; additionally, 7.38 – 7.18 (*m*, 20 arom. H); 4.85 (d, $J = 11.5$, PhC*H*); 4.74 (*d*, $J = 11.8$, PhC*H*); 4.68 – 4.61 (*m*, 2 PhC*H*); 4.68 (*d*, $J = 11.5$, PhC*H*); 4.56 (*d*, $J = 11.2$, PhC*H*); 4.55 (*d*, $J = 11.5$, PhC*H*); 4.45 (*d*, $J = 11.8$, PhC*H*); 1.42 (br. *s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 156.74 (*s*, C=O); 138.77 (2*s*); 138.67(2*s*); 128.70 – 127.73

Table 11. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the Carbamates* **18a**–**18d**, *and of the* manno-*Ammonium Chlorides* **2a**–**2d** *in D_2O, and the Aminocarbonyl Azides* **19c** *and* **19d** *in $CDCl_3$* (**18a**, **18c**, **19c**, **19d**, and **2a**–**2d** at 25°; **18b** at 50°, and **18d** at 60°)

Compound	**18a**	**18b**	**18c**	**18d**	**19c**	**19d**	**2a**	**2b**	**2c**	**2d**
H–C(2′)	2.88	2.75	2.89	2.74	2.88	2.84	3.06	2.96	2.96	2.90
H_{cis}–C(3′)	0.84	0.91	0.89	0.92	0.53	0.94	1.20	1.25	1.25	1.21
H_{trans}–C(3′)	1.17	1.20	1.15	1.19	0.56	0.90	1.51	1.51	1.32	1.36
H–C(2)	3.59	3.53	3.39	3.35	3.00	3.14	3.82	3.81	3.48	3.46
H–C(3)	3.76	3.59–3.73	3.84	3.87	3.66	3.84	3.85	3.76	3.84	3.84
H–C(4)	3.69	3.59–3.73	3.74	3.71	3.97	3.93	3.73	3.70	3.74	3.81
H–C(5)	3.36	3.59–3.73	3.49	3.36	3.45	3.51	3.42	3.44	3.55	3.46
H_a–C(6)	3.66	3.59–3.73	3.76	3.69	3.60–3.65	3.61	3.69	3.64	3.76	3.79
H_b–C(6)	3.83	3.80	3.94	3.82	3.60–3.65	3.73	3.87	3.83	3.98	3.87
J(2′,3′$_{cis}$)	5.3	5.6	5.3	5.3	5.7	5.3	5.6	5.9	5.3	5.0
J(2′,3′$_{trans}$)	8.6	9.3	8.3	8.3	7.5	8.4	9.3	9.7	8.6	8.4
J(3′$_{cis}$,3′$_{trans}$)	7.2	7.2	6.9	7.5	7.2	7.5	8.1	8.4	8.1	8.4
J(2,3)	3.1	3.1	3.4	3.7	3.1	3.1	3.4	3.5	3.4	3.1
J(3,4)	9.5	[a])	9.7	9.3	9.3	9.0	9.7	9.3	9.7	8.9
J(4,5)	9.0	[a])	9.3	9.2	9.7	9.0	9.3	9.0	9.3	9.0
J(5,6$_a$)	7.0	[a])	6.7	5.5	4.8	7.2	6.9	6.8	7.2	6.3
J(5,6$_b$)	2.2	2.1	2.2	1.9	3.0	1.9	2.5	2.1	1.9	1.9
J(6$_a$,6$_b$)	12.0	11.2	12.5	12.5	[a])	10.3	12.3	12.8	12.3	12.5

[a]) Not assigned.

(several *d*); 79.95 (*s*, Me_3C); 75.08, 73.37, 72.69, 72.35 (4*t*, 4 PhCH_2); 28.42 (*q*, Me_3C). HR-MALDI-MS: 688.3243 ([M + Na]$^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250). Anal. calc. for $C_{41}H_{47}NO_7$ (665.81): C 73.96, H 7.12, N 2.10; found: C 73.80, H 7.21, N 2.19.

*(1*R,*2′*S*)-2′-[(Azidocarbonyl)amino]-2,3,4,6-tetra*-O-*benzylspiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]* (**19d**). Colourless solid. R_f (AcOEt/hexane 1:3) 0.19. IR ($CHCl_3$): 3432*m*, 3088*m*, 3060*s*, 3005*s*, 2931*s*, 2870*s*, 2144*s*, 1704*s*, 1605*w*, 1585*w*, 1496*s*, 1453*s*, 1364*s*, 1305*m*, 1261*s*, 1106*s*, 1028*s*, 948*m*, 914*s*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 11*; additionally, 7.38–7.18 (*m*, 20 arom. H); 5.48 (*d*, J = 6.8, NH); 4.92 (*d*, J = 10.9, PhCH); 4.80 (*d*, J = 12.5, PhCH); 4.74 (*d*, J = 12.5, PhCH); 4.72 (*d*, J = 11.8, PhCH); 4.67 (*d*, J = 11.5, PhCH); 4.57 (*d*, J = 11.8, PhCH); 4.54 (*d*, J = 10.9, PhCH); 4.51 (*d*, J = 12.1, PhCH); 3.93 (*t*, $J \approx$ 9.3, H–C(4)); 3.84 (*dd*, J = 3.1, 9.0, irrad. at 3.14 → *d*, J = 9.0, H–C(3)); 3.73 (*dd*, J = 1.9, 10.3, H′–C(6)); 3.61 (*dd*, J = 7.2, 10.3, H–C(6)); 3.51 (*ddd*, J = 1.9, 7.2, 9.0, H–C(5)); 3.14 (*d*, J = 3.1, H–C(2)); 2.84 (*ddd*, $J \approx$ 5.3, 6.8, 8.4, irrad. at 5.48 → *dd*, J = 5.3, 8.4, H–C(2′)); 0.94 (*dd*, $J \approx$ 5.3, 7.5, H_{cis}–C(3′)); 0.90 (*t*, $J \approx$ 7.9, H_{trans}–C(3′)). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 157.37 (*s*, C=O); 138.49 (*s*); 138.33 (*s*); 13.44 (2*s*); 128.73–127.86 (several *d*); 75.26, 73.47, 72.90, 72.55 (4*t*, 4 PhCH_2). HR-MALDI-MS: 564.2769 ([M – CON_3 + H]$^+$, $C_{36}H_{38}NO_5^+$; calc. 564.2750), 586.2589 ([M – CON_3 + Na]$^+$, $C_{36}H_{37}NNaO_5^+$; calc. 586.2569), 629.2649 ([M – N_2 + Na]$^+$, $C_{37}H_{38}N_2NaO_6^+$; calc. 629.2628).

tert-*Butyl [(1*S,*2′*S*)-Spiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**18a**). Hydrogenation of **17a** (155 mg, 0.23 mmol) in MeOH (15 ml) containing 10% Pd/C (75 mg) at 6 bar for 12 h, filtration through *Celite*, and evaporation gave a colourless oil. Dissolution of the oil in H_2O (10 ml), filtration through *Celite*, and lyophilisation gave **18a** (69 mg, quant.). Colourless hygroscopic solid. R_f (MeOH/AcOEt 1:4) 0.51. $[\alpha]_D^{25}$ = 44.7 (c = 1, H_2O). IR (KBr): 3389*s* (br.), 2977*m*, 2930*m*, 1682*s*, 1537*m*, 1505*m*, 1455*m*, 1393*m*, 1367*s*, 1251*s*, 1168*s*, 1069*s* (br.), 974*w*. ^{1}H-NMR (D_2O): see *Table 11*; additionally, 1.42 (*s*, Me_3C). ^{13}C-NMR (D_2O): see *Table 9*; additionally, 161.89 (*s*, C=O); 84.46 (*s*, Me_3C); 30.30 (*q*, Me_3C). ESI-MS: 633 (28, [2M + Na]$^+$), 328 (26, [M + Na]$^+$), 323 (53, [M + NH_4]$^+$), 279 (28), 180 (35), 50 (100). Anal. calc. for $C_{13}H_{23}NO_7 \cdot H_2O$ (323.34): C 48.27, H 7.79, N 4.33; found: C 48.29, H 7.38, N 4.22.

tert-*Butyl [(1*R,*2′*R*)-Spiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**18b**). As described above, hydrogenation of **17b** (135 mg, 0.20 mmol) in MeOH (10 ml) containing 10% Pd/C (72 mg) at 6 bar for 10 h gave **18b** (52 mg, 84%). Colourless hygroscopic solid. R_f (MeOH/AcOEt 1:4) 0.39. $[\alpha]_D^{25}$ = 73.0 (c = 1, H_2O). IR (KBr): 3378*s* (br.), 2977*m*, 2931*m*, 1694*s*, 1519*m*, 1455*m*, 1393*m*, 1367*s*, 1282*m*, 1254*m*, 1223*m*,

1168*s*, 1095*m*, 1085*m*, 1066*s*, 1023*m*, 976*w*, 934*w*. ^{1}H-NMR (D_2O, 50°): see *Table 11*; additionally, 1.46 (*s*, *Me*$_3$C). ^{13}C-NMR (D_2O): see *Table 9*; additionally, 159.01 (*s*, C=O); 80.47 (*s*, Me$_3$*C*); 28.78 (*q*, *Me*$_3$C). ESI-MS: 633 (84, $[2M+Na]^+$), 328 (49, $[M+Na]^+$), 323 (33, $[M+NH_4]^+$), 279 (28), 213 (53), 65 (100). Anal. calc. for $C_{13}H_{23}NO_7 \cdot 0.5\ H_2O$ (314.33): C 49.67, H 7.70, N 4.46; found: C 50.08, H 7.49, N 4.34.

tert-*Butyl [(1*S*,2′*R*)-Spiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**18c**). Hydrogenation of **17c** (120 mg, 0.18 mmol) in MeOH (10 ml) containing 10% Pd/C (60 mg) at 6 bar for 18 h gave **18c** (52 mg, 94%). Colourless hygroscopic solid. R_f (MeOH/AcOEt 1:4) 0.48. $[\alpha]_D^{25} = 16.0$ ($c = 1$, H_2O). IR (KBr): 3382*s* (br.), 2978*m*, 2932*m*, 2873*w*, 1698*s*, 1519*m*, 1455*m*, 1393*m*, 1367*s*, 1272*m*, 1254*m*, 1170*s*, 1099*m*, 1063*s*, 1028*m*, 852*w*. ^{1}H-NMR (D_2O): see *Table 11*; additionally, 1.48 (*s*, Me$_3$C). ^{13}C-NMR (D_2O): see *Table 9*; additionally, 161.96 (*s*, C=O); 84.34 (*s*, Me$_3$*C*); 30.30 (*q*, *Me*$_3$C). ESI-MS: 633 (20, $[2M+Na]^+$), 328 (48, $[M+Na]^+$), 323 (49, $[M+NH_4]^+$), 279 (62), 50 (100). Anal. calc. for $C_{13}H_{23}NO_7 \cdot 0.5\ H_2O$ (314.33): C 49.67, H 7.70, N 4.46; found: C 49.60, H 7.33, N 4.29.

tert-*Butyl [(1*R*,2′*S*)-Spiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-yl]carbamate* (**18d**). Hydrogenation of **17d** (220 mg, 0.33 mmol) in MeOH (15 ml) containing 10% Pd/C (110 mg) at 6 bar for 12 h, concentration and reversed-phase chromatography (*C_{18}-RP* packing material (*Fluka*, cat. no. *60757*), MeOH/H_2O 1:9 → 1:4) gave **18d** (91 mg, 90%). Colourless hygroscopic solid. R_f (MeOH/AcOEt 1:4) 0.42. $[\alpha]_D^{25} = -57.5$ ($c = 0.8$, H_2O). IR (KBr): 3380*s* (br.), 3312*s*, 2978*w*, 2935*w*, 2880*w*, 1690*s*, 1519*m*, 1459*w*, 1420*w*, 1391*w*, 1364*m*, 1275*m*, 1255*m*, 1162*s*, 950*w*, 916*w*, 870*w*. ^{1}H-NMR (D_2O, 60°): see *Table 11*; additionally, 1.43 (br. *s*, Me$_3$C). ^{13}C-NMR (D_2O): see *Table 9*; additionally, 161.63 (*s*, C=O); 84.11 (*s*, Me$_3$*C*); 30.30 (*q*, *Me*$_3$C). ESI-MS: 633 (46, $[2M+Na]^+$), 328 (40, $[M+Na]^+$), 323 (32, $[M+NH_4]^+$), 279 (52), 213(53), 50 (100). Anal. calc. for $C_{13}H_{23}NO_7 \cdot 0.5\ H_2O$ (314.33): C 49.67, H 7.70, N 4.46; found: C 50.07, H 7.67, N 4.42.

*(1*S*,2′*S*)-Spiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**2a**). Treatment of **18a** (22 mg, 0.072 mmol) with 1N HCl (0.5 ml) for 15 min, addition of MeOH (5 ml) and evaporation, dissolution in H_2O (1 ml), filtration through a small cotton plug, and lyophilisation gave **2a** (17 mg, quant.). Colourless hygroscopic solid. $pK_{HA} = 6.7$ (H_2O). ^{1}H-NMR (D_2O): see *Table 11*. ^{13}C-NMR (D_2O): see *Table 9*. ESI-MS: 433 (28, $[2M-2\ HCl+Na]^+$), 228 (24, $[M-HCl+Na]^+$), 206 (45, $[M-Cl]^+$), 180 (88), 97 (32), 82 (50), 50 (100).

*(1*R*,2′*R*)-Spiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**2b**). Treatment of **18b** (20 mg (0.065 mmol)) with 1N HCl (0.5 ml) for 15 min, addition of MeOH (5 ml), and evaporation, dissolution in H_2O (1 ml), filtration through a small cotton plug, and lyophilisation gave **2b** (14 mg, *ca.* 90%). Pale brown hygroscopic solid. $pK_{HA} = 6.7$ (H_2O). ^{1}H-NMR (D_2O): see *Table 11*. ^{13}C-NMR (D_2O): see *Table 9*. ESI-MS: 433 (40, $[2M-2\ HCl+Na]^+$), 228 (14, $[M-HCl+Na]^+$), 206 (95, $[M-Cl]^+$), 180 (60), 97 (42), 82 (65), 50 (100). Anal. calc. for $C_8H_{16}ClNO_5 \cdot 1.33\ H_2O$ (265.62): C 36.17, H 7.08, N 5.27; found: C 36.31, H 7.44, N 4.93.

*(1*S*,2′*R*)-Spiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**2c**). Treatment of **18c** (22 mg, 0.072 mmol) with 1N HCl (0.5 ml) for 15 min, addition of MeOH (5 ml), evaporation, dissolution in H_2O (1 ml), filtration through a small cotton plug, and lyophilisation gave **2c** (17 mg, quant.). Colourless hygroscopic solid. $pK_{HA} = 7.8$ (H_2O). ^{1}H-NMR (D_2O): see *Table 11*. ^{13}C-NMR (D_2O): see *Table 9*. ESI-MS: 433 (30, $[2M-2\ HCl+Na]^+$), 279 (64), 228 (30, $[M-HCl+Na]^+$), 206 (64, $[M-Cl]^+$), 180 (80), 97 (12), 82 (3), 50 (100). Anal. calc. for $C_8H_{16}ClNO_5 \cdot 1.33\ H_2O$ (265.62): C 36.17, H 7.08, N 5.27; found: C 36.54, H 7.08, N 5.01.

*(1*R*,2′*S*)-Spiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**2d**). Treatment of **18d** (25 mg, 0.082 mmol) with 1N HCl (0.5 ml) for 15 min, addition of MeOH (5 ml), evaporation, dilution with H_2O (1 ml), filtration through a small cotton plug, and lyophilisation gave **2d** (19 mg, quant.). Pale-brown-coloured hygroscopic solid. $pK_{HA} = 7.7$ (H_2O). ^{1}H-NMR (D_2O): see *Table 11*. ^{13}C-NMR (D_2O): see *Table 9*. ESI-MS: 433 (52, $[2M-2\ HCl+Na]^+$), 228 (38, $[M-HCl+Na]^+$), 206 (65, $[M-Cl]^+$), 180 (22), 97 (30), 82 (30), 50 (100). Anal. calc. for $C_8H_{16}ClNO_5 \cdot 2.5\ H_2O$ (286.71): C 33.51, H 7.38, N 4.89; found: C 33.78, H 7.18, N 4.72.

*2-*O*-Acetyl-3,4,6-tri-*O*-benzyl-*D*-mannono-1,5-lactone* (**21**). A soln. of 3,4,6-tri-*O*-benzyl-1,2-*O*-(methoxyethylidene)-*β*-*D*-mannopyranose [76] (2 g, 3.95 mmol) in AcOH/H_2O 3:2 (100 ml) was stirred at 23° for 16 h, evaporated, and co-evaporated with toluene [77][78]. A soln. of the residue (1.94 g of crude **20**) in CH_2Cl_2 (80 ml) was treated with 4-Å molecular sieves (2 g) and pyridinium chlorochromate (PCC; 2.6 g, 12.1 mmol), and stirred at 23° for 14 h. Filtration through a small silica-gel column (hexane/Et_2O 1:1) and evaporation gave **21** (1.53 g 79%). Colourless solid. M.p. 75–76° (Et_2O/hexane). R_f (AcOEt/hexane 1:3) 0.28. $[\alpha]_D^{25} = 54.5$ ($c = 2$, $CHCl_3$). IR ($CHCl_3$): 3067*m*, 3008*m*, 2975*w*, 2927*m*, 2867*m*, 1781*s*, 1752*s*, 1606*w*, 1586*w*, 1496*m*, 1454*s*, 1386*m*, 1370*s*, 1339*m*, 1309*w*, 1091*s*, 1073*s*, 1028*m*, 915*w*, 835*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): 7.39–7.15 (*m*, 15 arom. H); 5.64 (*d*, $J = 2.8$, irrad. at 4.06 → *s*, H–C(2)); 4.70 (*d*, $J = 12.1$, PhC*H*); 4.59 (*d*, $J = 12.5$, PhC*H*); 4.57 (*d*, $J = 12.1$, PhC*H*); 4.51 (*d*, $J = 11.8$, PhC*H*); 4.41 (*td*, $J \approx 4.2$, 7.2, irrad. at 3.67 → *d*, $J = 6.3$, irrad. at 3.90 → *t*, $J = 4.7$, H–C(5)); 4.41 (*d*, $J = 11.5$, PhC*H*); 4.31 (*d*, $J = 12.5$, PhC*H*); 4.06 (*dd*, $J = 1.6$, 2.8, irrad. at 5.64 → *d*, $J = 1.3$, H–C(3)); 3.90 (*dd*, $J \approx 1.4$, 7.0, irrad. at 4.06 → *d*, $J = 6.9$, irrad. at 4.41 → *d*, $J = 1.4$, H–C(4)); 3.68–3.66

(*AB*, 2 H–C(6)); 2.22 (*s*, AcO). ^{13}C-NMR (75 MHz, $CDCl_3$): 169.79 (*s*, C=O); 166.65 (*s*, C(1)); 137.77, 137.29, 136.79 (3*s*); 128.71–127.98 (several *d*); 79.09, 76.05, 75.15 (3*d*, C(3), C(4), C(5)); 73.62, 72.75, 72.04 (3*t*, 3 Ph*C*H$_2$); 69.89 (*d*, C(2)); 68.87 (*t*, C(6)); 20.85 (*q*, Me). HR-MALDI-MS: 513.1884 ([*M* + Na]$^+$, $C_{29}H_{30}NaO_7^+$; calc. 513.1889). Anal. calc. for $C_{29}H_{30}O_7$ (490.54): C 71.01, H 6.16; found: C 70.92, H 6.31.

Treatment of **21** *with Dimethyltitanocene* (= *Dimethylbis(*η^5*-cyclopenta-2,4-dien-1-yl)titanium*). A soln. of **21** (5.185 g, 10.57 mmol) and dimethyltitanocene (4.40 g, 21.14 mmol) [63][64] in toluene (70 ml) was heated at 60° for 36 h. Evaporation and FC gave **22** (3.9 g, 75%) and **23** (165 mg, 3%).

3-O-*Acetyl-2,5-anhydro-4,5,7-tri*-O-*benzyl-1-deoxy*-D-manno-*hept-1-enitol* (**22**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.53. $[\alpha]_D^{25} = 9.4$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3088*w*, 3066*m*, 3006*m*, 2907*m*, 2870*m*, 1736*s*, 1662*m*, 1606*w*, 1586*w*, 1496*m*, 1454*s*, 1370*s*, 1275*s*, 1104*s*, 1087*s*, 1038*s*, 1028*s*, 967*m*, 912*w*, 883*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 7.40–7.18 (*m*, 15 arom. H); 5.82 (*d*, $J = 3.4$, H–C(3)); 4.89 (*d*, $J = 10.9$, PhC*H*); 4.79 (br. *s*, H–C(1)); 4.76 (*d*, $J = 11.5$, PhC*H*); 4.71 (*d*, $J = 12.1$, PhC*H*); 4.63 (*d*, $J = 0.9$, H′–C(1)); 4.57 (*d*, $J = 11.5$, PhC*H*); 4.56 (*d*, $J = 12.1$, PhC*H*); 4.54 (*d*, $J = 10.9$, PhC*H*); 4.05 (*t*, $J = 9.3$, H–C(5)); 3.83 (*dd*, $J \approx 4.0, 11.2$, H–C(7)); 3.78 (*dd*, $J \approx 2.2, 11.2$, H′–C(7)); 3.75 (*dd*, $J = 3.4, 9.0$, H–C(4)); 3.64 (*ddd*, $J = 2.2, 4.0, 9.3$, H–C(6)); 2.14 (*s*, AcO). ^{13}C-NMR (75 MHz, $CDCl_3$): 170.31 (*s*, C=O); 154.39 (*s*, C(2)); 138.26 (2*s*); 137.78 (*s*); 128.60–127.77 (several *d*); 100.29 (*t*, C(1)); 80.47, 80.13 (2*d*, C(4), C(6)); 75.20 (*t*, Ph*C*H$_2$); 73.75 (*d*, C(5)); 73.64, 71.85 (2*t*, 2 Ph*C*H$_2$); 69.03 (*t*, C(7)); 68.79 (*d*, C(3)); 21.37 (*q*, Me). HR-MALDI-MS: 511.2097 ([*M* + Na]$^+$, $C_{30}H_{32}NaO_6^+$; calc. 511.2097). Anal. calc. for $C_{30}H_{32}O_6$ (488.57): C 73.75, H 6.60; found: C 73.74, H 6.84.

2,5-Anhydro-4,5,7-tri-O-*benzyl-1-deoxy-3*-O-*(1-methylethenyl)*-D-manno-*hept-1-enitol* (**23**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.67. IR ($CHCl_3$): 3088*w*, 3066*w*, 3006*m*, 2923*m*, 2868*m*, 1659*s*, 1607*w*, 1586*w*, 1496*m*, 1454*s*, 1377*m*, 1369*m*, 1269*s*, 1146*m*, 1085*s*, 1028*s*, 986*m*, 910*w*, 877*m*. ^{1}H-NMR (C_6D_6): 7.40–7.18 (*m*, 15 arom. H); 4.83 (*d*, $J \approx 12.7$, PhC*H*); 4.82 (br. *d*, $J \approx 3.8$, H–C(3)); 4.79 (*d*, $J = 12.1$, PhC*H*); 4.58 (*d*, $J = 11.8$, PhC*H*); 4.51 (*d*, $J = 11.8$, PhC*H*); 4.49, 4.42 (2*s*, 2 H–C(1)); 4.42 (*d*, $J = 11.8$, PhC*H*); 4.39 (*d*, $J = 12.5$, PhC*H*); 4.33 (*t*, $J \approx 7.6$, H–C(5)); 4.05 (br. *d*, $J \approx 1.8$, irrad. at 1.81 → *d*, $J = 2.2$, H–C(2′)); 4.02–4.01 (br. *d*, irrad. at 1.81 → *d*, $J = 2.2$, H′–C(2′)); 3.85 (*ddd*, $J \approx 2.8$, 4.4, 7.5, H–C(6)); 3.82 (br. *dd*, $J \approx 4.6$, 10.4, H–C(7)); 3.76 (br. *dd*, $J \approx 3.4$, 7.8, H–C(4)); 3.74 (*dd*, $J = 2.8$, 10.6, H′–C(7)); 1.81 (br. *s*, Me). ^{13}C-NMR (C_6D_6): 159.05 (*s*, C(1′)); 155.70 (*s*, C(2)); 139.46 (2*s*); 139.25 (*s*); 128.88–127.87 (several *d*); 98.28 (*t*, C(1)); 84.24 (*t*, C(2′)); 80.89, 80.58 (2*d*, C(4), C(6)); 75.08 (*d*, C(5)); 74.46, 73.70 (2*t*, 2 Ph*C*H$_2$); 73.12 (*d*, C(3)); 72.20 (*t*, Ph*C*H$_2$); 69.88 (*t*, C(7)); 21.51 (*q*, Me). HR-MALDI-MS: 509.2291 ([*M* + Na]$^+$, $C_{31}H_{34}NaO_5^+$; calc. 509.2304).

Cyclopropanation of **22**. At 60°, a soln. of **22** (1.05 g, 2.1 mmol) in dry toluene (10 ml) was treated with Cu powder (30 mg, 0.47 mmol) and a soln. of ethyl diazoacetate (0.870 g, 7.6 mmol) in dry toluene (15 ml) over a period of 8 h (using a syringe pump) and stirred for an additional 30 min at 60°. Evaporation and FC (AcOEt/hexane 1:50 → 1:10) gave **22** (65 mg, 6%) and a *ca.* 18:42:17:23 mixture of **24a**–**24d** (1.11 g, 91%). Prep. HPLC (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) afforded pure samples of **24a**–**24d**.

*Ethyl (1*S*,2′*S*)-2*-O-*Acetyl-3,4,6-tri*-O-*benzylspiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]-2′-carboxylate* (**24a**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.35. Prep. HPLC: t_R (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) 25.4 min. IR ($CHCl_3$): 3007*m*, 2871*m*, 1740*s*, 1602*w*, 1501*w*, 1453*m*, 1374*m*, 1327*m*, 1176*s*, 1091*s*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.38–7.14 (*m*, 15 arom. H); 5.54 (irrad. at 3.83 → br. *s*, irrad. at 1.37 → NOE of 5.5%); 4.89 (*d*, $J = 10.9$, PhC*H*); 4.84 (*d*, $J = 10.9$, irrad. at 5.54 → NOE of 4.3%, PhC*H*); 4.66 (*d*, $J = 12.2$, PhC*H*); 4.50 (*d*, $J = 10.9$, PhC*H*); 4.49 (*d*, $J = 12.4$, PhC*H*); 4.48 (*d*, $J \approx 10.2$, PhC*H*); 4.19, 4.08 (2*qd*, $J = 7.2$, 10.9, MeC*H*$_2$O); 3.91 (irrad. at 3.54 → *d*, $J = 9.3$, irrad. at 3.54 → NOE of 2.6%); 3.83 (irrad. at 5.54 → *d*, $J = 9.3$, irrad. at 1.37 → NOE of 1.5%, irrad. at 3.54 → NOE of 4%, irrad. at 5.54 → NOE of 6.4%); 3.74 (irrad. at 3.54 → *d*, $J \approx 11.0$, irrad. at 3.54 → NOE of 4.4%); 3.66 (irrad. at 3.54 → *d*, $J = 10.9$, irrad. at 3.54 → NOE of 3.4%); 3.54 (irrad. at 1.27 → NOE of 1.0%); 2.23 (irrad. at 3.54 → NOE of 0.4%); 2.13 (*s*, AcO); 1.37 (irrad. at 1.27 → NOE of 5.0%, irrad. at 5.54 → NOE of 5.1%); 1.27 (irrad. at 1.37 → NOE of 20%, irrad. at 2.23 → NOE of 6.9%, irrad. at 3.54 → NOE of 3.6%); 1.25 (*t*, $J = 7.2$, *Me*CH$_2$O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 169.99, 169.90 (2*s*, 2 C=O); 138.53, 138.32, 138.01 (3*s*); 127.91–28.64 (several *d*); 75.36, 73.65, 71.99 (3*t*, 3 Ph*C*H$_2$); 61.35 (*t*, Me*C*H$_2$O); 20.99 (*q*, *Me*C=O); 14.14 (*q*, *Me*-CH$_2$O). FAB-MS: 597 (18, [*M* + Na]$^+$), 576 (29), 575 (83), 574 (37, M^+), 573 (58), 532 (17), 467 (43), 407 (100), 317 (25). HR-MALDI-MS: 597.2465 ([*M* + Na]$^+$, $C_{34}H_{38}NaO_8^+$; calc. 597.2464).

*Ethyl (1*R*,2′*R*)-2*-O-*Acetyl-3,4,6-tri*-O-*benzylspiro[1,5-anhydro*-D-*mannitol-1,1′-cyclopropane]-2′-carboxylate* (**24b**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.35. Prep. HPLC: t_R (hexane/Et_2O/AcOEt 8:1:1, 10 ml/min) 22.6 min. $[\alpha]_D^{25} = -7.5$ ($c = 1.0$, $CHCl_3$). IR ($CHCl_3$): 3007*m*, 2871*m*, 1735*s*, 1602*w*, 1496*w*, 1452*m*, 1373*m*, 1327*m*, 1177*s*, 1095*s*, 1045*m*, 968*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.37–7.14 (*m*, 15 arom. H); 5.86 (irrad. at 3.59 → br. *s*, irrad. at 1.59 → NOE of 7.6%, irrad. at 3.59 → NOE of 9.3%); 4.90 (*d*, $J = 10.6$, PhC*H*); 4.70 (*d*, $J = 11.5$, irrad. at 5.86 → NOE of 3.9%, PhC*H*); 4.65 (*d*, $J = 12.1$, PhC*H*); 4.49 (*d*, $J = 11.8$,

2 PhC*H*); 4.43 (*d*, *J* = 11.2, irrad. at 3.59 → NOE of 11.0%, irrad. at 5.86 → NOE of 2.9%, PhC*H*); 4.14, 4.03 (2*qd*, *J* = 7.2, 10.9, MeC*H*$_2$O); 3.76 (irrad. at 3.56 → *d*, *J* ≈ 11.0, irrad. at 3.56 → NOE of 3.4%,); 3.66 (irrad. at 3.56 → *d*, *J* ≈ 11.0, irrad. at 3.56 → NOE of 4.4%); 3.59 (irrad. at 5.86 → *d*, *J* ≈ 9.3, irrad. at 5.86 → NOE of 6.5%); 3.56 (irrad. at 1.92 → NOE of 6.5%); 2.21 (*s*, AcO); 1.92 (irrad. at 1.24 → NOE of 11.6%, irrad. at 3.56 → NOE of 6.2%); 1.62–1.56 (irrad. at 1.92 → NOE of 1.8%, irrad. at 5.86 → NOE of 2%); 1.24 (*t*, *J* = 7.2, Me). ^{13}C-NMR (75 MHz, $CDCl_3$, assignments based on a HSQC-GRASP spectrum): see *Table 9*; additionally, 170.89 (*s*, 2 C=O); 138.39, 138.34, 137.93 (3*s*); 128.63–127.95 (several *d*); 75.60, 73.66, 71.25 (3*t*, 3 PhCH_2); 61.23 (*t*, MeCH_2O); 21.27 (*q*, *Me*C=O); 14.25 (*q*, *Me*CH_2O). FAB-MS: 575 (36, $[M+H]^+$), 574 (21, M^+), 573 (39), 515 (23), 467 (58), 407 (100), 317 (27). HR-MALDI-MS: 597.2465 ($[M+Na]^+$, $C_{34}H_{38}NaO_8^+$; calc. 597.2464). Anal. calc. for $C_{34}H_{38}O_8$ (574.67): C 71.06, H 6.66; found: C 70.95, H 6.62.

*Ethyl (1S,2′*R*)-2-*O*-Acetyl-3,4,6-tri-*O*-benzylspiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-carboxylate* (**24c**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.28. Prep. HPLC: t_R (hexane/Et$_2$O/AcOEt 8:1:1, 10 ml/min) 31.2 min. IR ($CHCl_3$): 3007*m*, 2871*m*, 1733*s*, 1602*w*, 1556*w*, 1496*w*, 1451*m*, 1378*m*, 1248*s*, 1096*s*, 916*w*, 603*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.38–7.14 (*m*, 15 arom. H); 4.89 (*d*, *J* ≈ 10, PhC*H*); 4.88 (irrad. at 3.84 → br. *s*, irrad. at 1.03 → NOE of 5.9%, irrad. at 2.06 → NOE of 6.3%); 4.69 (*d*, *J* = 10.9, PhC*H*); 4.64 (*d*, *J* = 12.1, PhC*H*); 4.57 (*d*, *J* = 10.9, PhC*H*); 4.51 (*d*, *J* = 11.2, PhC*H*); 4.50 (*d*, *J* = 12.1, PhC*H*); 4.19, 4.10 (2*qd*, *J* = 7.2, 10.9, MeC*H*$_2$O); 4.00 (irrad. at 3.57 → *d*, *J* = 9.3, irrad. at 3.57 → NOE of 2.1%); 3.84 (irrad. at 4.88 → *d*, *J* = 9.0, irrad. at 1.03 → NOE of 2.1%, irrad. at 3.57 → NOE of 11.4%, irrad. at 4.88 → NOE of 6.4%); 3.79 (irrad. at 3.57 → br. *d*, *J* ≈ 11.0, irrad. at 3.57 → NOE of 11.4%); 3.71 (irrad. at 3.57 → br. *d*, *J* ≈ 10.9, irrad. at 3.57 → NOE of 11.4%); 3.57 (irrad. at 1.61 → NOE of 4.2%); 2.21 (*s*, AcO); 2.06 (irrad. at 1.03 → NOE of 6.8%, irrad. at 4.88 → NOE of 6.8%); 1.61 (irrad. at 1.03 → NOE of 33%, irrad. at 3.57 → NOE of 3.7%); 1.23 (*t*, *J* = 7.2, *Me*CH$_2$O); 1.03 (irrad. at 1.61 → NOE of 17%, irrad. at 4.88 → NOE of 3.5%). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 171.45, 168.26 (2*s*, 2 C=O); 138.69, 138.61, 137.85 (3*s*); 128.74–127.79 (several *d*); 75.39, 73.66, 71.97 (3*t*, 3 PhCH_2); 61.09 (*t*, MeCH_2O); 21.29 (*q*, *Me*C=O); 14.23 (*q*, *Me*CH_2O). FAB-MS: 597 (26, $[M+Na]^+$), 575 (19, $[M+H]^+$), 574 (12, M^+), 573 (26), 467 (18), 407 (53), 317 (15), 253 (19), 237 (25), 181 (100). HR-MALDI-MS: 597.2455 ($[M+Na]^+$, $C_{34}H_{38}NaO_8^+$; calc. 597.2464). Anal. calc. for $C_{34}H_{38}O_8$ (574.67): C 71.06, H 6.66; found: C 71.12, H 6.88.

*Ethyl (1*R*,2′*S*)-2-*O*-Acetyl-3,4,6-tri-*O*-benzylspiro[1,5-anhydro-*D*-mannitol-1,1′-cyclopropane]-2′-carboxylate* (**24d**). Colourless oil. R_f (AcOEt/hexane 1:3) 0.28. Prep. HPLC: t_R (hexane/Et$_2$O/AcOEt 8:1:1, 10 ml/min) 27.2 min. IR ($CHCl_3$): 3088*w*, 3006*m*, 2981*m*, 2907*w*, 2872*w*, 1732*s*, 1602*w*, 1501*w*, 1496*w*, 1454*m*, 1403*w*, 1372*m*, 1310*m*, 1095*s*, 1027*m*, 965*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 8*; additionally, 7.38–7.14 (*m*, 15 arom. H); 4.87 (*d*, *J* ≈ 10.6, PhC*H*); 4.70 (*d*, *J* = 12.1, PhC*H*); 4.69 (*d*, *J* = 10.9, PhC*H*); 4.55 (*d*, *J* = 10.9, PhC*H*); 4.47 (*d*, *J* = 12.1, 2 PhC*H*); 4.15, 4.07 (2*qd*, *J* = 7.2, 10.9, MeC*H*$_2$O); 2.20 (*s*, AcO); 1.23 (*t*, *J* = 7.2, *Me*CH$_2$O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 9*; additionally, 171.33, 168.91 (2*s*, 2 C=O); 138.46 (2*s*); 137.94 (*s*); 128.72–127.83 (several *d*); 75.52, 73.69, 72.12 (3*t*, 3 PhCH_2); 61.13 (*t*, MeCH_2O); 21.19 (*q*, *Me*C=O); 14.18 (*q*, *Me*CH_2O). FAB-MS: 597 (23, $[M+Na]^+$), 575 (12, $[M+H]^+$), 574 (12, M^+), 573 (25), 532 (17), 467 (25), 407 (60), 372 (22), 317 (26), 253 (28), 237 (38), 181 (100). HR-MALDI-MS: 597.2469 ($[M+Na]^+$, $C_{34}H_{38}NaO_8^+$; calc. 597.2464).

Cyclopropanation of **25**. A soln. of **25** (3.90 g, 7.27 mmol) [58] in abs. toluene (10 ml) was treated with Cu powder (580 mg, 9.13 mmol), heated to 100°, and treated dropwise (1 eq/h) with a soln. of ethyl diazoacetate (2.37 g, 20.7 mmol) in dry toluene (20 ml). Filtration over *Celite*, washing with toluene, and evaporation of the combined filtrate, and washings yielded crude **26a**–**26d** (6.17 g). FC (hexane/Et$_2$O 3:1 → 3:2) gave a 29:17:21:33 mixture **26a**–**26d** (3.24 g, 71%), which was used for the next steps without further purification. Isomerically pure samples of **26a**–**26d** were obtained by prep. HPLC (hexane/Et$_2$O 3:1).

*Ethyl (1*S*,2′*S*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-carboxylate* (**26a**). Colourless oil. R_f (hexane/Et$_2$O 3:2) 0.22. Prep. HPLC: t_R (hexane/Et$_2$O 3:1, 10 ml/min) 17 min. $[\alpha]_D^{25} = +28.9$ (*c* = 2.00, $CHCl_3$). IR ($CHCl_3$): 3089*w*, 3067*m*, 3031*m*, 3014*m*, 2938*m*, 2907*m*, 2970*m*, 1951*w*, 1877*w*, 1812*w*, 1714*s*, 1604*w*, 1497*m*, 1455*m*, 1402*m*, 1377*m*, 1354*m*, 1278*m*, 1177*s* (br.), 1092*s*, 1028*m*, 915*m*, 891*w*, 873*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.39–7.20 (*m*, 20 arom. H); 4.66 (*d*, *J* = 11.8, PhC*H*); 4.64 (*d*, *J* = 11.8, PhC*H*); 4.60 (*d*, *J* = 11.8, PhC*H*); 4.54 (*d*, *J* = 11.8, PhC*H*); 4.53 (*d*, *J* = 11.8, PhC*H*); 4.50 (*d*, *J* = 11.2, PhC*H*); 4.49 (*d*, *J* = 11.8, PhC*H*); 4.46 (*d*, *J* = 11.2, PhC*H*); 3.92, 3.57 (2*qd*, *J* = 7.2, 10.9, MeC*H*$_2$O); 1.04 (*t*, *J* = 7.2, *Me*CH$_2$O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 171.06 (*s*, C=O); 138.28 (*s*, 2 C); 138.18 (*s*, 2 C); 128.40–127.41 (several *d*); 73.38, 73.04, 72.89, 72.00 (4*t*, 4 PhCH_2); 60.68 (*t*, MeCH_2O); 14.32 (*q*, *Me*CH$_2$O). HR-MALDI-MS: 645.2829 ($[M+Na]^+$, $C_{39}H_{42}NaO_7$; calc. 645.2828).

*Ethyl (1*R*,2′*R*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-carboxylate* (**26b**). Colourless oil. R_f (hexane/Et$_2$O 3:2) 0.28. Prep. HPLC: t_R (hexane/Et$_2$O 4:1, 10 ml/min) 14 min.

Table 12. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the* galacto-*Cyclopropyl Esters* **26a**–**26d** *and the* O-*Benzylated Boc-Carbamates* **28a**–**28d** *in* $CDCl_3$

Compound	**26a**	**26b**	**26c**	**26d**	**28a**	**28b**	**28c**	**28d**
H–C(2′)	2.15	1.79	2.04	2.18	2.99	2.94	3.08	3.21–3.12
H_{cis}–C(3′)	1.30	1.46	1.35	1.70	0.84	0.95	0.42	0.66
H_{trans}–C(3′)	1.30	1.24	1.27	1.31	1.00	1.21	1.24	1.15
H–C(2)	4.00	4.23	4.33	4.37	4.09–4.05	4.49	4.23	4.29
H–C(3)	3.75	3.91	3.63	3.75	3.77	3.86	3.63	3.84
H–C(4)	4.14	4.08	4.09	4.14	4.07	4.12	4.05	3.98
H–C(5)	4.25	3.97–3.94	3.68	3.48–3.44	3.79–3.72	3.96	3.68	3.70
H_a–C(6)	4.44	3.73	3.60	3.65–3.57	3.67	3.50	3.55	3.55
H_b–C(6)	3.70	3.53	3.52	3.52–3.48	3.54	3.46	3.55	3.38
$J(2',3'_{cis})$	8.4	7.6	6.5	6.9	5.9	6.5	7.5	5.3
$J(2',3'_{trans})$	8.7	10.0	9.0	9.0	8.7	9.7	5.3	8.7
$J(3'_{cis},3'_{trans})$	[a])	6.2	5.3	5.9	6.9	6.9	≤ 1.5	7.0
$J(2,3)$	4.7	8.1	9.7	9.6	7.5	10.0	9.3	9.6
$J(3,4)$	2.8	3.1	2.8	2.8	2.5	2.2	2.6	1.8
$J(4,5)$	5.3	2.5	≤ 1.5	≤ 1.5	2.5	≤ 1.5	≤ 1.5	≤ 1.5
$J(5,6_a)$	10.0	6.9	7.2	[a])	6.5	5.9	5.9	6.7
$J(5,6_b)$	3.1	5.6	5.3	[a])	5.9	6.2	6.5	5.8
$J(6_a,6_b)$	10.9	10.0	9.3	[a])	9.3	10.3	[a])	9.5

[a]) Not assigned.

Table 13. *Selected ^{13}C-NMR Chemical Shifts* [ppm] *of the* galacto-*Spirocyclopropanes* **26a**–**26d** *and* **28a**–**28d** *in* $CDCl_3$, *and* **29a**–**29d** *and* **3a**–**3d** *in* D_2O

	C(2′)	C(3′)	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)
26a	27.55	15.20	60.85	73.48	75.99	74.01	75.73	66.46
26b	24.76	16.31	64.38	74.66	80.32	76.06	76.95	68.18
26c	23.61	13.01	66.19	74.91	84.49	74.91	77.53	68.45
26d	21.31	15.82	67.26	74.54	84.24	74.84	77.04	62.21
28a	34.61	14.60	60.68	74.21	82.56	74.65	75.16	67.76
28b	34.03	15.60	62.12	75.33	83.78	76.28	76.74	68.64
28c	29.94	14.63	61.29	74.31	83.95	74.92	77.29	68.74
28d	29.11	14.76	61.24	74.81	84.43	75.21	76.96	69.74
29a	35.48	14.74	65.34	68.65	76.88	71.88	79.52	63.76
29b	36.08	15.99	65.28	69.97	75.38	72.62	81.35	63.84
29c	31.45	14.98	64.65	69.00	75.89	72.54	81.38	64.15
29d	30.57	14.49	64.23	69.37	75.94	72.20	80.75	63.68
3a	34.02	13.58	62.70	68.26	76.57	71.79	80.32	63.70
3b	34.11	15.44	62.80	70.02	76.03	72.04	81.60	63.72
3c	30.35	13.23	63.45	68.20	75.72	75.51	82.15	64.47
3d	29.22	14.30	63.76	68.46	75.33	71.69	81.70	63.93

$[\alpha]_D^{25} = +24.4$ ($c = 1.50$, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3067*w*, 3030*m*, 3014*m*, 2908*m*, 2872*m*, 1951*w*, 1880*w*, 1813*w*, 1718*s*, 1603*w*, 1497*m*, 1454*m*, 1399*m*, 1376*m*, 1350*m*, 1316*m*, 1269*m*, 1163*m*, 1100*s*, 1068*s*, 1028*m*, 912*w*, 865w. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.36–7.21 (*m*, 20 arom. H); 4.83 (*d*, $J = 11.8$, PhC*H*); 4.69 (*d*, $J = 11.8$, PhC*H*); 4.64 (*d*, $J = 11.8$, PhC*H*); 4.61 (*d*, $J = 11.2$, PhC*H*); 4.57 (*d*, $J = 11.8$, PhC*H*); 4.57 (*d*, $J = 11.2$, PhC*H*); 4.46 (*d*, $J = 12.1$, PhC*H*); 4.42 (*d*, $J = 12.1$, PhC*H*); 3.98, 3.83 (2*qd*, $J = 7.2$, 10.9, MeCH_2O);

1.08 (t, J = 7.2, *Me*CH_2O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 170.00 (s, C=O); 138.52, 138.47, 138.12, 137.96 (4s); 128.43 – 127.44 (several d); 75.01, 73.97, 73.52, 72.99 (4t, 4 Ph*C*H_2); 60.78 (t, Me*C*H_2O); 14.33 (q, *Me*CH_2O). HR-MALDI-MS: 645.2830 ($[M+Na]^+$, $C_{39}H_{42}NaO_7^+$; calc. 645.2828).

*Ethyl (1S,2′*R*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-carboxylate* (**26c**). Colourless oil. R_f (hexane/Et_2O 3:2) 0.22. Prep. HPLC: t_R (hexane/Et_2O 4:1, 10 ml/min) 16 min. $[\alpha]_D^{25} = -5.9$ (c = 1.50, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3067*w*, 3032*m*, 3013*m*, 2910*m*, 2873*m*, 1951*w*, 1879*w*, 1811*w*, 1729*s*, 1603*w*, 1497*m*, 1454*m*, 1399*m*, 1380*m*, 1360*m*, 1302*m*, 1278*s*, 1156*s*, 1102*s*, 1065*m*, 1027*m*, 946*w*, 914*m*, 857*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.37 – 7.23 (*m*, 20 arom. H); 4.98 (*d*, *J* = 11.5, PhC*H*); 4.95 (*d*, *J* = 11.2, PhC*H*); 4.75 (*d*, *J* = 11.5, PhC*H*); 4.69 (*d*, *J* = 11.5, PhC*H*); 4.66 (*d*, *J* = 11.2, PhC*H*); 4.64 (*d*, *J* = 11.5, PhC*H*); 4.49 (*d*, *J* = 11.5, PhC*H*); 4.40 (*d*, *J* = 11.5, PhC*H*); 4.16, 4.04 (2*qd*, *J* = 7.2, 10.9, Me*CH*$_2$O); 1.23 (t, J = 7.2, *Me*CH_2O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 169.27 (s, C=O); 138.56, 138.30, 138.23, 138.05 (4s); 128.44 – 127.52 (several d); 75.42, 75.12, 73.58, 72.76 (4t, 4 Ph*C*H_2); 60.76 (t, Me*C*H_2O); 14.48 (q, *Me*CH_2O). HR-MALDI-MS: 645.2831 ($[M+Na]^+$, $C_{39}H_{42}NaO_7^+$; calc. 645.2828).

*Ethyl (1*R*,2′*S*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-carboxylate* (**26d**). Colourless oil. R_f (hexane/Et_2O 3:2) 0.28. Prep. HPLC: t_R (hexane/Et_2O 4:1, 10 ml/min) 12 min. $[\alpha]_D^{25} = +102.9$ (c = 2.00, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3067*m*, 3031*m*, 3014*m*, 2909*m*, 2875*m*, 1951*w*, 1880*w*, 1812*w*, 1724*s*, 1604*w*, 1497*m*, 1454*m*, 1381*m*, 1361*m*, 1284*s*, 1264*m*, 1159*s*, 1102*s*, 1068*m*, 1028*m*, 912*w*, 865*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.41 – 7.23 (*m*, 20 arom. H); 5.02 (*d*, *J* = 11.5, PhC*H*); 4.93 (*d*, *J* = 11.2, PhC*H*); 4.80 (*d*, *J* = 11.8, PhC*H*); 4.75 (*d*, *J* = 11.8, PhC*H*); 4.67 (*d*, *J* = 11.5, PhC*H*); 4.61 (*d*, *J* = 11.2, PhC*H*); 4.47 (*d*, *J* = 11.7, PhC*H*); 4.40 (*d*, *J* = 11.7, PhC*H*); 4.16, 4.12 (2*qd*, *J* = 7.2, 10.9, Me*CH*$_2$O); 1.25 (t, J = 7.2, *Me*CH_2O). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 170.33 (s, C=O); 138.61, 138.37, 138.10, 137.85 (4s); 128.40 – 127.39 (several d); 75.48, 74.95, 73.51, 72.73 (4t, 4 Ph*C*H_2); 60.73 (t, Me*C*H_2O); 14.45 (q, *Me*CH_2O). HR-MALDI-MS: 645.2830 ($[M+Na]^+$, $C_{39}H_{42}NaO_7^+$; calc. 645.2828).

Hydrolysis of **26a** – **26d** *and* Curtius *Degradation of* **27a** – **27d**. As described above, a *ca.* 1:1:1:1 mixture of **26a** – **26d** (812 mg, 1.30 mmol) was dissolved in a soln. of KOH (660 mg, 11.8 mmol) in EtOH/H_2O 1:4 (30 ml) and stirred at 80° for 3.5 h. Usual workup gave a mixture of crude **27a** – **27d** (726 mg, 94%), as a colourless foam (R_f (hexane/Et_2O 1:20) 0.34, 0.38, 0.45, 0.51). This material was used for the next step without further purification. A soln. of this foam (726 mg, 1.22 mmol) in dry acetone (20 ml) at 0° was treated with Et_3N (0.25 ml, 1.80 mmol), $ClCO_2Et$ (0.17 ml, 1.73 mmol), and NaN_3 (127 mg, 1.95 mmol) in H_2O (6.5 ml), and stirred for 15 min at 0° and 1 h at 23°. Usual workup gave a mixture of the crude carbonyl azides (752 mg, 93%; R_f (hexane/AcOEt 1:1) 0.73) as a slightly yellow oil, which was sufficiently clean for the following reaction. It was dissolved in dry toluene (30 ml) and kept at 100° until TLC showed complete consumption of the azide (*ca.* 2 h). After the addition of dry *t*-BuOH (30 ml), heating was continued for another 24 h at 90°. Evaporation and FC (hexane/AcOEt 4:1 → 3:1) gave **28a**/**28c** 1:1 (326 mg, 40%) and **28b**/**28d** 3:2 (266 mg, 33%). Prep. HPLC (hexane/AcOEt 4:1) yielded isomerically pure samples of **28a** – **28d**.

tert-*Butyl [(1S,2′*S*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-galactitol-1,1′ -cyclopropane]-2′-yl]carbamate* (**28a**). Colourless oil. R_f (hexane/AcOEt 2:1) 0.33. Prep. HPLC: t_R (hexane/AcOEt 4:1, 10 ml/min) 16 min. $[\alpha]_D^{25} = +30.5$ (c = 1.50, $CHCl_3$). IR ($CHCl_3$): 3449*m*, 3090*w*, 3068*w*, 3015*m*, 2981*m*, 2930*m*, 2872*m*, 1951*w*, 1879*w*, 1812*w*, 1712*s*, 1603*w*, 1497*m*, 1455*m*, 1393*m*, 1367*m*, 1321*w*, 1244*m*, 1163*s*, 1091*s*, 1029*m*, 911*w*, 845*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.34 – 7.23 (*m*, 20 arom. H); 4.86 (*d*, *J* = 10.3, NH); 4.83 (*d*, *J* = 11.2, PhC*H*); 4.83 (*d*, *J* = 10.9, PhC*H*); 4.79 (*d*, *J* = 11.5, PhC*H*); 4.62 (*d*, *J* = 10.9, PhC*H*); 4.59 (*d*, *J* = 11.5, PhC*H*); 4.54 (*d*, *J* = 11.2, PhC*H*); 4.42 (*s*, PhCH_2); 1.38 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 155.58 (s, C=O); 138.36, 137.90, 137.81, 137.68 (4s); 128.51 – 127.62 (several d); 79.17 (*s*, Me_3C); 74.06, 73.96, 73.48, 72.95 (4t, 4 Ph*C*H_2); 28.54 (q, *Me*$_3$C). HR-MALDI-MS: 632.2626 ($[M-C_4H_8+Na]^+$, $C_{37}H_{39}NNaO_7^+$; calc. 632.2624), 688.3250 ($[M+Na]^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250).

tert-*Butyl [(1*R*,2′*R*)-2,3,4,6-Tetra-*O*-benzylspiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-yl]carbamate* (**28b**). Colourless oil. R_f (hexane/AcOEt 2:1) 0.37. Prep. HPLC: t_R (hexane/AcOEt 4:1, 10 ml/min) 12 min; t_R (hexane/Et_2O 3:2, 10 ml/min) 10 min. $[\alpha]_D^{25} = +85.3$ (c = 0.50, $CHCl_3$). IR ($CHCl_3$): 3423*w*, 3090*w*, 3067*w*, 3031*m*, 3016*m*, 2915*w*, 2864*w*, 1951*w*, 1880*w*, 1812*w*, 1704*s*, 1603*w*, 1498*s*, 1455*m*, 1393*w*, 1367*m*, 1270*w*, 1164*s*, 1102*s*, 1065*m*, 1012*m*, 931*w*, 911*w*, 822*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.37 – 7.23 (*m*, 20 arom. H); 5.08 (*d*, *J* = 7.2, NH); 4.98 (*d*, *J* = 11.5, PhC*H*); 4.96 (*d*, *J* = 11.5, PhC*H*); 4.75 (*d*, *J* = 11.5, PhC*H*); 4.67 (*d*, *J* = 11.5, PhC*H*); 4.66 (*d*, *J* = 11.5, PhC*H*); 4.62 (*d*, *J* = 11.5, PhC*H*); 4.45 (*d*, *J* = 11.5, PhC*H*); 4.39 (*d*, *J* = 11.5, PhC*H*); 1.43 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 156.47 (s, C=O); 138.68 (s); 138.36 (*s*, 2 C); 137.97 (s); 128.41 – 127.21 (several d); 79.22 (*s*, Me_3C); 75.59, 74.99, 73.58, 72.81 (4t, 4 Ph*C*H_2); 28.70 (q, *Me*$_3$C). HR-MALDI-MS: 632.2620 ($[M-C_4H_8+Na]^+$, $C_{37}H_{39}NNaO_7^+$; calc. 632.2624), 688.3240 ($[M+Na]^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250).

tert-*Butyl [(1S,2′R)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*galactitol-1,1′-cyclopropane]-2′-yl]carbamate* (**28c**). Colourless oil. R_f (hexane/AcOEt 2:1) 0.33. Prep. HPLC: t_R (hexane/AcOEt 4:1, 10 ml/min) 21 min. $[\alpha]_D^{25} = -4.1$ ($c = 1.00$, $CHCl_3$). IR ($CHCl_3$): 3445*m*, 3090*w*, 3067*w*, 3016*m*, 2982*m*, 2913*m*, 2872*m*, 1950*w*, 1879*w*, 1811*w*, 1708*s*, 1603*w*, 1497*m*, 1455*m*, 1393*m*, 1367*m*, 1304*w*, 1258*m*, 1162*m*, 1102*s*, 1065*m*, 1028*m*, 944*w*, 911*w*, 855*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.38–7.22 (*m*, 20 arom. H); 4.98 (*d*, $J =$ 11.2, PhC*H*); 4.95 (*d*, $J = 5.0$, NH); 4.85 (*d*, $J = 10.9$, PhC*H*); 4.73 (*d*, $J = 11.7$, PhC*H*); 4.69 (*d*, $J = 11.7$, PhC*H*); 4.62 (*d*, $J = 11.2$, 2 PhC*H*); 4.43 (*s*, PhCH_2); 1.44 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 156.43 (*s*, C=O); 138.49, 138.34, 138.10, 137.89 (4*s*); 128.49–127.52 (several *d*); 79.47 (*s*, Me_3C); 75.27, 74.98, 73.56, 72.91 (4*t*, 4 PhCH_2); 28.65 (*q*, Me_3C). HR-MALDI-MS: 632.2668 ([$M - C_4H_8 + Na$]$^+$, $C_{37}H_{39}NNaO_7^+$; calc. 632.2624), 688.3304 ([$M + Na$]$^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250).

tert-*Butyl [(1R,2′S)-2,3,4,6-Tetra*-O-*benzylspiro[1,5-anhydro*-D-*galactitol-1,1′-cyclopropane]-2′-yl]carbamate* (**28d**). Colourless oil. R_f (hexane/AcOEt 2:1) 0.37. Prep. HPLC: t_R (hexane/AcOEt 4:1, 10 ml/min) 12 min. $[\alpha]_D^{25} = +36.7$ ($c = 2.00$, $CHCl_3$). IR ($CHCl_3$): 3452*m*, 3090*w*, 3067*w*, 3028*m*, 3014*m*, 2983*m*, 2910*m*, 2870*m*, 1951*w*, 1878*w*, 1811*w*, 1705*s*, 1603*w*, 1497*s*, 1455*m*, 1393*m*, 1367*m*, 1275*m*, 1256*m*, 1162*s*, 1104*s*, 1064*m*, 1028*m*, 911*w*, 847*w*, 838*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): see *Table 12*; additionally, 7.38–7.22 (*m*, 20 arom. H); 4.96 (*d*, $J = 11.7$, PhC*H*); 4.89 (*d*, $J = 11.4$, PhC*H*); 4.75 (*s*, PhCH_2); 4.77–4.71 (br. *s*, NH); 4.63 (*d*, $J = 11.7$, PhC*H*); 4.56 (*d*, $J = 11.4$, PhC*H*); 4.47 (*d*, $J = 12.1$, PhC*H*); 4.39 (*d*, $J = 12.1$, PhC*H*); 1.43 (*s*, Me_3C). ^{13}C-NMR (75 MHz, $CDCl_3$): see *Table 13*; additionally, 156.64 (*s*, C=O); 138.53 (*s*, 2 C); 138.40, 138.06 (2*s*); 128.42–127.48 (several *d*); 79.51 (*s*, Me_3C); 75.28, 74.68, 73.52, 73.04 (4*t*, 4 PhCH_2); 28.60 (*q*, Me_3C). HR-MALDI-MS: 632.2627 ([$M - C_4H_8 + Na$]$^+$, $C_{37}H_{39}NNaO_7^+$; calc. 632.2624), 688.3251 ([$M + Na$]$^+$, $C_{41}H_{47}NNaO_7^+$; calc. 688.3250).

Debenzylation of **28a**/**28c**. Hydrogenation of a *ca.* 1:1-mixture of **28a**/**28c** (326 mg, 0.49 mmol) in MeOH (20 ml) containing 10% Pd/C (400 mg) at 4 bar for 21 h, filtration through *Celite*, washing of the residue with MeOH (20 ml), and evaporation of the combined filtrate and washings gave crude **29a**/**29c** *ca.* 1:1 (155.7 mg, quant.). The isomers were separated by FC ($CHCl_3$/EtOH/20% aq. NH_3 9:5:1) to give **29a** (67.5 mg, 45%) and **29c** (61.8 mg, 41%). Pure **29a** was recrystallised from acetone.

tert-*Butyl [(1S,2′S)-Spiro[1,5-anhydro*-D-*galactitol-1,1′-cyclopropane]-2′-yl]carbamate* (**29a**). Colourless solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.55. M.p. 205° (acetone; dec.). $[\alpha]_D^{25} = +57.1$ ($c = 1.50$, H_2O). IR (KBr): 3406*m*, 3299*m* (br.), 2975*w*, 2931*w*, 1676*s*, 1537*m*, 1366*m*, 1345*w*, 1249*w*, 1165*m*, 1131*w*, 1093*m*, 1068*m*, 1013*m*, 790*w*. ^{1}H-NMR (300 MHz, D_2O): see *Table 14*; additionally, 1.45 (*s*, Me_3C). ^{13}C-NMR (75 MHz, D_2O): see *Table 13*; additionally, 161.07 (*s*, C=O); 84.01 (*s*, Me_3C); 30.32 (*q*, Me_3C). HR-MALDI-MS: 272.0737 ([$M - C_4H_8 + Na$]$^+$, $C_9H_{15}NNaO_7^+$; calc. 272.0746), 328.1370 ([$M + Na$]$^+$, $C_{13}H_{23}NaNO_7^+$; calc. 328.1372). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 51.09, H 7.62, N 4.55.

tert-*Butyl [(1S,2′R)-Spiro[1,5-anhydro*-D-*galactitol-1,1′-cyclopropane]-2′-yl]carbamate* (**29c**). Colourless solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.53. M.p. 99–104°. $[\alpha]_D^{25} = +67.7$ ($c = 1.50$, H_2O). IR (KBr): 3395*s* (br.), 2978*w*, 2931*w*, 1687*s*, 1522*m* (br.), 1452*w*, 1394*m*, 1367*m*, 1252*m*, 1170*s*, 1092*s*, 1058*m*, 948*w*, 851*w*, 782w. ^{1}H-NMR (300 MHz, D_2O): see *Table 14*; additionally, 1.45 (*s*, Me_3C). ^{13}C-NMR (75 MHz, D_2O): see *Table 13*; additionally, 161.74 (*s*, C=O); 84.01 (*s*, Me_3C); 30.32 (*q*, Me_3C). HR-MALDI-MS: 272.0737 ([$M - C_4H_8 +$ Na]$^+$, $C_9H_{15}NNaO_7^+$; calc. 272.0746), 328.1370 ([$M + Na$]$^+$, $C_{13}H_{23}NaNO_7^+$; calc. 328.1372). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 51.02, H 7.63, N 4.45.

Debenzylation of **28b**/**28d**. Hydrogenation of a mixture of **28b**/**28d** (266 mg, 0.40 mmol) in MeOH (15 ml) containing 10% Pd/C (300 mg) at 4 bar for 21 h, filtration through *Celite*, washing of the residue with MeOH (20 ml), and evaporation of the combined filtrate and washings gave crude **29b**/**29d** *ca.* 3:2 (125.3 mg, quant.). Crystallisation from acetone yielded pure **29d** (39.2 mg, 32%). FC ($CHCl_3$/EtOH/20% aq. NH_3 9:5:1) of the mother liquor gave **29b** (61.9 mg, 51%) and **29d** (5.2 mg, 4%).

tert-*Butyl [(1R,2′R)-Spiro[1,5-anhydro*-D-*galactitol-1,1′-cyclopropane]-2′-yl]carbamate* (**29b**). Colourless solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.55. M.p. 80–95°. $[\alpha]_D^{25} = +94.8$ ($c = 1.50$, H_2O). IR (KBr): 3401*s* (br.), 2976*m*, 2928*m*, 1687*s*, 1521*m*, 1393*m*, 1367*m*, 1251*m*, 1170*s*, 1093*s*, 1058*m*, 1018*m*, 778*w*. ^{1}H-NMR (300 MHz, D_2O): see *Table 14*; additionally, 1.48 (*s*, Me_3C). ^{13}C-NMR (75 MHz, D_2O): see *Table 13*; additionally, 160.82 (*s*, C=O); 83.90 (*s*, Me_3C); 30.38 (*q*, Me_3C). HR-MALDI-MS: 272.0737 ([$M - C_4H_8 +$ Na]$^+$, $C_9H_{15}NNaO_7^+$; calc. 272.0746), 328.1367 ([$M + Na$]$^+$, $C_{13}H_{23}NaNO_7^+$; calc. 328.1372). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 51.28, H 7.53, N 4.49.

tert-*Butyl [(1R,2′S)-Spiro[1,5-anhydro*-D-*galactitol-1,1′-cyclopropane]-2′-yl]carbamate* (**29d**). Colourless solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.53. M.p. 216° (acetone; dec.). $[\alpha]_D^{25} = +1.0$ ($c = 1.50$, H_2O). IR (KBr): 3484*m*, 3440*m*, 3393*s*, 3374*s*, 2991*w*, 2971*w*, 2943*w*, 2916*w*, 2893*w*, 1684*s*, 1522*m*, 1461*w*, 1444*w*, 1369*m*, 1276*m*, 1261*m*, 1212*w*, 1161*m*, 1098*m*, 1084*m*, 1063*m*, 1011*m*, 989*w*, 959*w*, 927*w*, 858*w*, 783*w*. ^{1}H-NMR

Table 14. *Selected ^{1}H-NMR Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the Debenzylated Boc-Carbamates* **29a**–**29d** *and of the* galacto-*Ammonium Chlorides* **3a**–**3d** *in* D_2O

Compound	**29a**	**29b**	**29c**	**29d**	**3a**	**3b**	**3c**	**3d**
H–C(2′)	2.92	2.84	2.87	2.89	3.00	2.89	2.90	2.94
H_{cis}–C(3′)	1.20–1.09	1.26	0.65	0.79	1.39	1.52–1.46	0.99	1.12
H_{trans}–C(3′)	1.20–1.09	1.33	1.23	1.21	1.32	1.52–1.46	1.36	1.40
H–C(2)	4.20	4.28	4.09	4.04	4.34	4.37	4.10	4.14
H–C(3)	3.74–3.61	3.78	3.65	3.73–3.50	3.75	3.80	3.68	3.70
H–C(4)	3.99	4.09	4.02	3.97	4.01	4.09	4.04	4.08
H–C(5)	3.74–3.61	3.96	3.80–3.68	3.73–3.50	3.68	3.76–3.67	3.81–3.73	3.66
H_a–C(6)	3.74–3.61	3.71	3.80–3.68	3.73–3.50	3.68	3.76–3.67	3.81–3.73	3.78
H_b–C(6)	3.74–3.61	3.71	3.80–3.68	3.73–3.50	3.68	3.76–3.67	3.81–3.73	3.73
J(2′,3′$_{cis}$)	5.8	6.7	5.3	6.0	5.6	*ca.* 7.6	5.3	5.0
J(2′,3′$_{trans}$)	7.8	9.5	8.7	8.4	9.5	*ca.* 7.6	8.7	8.7
J(3′$_{cis}$,3′$_{trans}$)	[a])	7.5	6.9	7.5	7.8	[a])	7.8	8.1
J(2,3)	9.0	10.0	9.8	9.7	9.7	10.1	9.8	10.0
J(3,4)	≤1.5	3.0	3.2	≤1.5	3.2	3.4	3.4	3.2
J(4,5)	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5	0.9
J(5,6$_a$)	[a])	*ca.* 5.6	[a])	[a])	[a])	[a])	[a])	7.5
J(5,6$_b$)	[a])	*ca.* 5.6	[a])	[a])	[a])	[a])	[a])	4.0
J(6$_a$,6$_b$)	[a])	[a])	[a])	[a])	[a])	[a])	[a])	11.8

[a]) Not assigned.

(300 MHz, D_2O): see *Table 14*; additionally, 1.41 (*s*, Me_3C). ^{13}C-NMR (75 MHz, D_2O): see *Table 13*; additionally, 160.93 (*s*, C=O); 83.41 (*s*, Me_3C); 30.28 (*q*, Me_3C). HR-MALDI-MS: 272.0736 ($[M-C_4H_8+Na]^+$, $C_9H_{15}NNaO_7^+$; calc. 272.0746), 328.1368 ($[M+Na]^+$, $C_{13}H_{23}NaNO_7^+$; calc. 328.1372). Anal. calc. for $C_{13}H_{23}NO_7$ (305.32): C 51.14, H 7.59, N 4.59; found: C 51.20, H 7.53, N 4.52.

X-Ray Analysis of **29d**. Monoclinic $P2_1$; $a=5.308(2)$, $b=8.258(3)$, $c=16.998(5)$, $\beta=97.06(2)$; $V=739.4(4)$ Å^3, $D_{calc}=1.371$ Mg/m^3, $Z=2$. The reflections were measured on an *Enraf-Nonius-CAD4* diffractometer (graphite monochromator, CuK_α radiation, $\lambda=1.54184$) at 293(2) K. $R=0.0385$, $R_w=0.1225$. The structure was solved by direct method with SIR97 [74]. The non-H-atoms were refined anisotropically with SHELXL-97 [75]. H-atoms were calculated at idealised positions and included in the structure-factor calculation with fixed isotropic displacement parameters.

*(1*S*,2′*S*)-Spiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**3a**). As described above, **29a** (17.5 mg, 57.3 μmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **3a** (14.1 mg, quant.). Colourless hygroscopic solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.31. $[\alpha]_D^{25}=+82.6$ ($c=1.00$, H_2O). ^{1}H-NMR (300 MHz, D_2O): see *Table 14*. ^{13}C-NMR (75 MHz, D_2O): see *Table 13*. HR-MALDI-MS: 206.1021 ($[M+H]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028), 228.0835 ($[M+Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848).

*(1*R*,2′*R*)-Spiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-ammo nium Chloride* (**3b**). As described above, **29b** (17.4 mg, 57.0 μmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **3b** (14.2 mg, quant.). Colourless hygroscopic solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.31. $[\alpha]_D^{25}=+65.2$ ($c=1.00$, H_2O). ^{1}H-NMR (300 MHz, D_2O): see *Table 14*. ^{13}C-NMR (75 MHz, D_2O): see *Table 13*. HR-MALDI-MS: 206.1031 ($[M+H]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028), 228.0844 ($[M+Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848).

*(1*S*,2′*R*)-Spiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**3c**). As described above, **29c** (43.4 mg, 142 μmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **3c** (37.4 mg, quant.). Colourless hygroscopic solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.25. $[\alpha]_D^{25}=+79.8$ ($c=2.00$, H_2O). ^{1}H-NMR (300 MHz, D_2O): see *Table 14*. ^{13}C-NMR (75 MHz, D_2O): see *Table 13*. HR-MALDI-MS: 206.1024 ($[M+H]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028), 228.0836 ($[M+Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848).

*(1*R,*2′*S*)-Spiro[1,5-anhydro-*D*-galactitol-1,1′-cyclopropane]-2′-ammonium Chloride* (**3d**). As described above, **29d** (19.5 mg, 63.9 μmol) was dissolved in 1N HCl (5 ml) and evaporated with MeOH (2 × 10 ml) at 50°. Dissolution of the residue in H_2O (5 ml) and lyophilisation gave **3d** (16.3 mg, quant.). Colourless hygroscopic solid. R_f ($CHCl_3$/EtOH/20% aq. NH_3 3:7:2) 0.24. $[\alpha]_D^{25} = +109.4$ ($c = 1.00$, H_2O). ^{1}H-NMR (300 MHz, D_2O): see *Table 14*. ^{13}C-NMR (75 MHz, D_2O): see *Table 13*. HR-MALDI-MS: 206.1021 ($[M+H]^+$, $C_8H_{16}NO_5^+$; calc. 206.1028), 228.0844 ($[M+Na]^+$, $C_8H_{15}NaNO_5^+$; calc. 228.0848).

Inhibition Studies. Determination of the K_i or the IC_{50} values was performed with a range of inhibitor concentrations (typically 7 concentrations), which bracket the K_i or IC_{50} value, and substrate concentrations, which bracket the K_M of each enzyme (for K_i, typically 7 concentrations), or correspond to it (for IC_{50}). Samples of **1a**–**1d**, **2a**–**2d**, and **3a**–**3d** were purified by FC (SiO_2; $CHCl_3$/EtOH/20% aq. NH_3 9:5:1).

a) *Inhibition of Sweet Almond β-Glucosidases.* $K_M = 2.9-3.1$ mM ([79]: 67–80 mM at pH 5.2–6.0). K_i and IC_{50} values were determined at 37° at an enzyme concentration of 215 units/l, with a 0.08M KH_2PO_4/K_2HPO_4 buffer (pH 6.8) and 4-nitrophenyl β-D-glucopyranoside as the substrate. The enzymatic reaction was started after incubation of the enzyme (75 μl) in presence of the inhibitor (20 μl) during 15 min at 37°, by the addition of the substrate (5 μl). The increase of absorption per min at 405 nm was taken as the rate for the hydrolysis of the substrate. The increase was linear during 10 min. IC_{50} Values were determined by plotting the reciprocal value of the rate of substrate hydrolysis *vs.* the inhibitor concentration. After fitting a straight line to the data by linear regression, the negative [*I*] intercept of this plot provided the appropriate IC_{50} value. K_i Values were determined by taking the slopes from the *Lineweaver–Burk* plots [80] and plotting them *vs.* the inhibitor concentrations [81]. After fitting a straight line to the data by linear regression, the negative [*I*] intercept of this plot provided the appropriate K_i value.

b) *Inhibition of* Caldocellum saccharolyticum *β-Glucosidase.* $K_M = 0.50-0.78$ mM ([82]: 0.51 mM). K_i and IC_{50} values were determined at 55° at an enzyme concentration of 5 units/l, with a 0.08M KH_2PO_4/K_2HPO_4 buffer (pH 6.8) and 4-nitrophenyl β-D-glucopyranoside as the substrate. The enzymatic reaction was started after incubation of the enzyme (75 μl) in presence of the inhibitor (20 μl) during 15 min at 55°, by the addition of the substrate (5 μl). After 15 min, the enzyme reaction was quenched by addition of 0.2M borate buffer (pH 9.2, 100 μl), and the absorption at 405 nm was taken as rate for the hydrolysis of the substrate. IC_{50} and K_i values were determined by plots as described in *a*.

c) *Inhibition of Brewer's Yeast α-Glucosidase.* $K_M = 0.18-0.25$ mM. As described in *a*, K_i and IC_{50} values were determined at 37° at an enzyme concentration of 130 units/l, with a 0.08M KH_2PO_4/K_2HPO_4 buffer (pH 6.8) and 4-nitrophenyl α-D-glucopyranoside as the substrate.

d) *Inhibition of Jack Bean α-Mannosidase.* $K_M = 2.5$ mM [83]. Inhibition studies were carried out at 37°, with a 0.05M acetate buffer (pH 4.5) containing 2 mmol of $ZnCl_2$ and 4-nitrophenyl α-D-mannopyranoside as substrate. Reactions were initiated by adding the enzyme (75 μl) to a pre-incubated cuvet containing the substrate soln. in buffer (1350 μl) and inhibitor soln. (75 μl). The rate of the substrate hydrolysis was measured by treatment of 500 μl aliquots, after 1, 2, and 3 min, with 500 μl of 0.2M borate buffer (pH 9.2) and measuring the absorption at 405 nm.

e) *Inhibition of Almond α-Mannosidase.* $K_M = 4.2$ mM [79]. As described in *b*, the IC_{50} values were determined at 25°, with a 0.05M acetate buffer (pH 4.5) and 4-nitrophenyl α-D-mannopyranoside as the substrate. The enzyme reaction was quenched after 5 min.

f) *Inhibition of Snail β-Mannosidase.* As described in *b*, the IC_{50} values were determined at 25°, with a 0.05M acetate buffer (pH 4.5) and 4-nitrophenyl β-D-mannopyranoside as the substrate. The enzyme reaction was quenched after 5 min.

g) *Inhibition of* Aspergillus niger *α-Galactosidase.* $K_M = 0.5-1.0$ mM ([84]: 0.35 mM). As described in *b*, K_i and IC_{50} values were determined at 25° at an enzyme concentration of 10 units/l, with a 0.05M acetate buffer (pH 4.0) and 4-nitrophenyl α-D-galactopyranoside as the substrate. The enzyme reaction was quenched after 25 min.

h) *Inhibition of Green Coffee Bean α-Galactosidase.* $K_M = 0.35-0.75$ mM ([85]: 0.19 mM). As described in *a*, K_i and IC_{50} values were determined at 30° at an enzyme concentration of 50 units/l, with a 0.08M NaH_2PO_4/Na_2HPO_4 buffer (pH 6.0) and 4-nitrophenyl α-D-galactopyranoside as the substrate. The increase in absorption was linear during 7 min.

i) *Inhibition of Bovine Liver β-Galactosidase.* $K_M = 0.77-1.05$ mM. As described in *a*, K_i and IC_{50} values were determined at 37° at an enzyme concentration of 30 units/l, with a 0.05M NaH_2PO_4/Na_2HPO_4 buffer containing 1 mM of $MgCl_2$ (pH 7.0), and 2-nitrophenyl β-D-galactopyranoside as the substrate. The increase of absorption was linear during 7 min.

j) *Inhibition of* Escherichia coli *β-Galactosidase.* $K_M = 0.11 - 0.20$ mM ([86]: 0.18 mM). As described in *a*, K_i and IC_{50} values were determined at 30° at an enzyme concentration of 150 units/l, with a 0.2M NaH_2PO_4/Na_2HPO_4 buffer containing 1 mM of $MgCl_2$ (pH 7.0), and 2-nitrophenyl β-D-galactopyranoside as the substrate. The increase in absorption was linear during 7 min.

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