173. Glycosylidene Carbenes

Part 19

Regioselective Glycosidation of Allyl 2-Deoxy-2-phthalimido-D-allopyranosides

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The regio- and stereoselectivity of the glycosidation of the partially protected mono-alcohols **3** and **7**, the diols **2** and **8**, and the triol **4** by the diazirine **1** have been investigated. Glycosidation of the α-D-diol **2** (*Scheme 2*) gave regioselectively the 1,3-linked disaccharides **11** and **12** (80%, α-D/β-D 9:1), whereas the analogous reaction with the β-D-anomer **8** led to a mixture of the anomeric 1,3- and 1,4-linked disaccharides **13** (12.5%), **14** (16%), **15** (13%), and **16** (20.5%; *Table 2*). Protonation of the carbene by O*H*–C(4) of **2** is evidenced by the observation that the α-D-mono-alcohol **3** did not react with **1** under otherwise identical conditions, and that the β-D-alcohol **7** yielded predominantly the β-D-glucoside **18** (52%) besides 14% of **17**. Similarly as for the glycosidation of the diol **2**, the influence of the H-bond of *H*O–C(4) on the direction of approach of the carbene, the role of *H*O–C(4) in protonating the carbene, and the stereoelectronic control in the interception of the ensuing oxycarbenium cation are evidenced by the reaction of the triol **4** with **1** (*Scheme 3*), leading mostly to the α-D-configurated 1,3-linked disaccharide **19** (41%), besides its anomer **20** (16%), and some 4-substituted β-D-glucoside **21** (9%). No 1,6-linked disaccharides could be detected. In agreement with the observed reactivity, the ^{1}H-NMR and IR spectra reveal a strong H-bond between *H*O–C(3) and the phthalimido group in the α-D-, but not in the β-D-allosides. The different H-bonds in the anomeric phthalimides are in keeping with the results of molecular-mechanics calculations.

Introduction. – The regioselectivity in the glycosidation of diols and triols by diazirine-derived glycosylidene carbenes is determined both by the protonation of the carbene and the interception of the ensuing oxycarbenium ion by an oxy anion or a OH group ([1] [2]; for reviews, see [3–5]). Both processes are stereoelectronically controlled, protonation occurring in the σ-plane of the carbene and nucleophilic attack in the π-plane of the oxycarbenium cation.

The regioselectivity of the deprotonation of a diol or triol by the carbene is determined by the relative kinetic acidity of the individual OH groups, which depends mainly upon intramolecular H-bonds[2]). The regioselectivity of the C–O bond formation depends upon the position of the carbene/oxycarbenium cation relative to the diol or triol unit [7–10]. As illustrated in *Fig. 1*, the carbene may be close in space to only one (the protonating) OH group, or close to two of them; in the first case, the regioselectivity of the deprotonation determines the regioselectivity of the C–O bond formation, in the

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[2]) The influence of *intermolecular* H-bonds is seen for relatively weakly acidic alcohols (no intramolecular H-bond-accepting OH groups) [4] [6] [7].

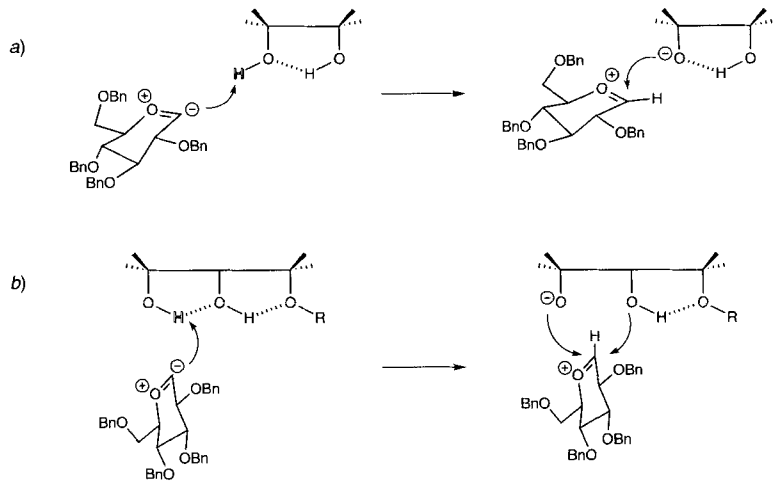


Fig. 1. *Protonation of the carbene derived from* **1** *by a diol and attack of the ensuing oxycarbenium ion:* a) *Protonation by a free OH group and* b) *protonation by an H-bonded OH group*

second case, the regioselectivity of the C–O bond formation depends on the position of the oxycarbenium cation relative to the deprotonated OH group and its neighbor. Evidently, these considerations are only valid if, in the second case, the carbene is protonated by H-bonded rather than by free OH groups.

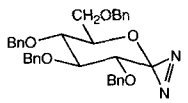
No regioselectivity is observed when the carbene is located between two *trans*-diequatorially oriented OH groups, as in 2,3-unprotected α-D-glucopyranosides [9]. In 1,2-*cis*-diols, regioselectivity has been observed both when the deprotonated OH group is equatorial, as in 2,3-unprotected α-D-allopyranosides [1], and when it is axial, as in benzyl α-D- and β-L-ribopyranosides [2].

β-D-Anomers are selectively formed when, in sufficiently acidic alcohols, the regioselectivity of deprotonation and C–O bond formation coincide [11]; when, however, they differ from each other as in 1,2-*cis*-diols, α-D(or β-L)-configurated glycosides are formed in excess [1] [2]. The preferred formation of α-D(or β-L)-glycosides is independent upon the relative and absolute configuration of the glycosyl acceptor, and this has been taken as evidence for a finite lifetime of the oxycarbenium cation, which can reorient itself (presumably by rotation around the C(1)–C(4) axis) and thus allow formation of an axial C–O bond.

In the context of our synthesis of allosamidin [12] [13], we noted a regioselective glycosidation under *Königs-Knorr*-type conditions of the axial OH group of the diol **2** [12]. The regioselectivity of the glycosidation differed conspicuously from the one of methyl 4,6-*O*-benzylidene-α-D-galactopyranoside, where the equatorial OH group is preferentially glycosylated [14]. Apparently, HO–C(3) of **2** possesses an enhanced nucleophilicity[3]), possibly due to a strong H-bond to the phthalimido and/or allyloxy

[3]) This interpretation implies that intramolecular H-bonds may be more relevant for the nucleophilicity of OH groups than the σ-acceptor effect of substituents. The *N*-phthaloyl group of a glucopyranosyl residue has been claimed to reduce the nucleophilicity of even remote OH groups [15] [16].

group. Glycosidation by glycosylidene carbenes is a useful tool to characterize H-bonds; we have investigated the glycosidation by the diazirine **1** of 2-phthalimido-allopyranosides to study their intramolecular H-bonds, to further evidence the mechanism proposed for the reaction of 1,2-*cis*-diols with glycosylidene carbenes, and to illustrate the compatibility of glycosylidene carbenes with the *N*-phthalimido group.



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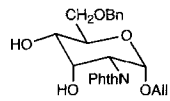
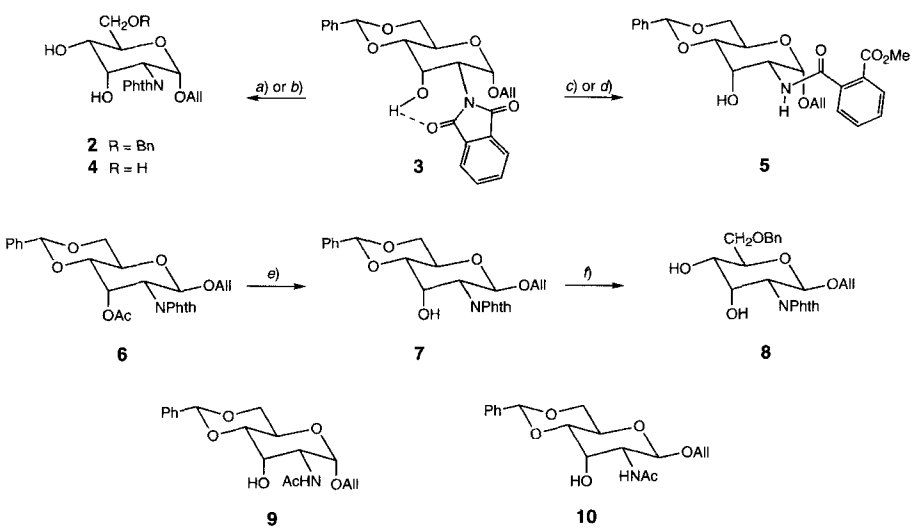


2

Phth = Phthaloyl, All = CH_2=$CHCH_2$

Results and Discussion. – 1. *Intramolecular Hydrogen Bonds of the* N-*Phthaloyl-allosamine Derivatives* **2**–**4**, **7**, *and* **8**. The synthesis of **2**, **3**, and **6** has been described in [12]. The triol **4** was obtained by hydrolysis of the benzylidene acetal **3**. Deacetylation of **6** (K_2CO_3, MeOH) gave the hydroxyphthalimide **7** (72%), and the reductive opening of its dioxane ring led to the diol **8** (82%). The stability of the *N*-phthaloyl moiety of **6** and **7** contrasts with the high reactivity of this moiety in **3**; similar treatment of the latter with MeOH in the presence of K_2CO_3 led smoothly to the carbamoylester **5** [12]. Apparently, the H-bond of *HO*–C(3) to the phthaloyl group in **3** increases its electrophilicity sufficiently to render it sensitive to the mild conditions of alcoholysis.

Scheme 1



Phth = Phthaloyl, All = CH_2=$CHCH_2$

a) $NaBH_3CN$, THF, 0°, 2 h; HCl soln. in Et_2O [17], 76% of **2**. *b*) 80% AcOH, 80°, 1.5 h, 78% of **4**. *c*) NaOMe, MeOH, r.t., 5 h, 88%. *d*) Anh. K_2CO_3, MeOH, 0°, 10 min, > 80%. *e*) As *d*), 72%. *f*) $Me_3N \cdot BH_3$, $AlCl_3$, THF [18], r.t., 12.5 h, 82%.

In the ^{1}H-NMR spectra ($CDCl_3$), the α-D-anomers **2–4** show characteristic low-field absorptions for OH–C(3) at *ca.* 6.1 ppm (*Table 1*). This shift appears to be only weakly influenced by the solvent (**2**: 6.5 ppm in C_6D_6 and 6.0 ppm in (D_8)dioxane). OH–C(3) resonates at much higher fields in the spectra of the β-D-anomers **7** and **8** (2.91 and *ca.* 3.8 ppm, resp.), similarly as for the α-D- and β-D-acetamides **9** and **10** [12] (2.86 and *ca.* 2.52 ppm, resp.), and the α-D-benzamide **5** (2.92 ppm). These chemical-shift values show that the anomeric 2-phthalimido-allopyranosides possess different intramolecular H-bonds [19].

Table 1. *^{1}H-NMR* (400 MHz, $CDCl_3$) *Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the OH Groups of the Allosamine Derivatives* **2–5**, **7–16**, *and* **19–21**

	OH–C(3)	OH–C(4)	OH–C(6)	J(3,OH)	J(4,OH)	J(6,OH)
3 [12]	6.13	–	–	< 2	–	–
2 [12]	6.09	2.81	–	1.4[a])	10.8	–
4	6.11	2.83	1.99	< 2	11.1	*ca.* 6.4
11	–	3.97	–	–	12.3	–
12	–	3.37	–	–	11.1	–
19	–	3.99	1.90	–	12.4	*ca.* 6.0
20	–	3.34	1.66	–	11.8	*ca.* 6.4
21	5.95	–	1.87	< 2		[b])
5 [12]	2.92	–	–	6.7	–	–
9 [12]	2.86	–	–	6.7	–	–
7	2.91	–	–	*ca.* 1.3[c])	–	–
8	3.83–3.77	3.06	–	[b])	6.4	–
10 [12]	2.52	–	–	< 2[d])	–	–
13	–	3.62–3.56	–	–	12.4	–
14	–	3.16	–	–	10.7	–
15	3.87	–	–	< 2	–	–
16	3.10	–	–	< 2	–	–

[a]) Determined by selective irradiation and resolution enhancement. ^4J(2,OH) ≈ ^4J(4,OH) ≈ 0.8 Hz. [b]) Not determined. [c]) ^4J(2,OH) ≈ 1.3 Hz. [d]) ^4J(2,OH) ≈ 1.1 Hz.

Molecular-mechanics calculation of the dimethoxy analogue of the α-D-anomer **2** (*Fig. 2*) gave three minima $\mathbf{A_1}$–$\mathbf{A_3}$ with H-bonds O(4)–H···O(3) and O(3)–H···O=C and/or O(3)–H···O(1), three minima $\mathbf{B_1}$–$\mathbf{B_3}$ with H-bonds O(3)–H···O(4) and O(4)–H···O(6), and the minimum **C** with H-bonds O(3)–H···O=C and O(4)–H···O(6). For the dimethoxy analogue of the β-D-anomer **8**, we found three minima, **D**, **E**, and **F**, representing the three different H-bonding types. Molecular-dynamics calculation show that **C** (→ **B**) and **F** (→ **E**) are only shallow minima, and that $\mathbf{A_1}$–$\mathbf{A_3}$ are interconverted at room temperature. Similarly, the rotamers $\mathbf{B_1}$–$\mathbf{B_3}$ easily interconvert, indicating low barriers for the rotation around C(2)–N(2). This is in contrast to the behavior of the β-D-rotamer **E**, where molecular-dynamics calculations indicate the exclusive presence of the rotamer depicted in *Fig. 2* (dihedral angle H–C(2)–N(2)–C(=O) of +30 ± 20°). In keeping with this, calculation of the conformers resulting from rotation (15° per step) around the C(2)–N(2) bond of $\mathbf{B_1}$ and **E** led to a rotational barrier of 7.2 kJ/mol for the α-D-anomer (at a dihedral angle H–C(2)–N(2)–C(=O) of +150°) and to one of 35.4 kJ/mol for the β-D-anomer (at a dihedral angle H–C(2)–N(2)–C(=O) of +150°). The distribution of these conformers has, therefore, a strong influence upon the H-bonds of both anomers of 2-phthalimido-allosides, assuming that the results of these calculations are not significantly affected by the nature of the *O*-alkyl groups. The α-D-anomers (low barrier) can easily adopt a

conformation where *HO*–C(3) forms a H-bond to one of the phthalimido C=O groups; the conformers $\mathbf{A_1}$/$\mathbf{A_2}$ are *ca.* 4 kJ/mol more stable than the conformers **B**. A conformer of the β-D-anomers similar to $\mathbf{A_1}$ (dihedral angle H–C(2)–N(2)–C(=O) of +132°, H···O(=C) distance of 1.77 Å) possesses severe destabilizing dipole-dipole and steric interactions between the C=O groups and O–C(1) and O–C(3). These interactions are energetically more important than a strong H-bond between *HO*–C(3) and a C=O group. A weaker H-bond is still present in **D** (H–C(2)–N(2)–C(=O) of +176°, H···O(=C) distance of 1.85 Å). The conformer of type **E** is devoid of these nonbonding interactions of the C=O groups and clearly favored.

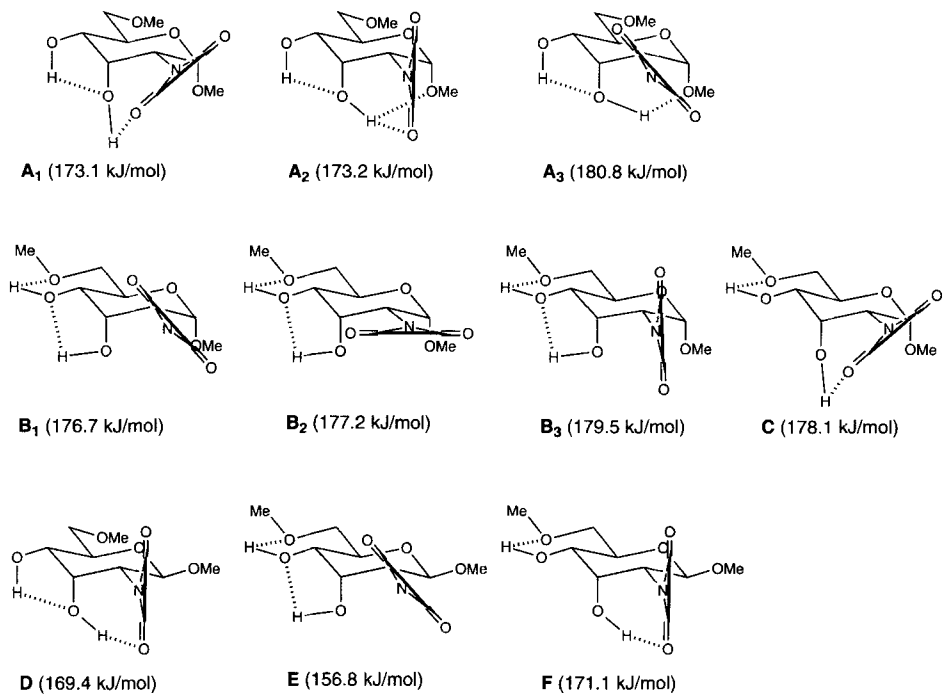


Fig. 2. *Molecular mechanics* (Macromodel V4.0, MM3 force field [20]) *calculated minima of the dimethoxy analogues of* **4** (**A–C**) *and* **8** (**D–F**). Final energy (gas phase) in parentheses.

The small vicinal coupling constants *J*(3,OH) of the α-D-anomers **2**–**4** (*Table 1*) are compatible with the conformations **A** and **B**. The large *J*(4,OH) of **2** and **4**, however, indicate the predominance of conformers of the type **A**. Assuming a dihedral angle H–C(4)–O–H of 160° (as calculated for $\mathbf{A_1}$), the *Karplus* equation of *Fraser et al.* [21] even predicts the exclusive presence of the conformers **A** where *HO*–C(4) acts as H-bond donor to O–C(3). The small *J*(3,OH) of **2**–**4** allows at the best a small contribution of a conformer involving a H-bond of *HO*–C(3) exclusively to the anomeric MeO group (as $\mathbf{A_3}$). Such a conformer is, however, predominant (*ca.* 60%) in the tautomeric equilibria of the benzamide **5** and the acetamide **9** (*J*(3,OH) = 6.7 Hz). The NMR data of **2**–**4** do not allow to distinguish between the linear H-bond in type $\mathbf{A_1}$ and the bifurcated one in type

$\mathbf{A_2}$. In contrast to the situation for the α-D-anomers, $J(4,OH) = 6.4$ Hz of the β-D-anomer **8** corresponds to a 55:45 mixture of the conformers of type **D** (H–C(4)–O–H of 160°) and **E** (H–C(4)–O–H of 70°).

Intramolecular H-bonds of the type realized for O*H*–C(3) in $\mathbf{A_1}$ are observed in the solid state of a 2-hydroxyphthalimide [22] and of 2-hydroxyacylamides [23–29]. For some of these compounds, a low-field absorption of the OH group in the ^{1}H-NMR spectrum has been reported (5.1–7.22 ppm [22] [23b] [26] [28]). The *Cambridge Data Base* does not contain any example of a bifurcated intramolecular H-bond of an 1-alkoxy-3-hydroxy-2-acylamide (type $\mathbf{A_2}$). The intramolecular H-bonds between the CH_2OH group and one C=O group of β-D-furanosyl-pyrimidinediones [30–33] or α-D-pyranosyl-pyrimidinediones [34] [35] may be considered as examples of a strongly asymmetric intramolecular bifurcated H-bond of a OH group to a C=O (distance H···O of 1.83–2.1 Å) and to an alkoxy group (= ring O-atom; distance H···O of 2.15–2.62 Å). Molecular-mechanics calculations of a β-D-furanosyl-pyrimidinedione led to a structure closely related to the one observed in the solid state.

The presence of intramolecular H-bonds of type $\mathbf{A_1}$ in the solid state is an indication of their strength [36]. This is corroborated by the IR spectra of **2** and **3**. The region above 3000 cm^{-1} in the FT-IR spectrum of **2** (CH_2Cl_2) does not change upon dilution from 0.05 to 0.01M. It shows a strong, broad absorption band at 3383 cm^{-1} with a shoulder at *ca.* 3470 cm^{-1} and a weaker band[4]) at 3544 cm^{-1}. The IR spectrum of **2** in $CHCl_3$ is quite similar (3545, *ca.* 3470 (sh), and 3391 (br.) cm^{-1}). The broad band at 3383 cm^{-1} is assigned to the H-bond O(3)–H···O(=C) (compare with 3268 cm^{-1} for a 2-hydroxycarbamate [23b]) and the band at 3544 cm^{-1} to the H-bond O(4)–H···O(3). In agreement with this, the IR spectrum of **3** in $CHCl_3$ possesses only one broad OH band at 3400 cm^{-1}. The IR spectra ($CHCl_3$) of **5** and **9**, however, show OH bands at 3590 (O(3)–H···O(4)) and at *ca.* 3520 cm^{-1} (O(3)–H···O(1)). The β-D-anomers **7** (0.085M in $CHCl_3$) shows a dominant OH band at 3590 cm^{-1} for O–H···O(4) and a weak, broad band at 3550–3300 cm^{-1} which probably stems from intermolecular H-bonds rather than from a contribution of the intramolecular H-bond O–H···O=C. The absorptions of the β-D-diol **8** (*ca.* 0.085M in $CHCl_3$) at 3560 and 3480 (broad) cm^{-1} are of similar intensity. The former is assigned to the intramolecular H-bond between *H*O–C(3) and *H*O–C(4) (both act as H-donors as deduced from $J(4,OH)$, see above) and the latter to the intramolecular H-bonds of *H*O–C(4) to O–C(6) and of *H*O–C(3) to the C=O group and to intermolecular H-bonds. The shift of the broad bands of the β-D-anomers to higher wave numbers indicates that the intramolecular H-bond between *H*O–C(3) and the C=O group – if really present – is weaker than in the α-D-anomers (as suggested by molecular-mechanics calculation). In summary, the IR spectra agree with the intramolecular H-bonds deduced from the ^{1}H-NMR spectra and corroborated by the calculations.

The different strength of the intramolecular H-bonds in **2** (tautomers of type $\mathbf{A_1}/\mathbf{A_2}$) suggests that the carbene derived from **1** should be protonated by *H*O–C(4). Insofar as this protonation is by a H-bonded OH group, the direction of approach of the carbene should reflect the preferred geometry of a bifurcated H-bond (*cf.* [1]); the oxycarbenium ion will then be located in such a way between HO–C(3) and $^-$O–C(4) that HO–C(3),

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[4]) Weak bands at 3692 and 3595 cm^{-1} which are also present in the spectrum of wet CH_2Cl_2 are assigned to traces of H_2O.

which is more or less in the π-plane of the ensuing oxycarbenium cation, should act as glycosyl acceptor (*Fig. 3*). The same is expected for the tautomer of type **D** of **8**; although the H-bond O(3)–H···O(=C) is weaker than the one of **2**, it is still stronger than O(4)–H···O(3). In the tautomer of type **E**, *H*O–C(3) is involved in the weaker H-bond and should protonate the carbene. As both tautomers may be glycosylated, one has to expect a poor regioselectivity in the glycosidation of **8**.

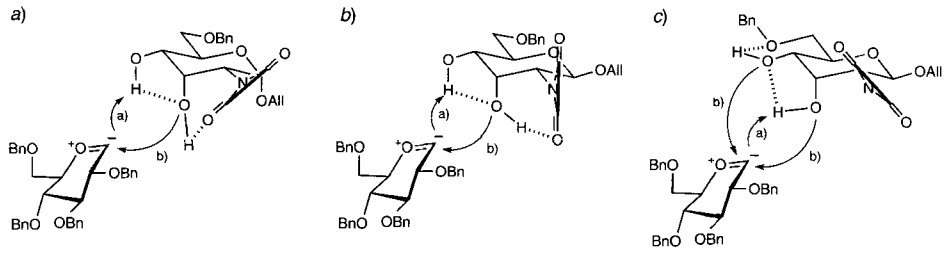


Fig. 3. *Protonation of the carbene derived from* **1** *by the predominant conformers of* **2** *and* **8** *and preferred attack of the ensuing oxycarbenium ion:* a) *Conformer of type* $\mathbf{A_1}$ *of* **2**, b) *conformer of type* **D** *of* **8**, *and* c) *conformer of type* **E** *of* **8**

2. *Glycosidation of the* N-*Phthaloylallosamine Derivatives* **2**–**4**, **7**, *and* **8**. Glycosidation of the α-D-diol **2** by the diazirine **1** in dioxane at room temperature gave selectively the 1,3-linked disaccharides **11** and **12** (80%) in a α-D/β-D ratio of 9:1 besides traces of the β-D-configurated 1,4-linked isomer (*Scheme 2, Table 2*). However, glycosidation of the β-D-diol **8** under the same conditions gave the four possible disaccharides **13** (12.5%), **14** (16%), **15** (13%), and **16** (20.5%) with a slight preference for the 1,4-linked disaccharides and for the β-D-anomers. That the different reactivities of the anomeric phthalimides is indeed due to the different H-bonding, and that the preference for the α-D-anomers derived from **2** denotes protonation of the carbene by HO–C(3) is evidenced by the glycosidation of the mono-alcohols **3** and **7**. As expected, **3** did not react and was recovered in 95%, whereas HO–C(3) of **7** was glycosylated by **1** and afforded mostly (52%) the β-D-disaccharide **18** besides 14% of the α-D-anomer **17**. As pointed out in the *Introduction*, this is the expected diastereoselectivity for relatively acidic alcohols when the regioselectivity of the deprotonation by the carbene and of the C–O bond formation coincide [6].

These results suggest that the diazirine **1** may react with the triol **4** similarly as with **2**. Indeed, chemical shifts and coupling constants for HO–C(3) and HO–C(4) of **2** and **4** in $CDCl_3$ solution are similar to each other (*Table 1*) and strongly suggest similar H-bonding. The J(5,6) values of **4** are 4.7 and 3.5 Hz. Assuming that $H_{pro\text{-}R}$–C(6) is more shielded and exhibits a larger vicinal coupling constant than $H_{pro\text{-}S}$–C(6) (as it is usually the case, *cf.* [37]) and applying the parameters of *Bock* and *Duus* [37], one obtains a rotameric distribution (in $CDCl_3$ solution) *gg*/*gt*/*tg* of 0.57:0.35:0.08 for **4**. The predominant *gg*-rotamer can only form intermolecular H-bonds, whereas O*H*–C(6) of the *gt*-rotamer may act as H-donor to the ring O-atom, and *H*O–C(6) of the *tg*-rotamer as H-donor to O–C(4). In dioxane solution, *H*O–C(6) should form an intermolecular H-bond to the solvent. This is evidenced by the IR spectrum in this solvent. A strong, broad band at 3450 cm^{-1} is assigned to intermolecular H-bonds and to the intramolecular H-bond

Scheme 2

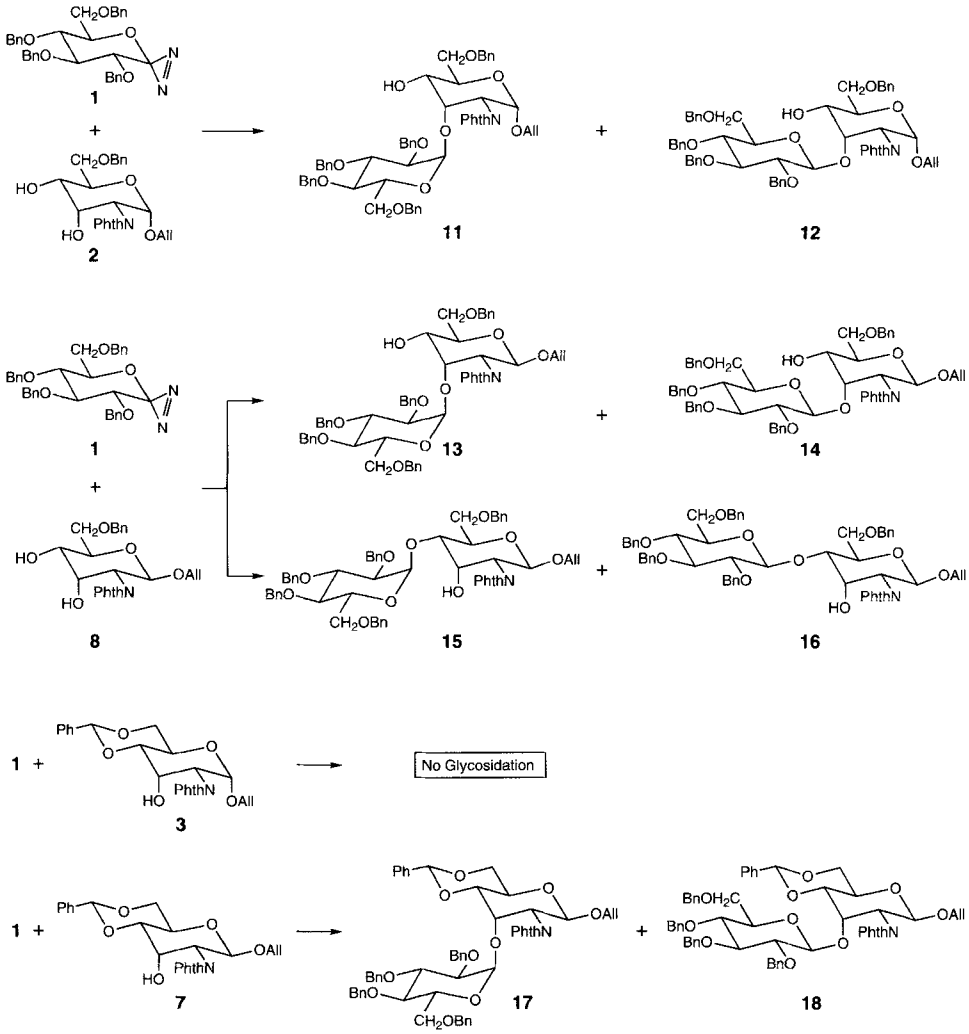


Table 2. *Regioselectivity and Diastereoselectivity of the Glycosidation of* **2–4**, **7**, *and* **8** *with* **1** *at Room Temperature in Dioxane*

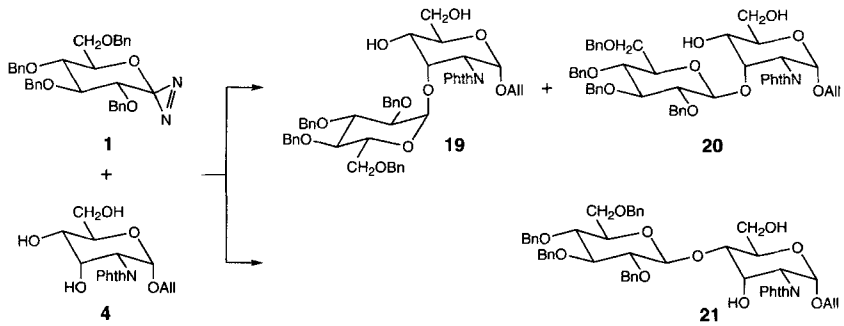
	Recovered aglycone[a]) [%]	Total yield of disaccharides [%]	Partial yields of disaccharides[a]) [%]					
			α-1,3	β-1,3	α-1,4	β-1,4	α-1,6	β-1,6
3	95	–	[b])	[b])	–	–	–	–
2	16	80	72	8	[b])	trace	–	–
4	32	66	41	16	trace	9	[b])	[b])
7	32	66	14	52	–	–	–	–
8	30	62	12.5	16	13	20.5	–	–

[a]) After purification by FC. [b]) Not detected.

O(3)–H···O(=C), and the shoulder at 3580 cm^{-1} to the intramolecular H-bond O(4)–H···O(3).

The reaction of **1** with **4** in dioxane solution gave 57% of the 1,3-linked disaccharides **19** and **20** in a α-D/β-D ratio of 72:28 and 9% of the β-D-configurated 1,4-linked isomer **21** (*Scheme 3*). Whereas 32% of **4** was recovered, no 1,6-linked disaccharides were found (*Table 2*). To the best of our knowledge[5]), this is the first reported case of a selective glycosylation of a secondary OH group in the presence of a primary one.

Scheme 3



The results of the glycosidation of these allopyranosides confirm earlier hypotheses rationalizing the course of the glycosidation, particularly of 1,2-*cis*-diols, by the diazirine **1**. The difference in reactivity of the diol **2** and the alcohol **3** demonstrates the strength of the H-bond of *H*O–C(3), and offers strong evidence that glycosidation of **2** at HO–C(3) is initiated by protonation of the carbene by the H-bonded *H*O–C(4), resulting in the preferred formation of an α-D-glycoside. This interpretation is corroborated by the quantitative and qualitative differences of reactivity of the anomers **2** and **8** on the one hand, and **3** and **7** on the other hand. The regio- and stereoselectivity of the glycosidation of the triol **4** is difficult to interprete in other ways; it also demonstrates that *H*O–C(6) is involved in inter- and intramolecular H-bonds which are stronger than the one of *H*O–C(4), and that the H-bonding is not qualitatively different in $CDCl_3$ and in dioxane solution.

The constitution of the disaccharides **11**–**21** is deduced from the signal pattern of the H–C(OH) group in the ^{1}H-NMR spectra. The configuration of the new anomeric centre is easily deduced from the $J(1',2')$ values, the chemical shifts of H–C(1′) and C(1′), and the characteristic downfield shift (*cf.* [1] [2] [7–10]) of H–C(3′) and H–C(5′) of the α-D-glucosides (see *Tables 3* and *4* in the *Exper. Part*). The disaccharides show characteristic shifts and coupling patterns of the OH signals (*Table 1*). The low-field shift of OH–C(3) of **21** reveals the presence of the H-bond to the C=O group which is not observed in the 4-substituted β-D-allopyranosides **15** and **16**. In all 1,3-linked disaccharides (including the β-D-allopyranosides **13** and **14**), the large J(4,OH) indicates that O*H*–C(4) is completely involved in an intramolecular H-bond to O–C(3). This leads to a synclinal arrangement of C(2) and C(1′) and to a hindered rotation around C(2)–NPhth

[5]) Searches were performed in CASREACT, CHEMINFORMRX, and CHEMREACT.

also in the α-D-anomers, as indicated by the low-field shift in 3-*O*-alkylated-2-phthalimido-α-D-allopyranosides of H–C(1) ($\Delta\delta$ 0.4–0.6 ppm relative to **2**, **4**, or **9**) and H–C(3) ($\Delta\delta$ 0.4 ppm relative to **2** or **4**, 0.6 relative to **9**; *cf.* [12] and *Table 3*). Molecular-mechanics calculations show that the plane of the phthalimido moiety in the favored rotamer of the α-D-anomer is parallel to C(1)–C(2) (dihedral angle C(1)–C(2)–N–C of −3°). In this conformation, both H–C(1) and H–C(3) are in close neighborhood to a C=O group (H···O(=C) distances of 2.51 and 2.43 Å, resp.). In the β-D-anomers, the dihedral angle C(1)–C(2)–N–C of the favored rotamer is −34°; and H–C(1) is closer to the C=O group (H···O(=C) distance of 2.37 Å) than in the α-D-anomer, while H–C(3) is farther away (H···O(=C) distance of 3.12 Å). Indeed, H–C(1) of the 3-substituted β-D-allopyranosides is shifted downfield by 1–1.3 ppm (relative to **10**), whereas the shift difference of H–C(3) varies between 0 and 0.5 ppm.

All the 1,3-linked disaccharides show a characteristic upfield shift for one benzylic CH_2 group (*ca.* 0.3–0.5 ppm for one and *ca.* 0.5–0.8 ppm for the other H, *Table 3*). Moreover, the α-D-glucopyranosides **11**, **13**, **17**, and **19** show an upfield shift for H–C(2′) (*ca.* 0.15–0.25 ppm), while the β-D-glucopyranosides **12**, **14**, **18**, and **20** show one for H–C(5′), H_A–C(6′), and H_B–C(6′) (*ca.* 0.2, 0.4–0.8, and 0.5–1.0 ppm, resp.). This suggests that different sides of the anomeric glucopyranosyl residues are located in the shielding zone of the phthalimido group. Molecular-mechanics calculations of **11** and **12** (*Fig. 4*) indeed reveal that the CH(2′)OBn moiety of the α-D-glucosides and CH(5′)–CH_2(6′)OBn moiety of the β-D-glucosides lie in the π-plane of the phthalimido group[6]). The calculations even ascertain the stronger shielding observed in the β-D-glucosides.

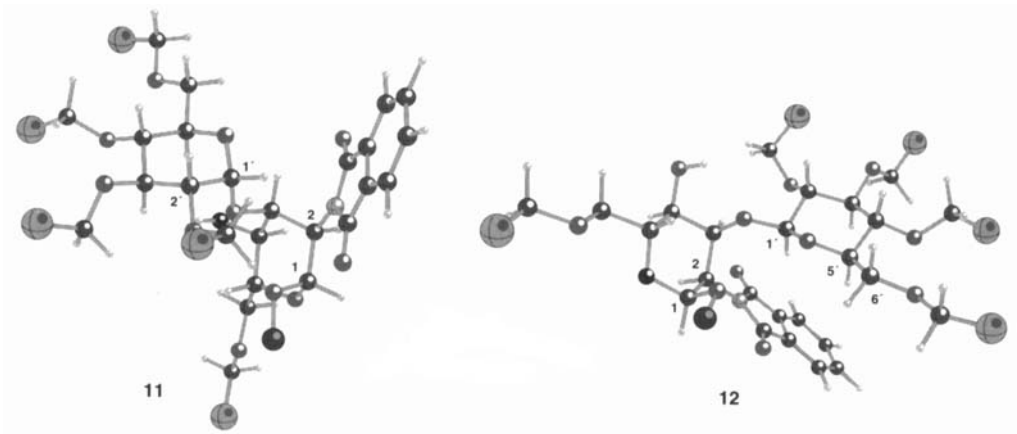


Fig. 4. *Molecular-mechanics* (Macromodel V4.0, MM3 force field) *calculated minima of the disaccharides* **11** *and* **12**. For the sake of clarity, the allyl and phenyl groups are replaced by a single 'heavy' atom.

We thank Mr. *M. Vöhler* and Dr. *D. Nanz* for their help with the NMR experiments and the *Swiss National Science Foundation* and *F. Hoffmann-La Roche AG*, Basel, for generous support.

[6]) A similar conformation was already detected in 3-substituted disaccharides derived from methyl 4,6-*O*-benzylidene-α-D- and -β-D-allopyranosides by the upfield shifts of both H–C(6′) of the α-D-glucopyranosyl moiety which are located in the shielding zone of the 4,6-*O*-benzylidene group [1].

Experimental Part

General. See [12]. Dioxane was distilled over CaH_2. The glycosidations were performed in the dark. The ratio of the products was determined by anal. HPLC, and the disaccharides were separated by prep. HPLC. HPLC: Anal. *Merck-LiChrosorb-Si60* 250 × 4.0 mm cartridge. ^{13}C-NMR Spectra: signal assignment based on ^{1}H,^{13}C-HMQC [38] of **11**, **19**, and **20** and by comparison with the δ's of the phthalimido-D-allopyranosides in [12] and of the tetra-*O*-benzyl-D-glucopyranosides in [1] [9]. Mass spectra: CI (chemical ionization; NH_3) at 70 eV on a *Varian-112-S* spectrometer or ESI (electrospray ionization [39]) on a *Finnigan-MAT-TSQ-700* spectrometer. Molecular-mechanics calculations were performed with the program Macromodel V4.0 (MM3 force field) [20] on a *Silicon-Graphics IRIS-Crimson-Elan.*

Allyl 2-Deoxy-2-phthalimido-α-D-allopyranoside (**4**). A soln. of **3** [12] (151 mg, 0.345 mmol) in 80% aq. AcOH (10 ml) was kept at 80° for 1.5 h and then evaporated. The residue was dissolved in a minimum of $CHCl_3$ and adsorbed on silica gel. FC (toluene/AcOEt 1:3 → 1:10) yielded **4** (94 mg, 78%). The white solid could not be recrystallized. R_f (toluene/AcOEt 1:3) 0.28. $[\alpha]_D^{25} = +123.5$ ($c = 0.2$, $CHCl_3$). IR (dioxane): 3580*w* (sh), 3450*m* (br.), 1790*w* (sh), 1775*w*, 1715*s*, 1650*w*, 1610*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.92–7.90 (*m*, 2 arom. H); 7.81–7.79 (*m*, 2 arom. H); 6.11 (*m*, exchange with D_2O, HO–C(3)); 5.75 (*dddd*, $J = 17.2, 10.5, 5.5, 4.8$, 1 olef. H); 5.23 (*dq*, $J \approx 17.2, 1.7$, 1 olef. H); 5.08 (*dq*, $J \approx 10.5, 1.5$, 1 olef. H); 4.22 (*ddt*, $J = 13.4, 4.8, 1.7$, 1 allyl. H); 3.76 (*td*, $J \approx 10.4, 2.9$, with D_2O *dd*, $J = 9.9, 2.9$, H–C(4)); 2.83 (*d*, $J = 11.1$, exchange with D_2O, HO–C(4)); 1.99 (*t*, $J \approx 6.4$, exchange with D_2O, HO–C(6)). ^{13}C-NMR (50 MHz, (D_6)DMSO): see *Table 4*; additionally, 169.0 (*s*, 2 C); 135.1 (*d*, 2 C); 134.7 (*d*, 1 olef. C); 131.2 (*s*, 2 C); 123.7 (*d*, 2 C); 115.7 (*t*, 1 olef. C). CI-MS (NH_3): 350.3 (8, $[M + 1]^+$), 309.3 ($[M - AllO + NH_3]^+$), 292.3 (100, $[M - AllO]^+$). Anal. calc. for $C_{17}H_{19}NO_7$ (349.34): C 58.45, H 5.48, N 4.01; found: C 58.26, H 5.26, N 3.91.

Allyl 4,6-O-Benzylidene-2-deoxy-2-phthalimido-β-D-allopyranoside (**7**). Finely ground, dry K_2CO_3 (54.4 mg, 0.39 mmol) was added to a stirred soln. of **6** [12] (210 mg, 0.44 mmol) in MeOH (4 ml) at 0°. After 10 min, the mixture was filtered and the filtrate evaporated. FC (toluene/AcOEt 6:1) afforded **7** (138 mg, 72%). For analysis, the white solid was recrystallized in CH_2Cl_2/hexane. R_f (toluene/AcOEt 2:1) 0.52. M.p. 128–129° (CH_2Cl_2/hexane). $[\alpha]_D^{25} = -78.7$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3590*w*, 3480*w*, 3410*w*, 3090*w*, 3080*w*, 3040*w*, 3020*w*, 2960*w* (sh), 2925*w* (br.), 2880*w*, 1780*m*, 1720*s*, 1615*w*, 1570*w*, 1560*w*, 1395*s* (sh), 1385*s*, 1360*m* (sh), 1335*w*, 1315*m*, 1280*w*, 1260*w*, 1170*m* (br.), 1135*m*, 1105*s*, 1090*s*, 1045*m*, 1030*m* (sh), 1015*s* (sh), 1000*s*, 940*w*, 920*w*, 875*w*, 860*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.88–7.86 (*m*, 2 arom. H); 7.75–7.73 (*m*, 2 arom. H); 7.51–7.48 (*m*, 2 arom. H); 7.39–7.36 (*m*, 3 arom. H); 5.81 (*dddd*, $J = 17.2, 10.3, 6.2, 5.6$, 1 olef. H); 5.18 (*dq*, $J \approx 17.2, 1.5$, 1 olef. H); 5.09 (*dq*, $J \approx 10.5, 1.3$, 1 olef. H); 4.14 (*ddt*, $J \approx 12.5, 6.2, 1.3$, 1 allyl. H); 2.91 (*t*, $J = 1.3$, exchange with D_2O, OH–C(3)). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 168.4 (*s*, 2 C); 137.0 (*s*); 134.1 (*d*, 2 C); 131.7 (*s*, 2 C); 129.2 (*d*); 128.3 (*d*, 2 C); 126.2 (*d*, 2 C); 123.4 (*d*, 2 C). CI-MS (NH_3): 455.5 (7, $[M + NH_4]^+$), 397.4 (100, $[M - AllO + NH_3]^+$), 380.4 (80, $[M - AllO]^+$).

Allyl 6-O-Benzyl-2-deoxy-2-phthalimido-β-D-allopyranoside (**8**). A mixture of **7** (50 mg, 0.114 mmol), $BH_3 \cdot NEt_3$ (50 mg, 0.686 mmol), and powdered 4-Å molecular sieves (50 mg) in THF (5 ml) [18] was stirred for 30 min at r.t. After the addition of $AlCl_3$ (91.4 mg, 0.686 mmol), the mixture was stirred for 12 h and filtered. Evaporation of the filtrate and FC (toluene/AcOEt 1:1) yielded **8** (41 mg, 82%). Colorless oil. R_f (toluene/AcOEt 2:1) 0.11. $[\alpha]_D^{25} = -42.1$ ($c = 0.9$, $CHCl_3$). IR ($CHCl_3$): 3560*w*, 3480*w*, 3450*w* (sh), 3090*w*, 3070*w*, 3040*w*, 3010*w*, 2970*w*, 2880*w*, 1780*m*, 1715*s*, 1610*w*, 1495*w*, 1470*w*, 1455*w*, 1390*s*, 1365*m*, 1355*m* (sh), 1335*m*, 1215*w*, 1175*m*, 1120*m*, 1080*s*, 1055*s*, 1030*m* (sh), 990*m*, 970*w*, 935*w*, 875*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.88–7.86 (*m*, 2 arom. H); 7.76–7.73 (*m*, 2 arom. H); 7.38–7.35 (*m*, 5 arom. H); 5.76 (*dddd*, $J = 17.2, 10.5, 5.6, 4.3$, 1 olef. H); 5.13 (*dq*, $J \approx 17.2, 1.6$, 1 olef. H); 5.04 (*dq*, $J \approx 10.5, 1.3$, 1 olef. H); 3.06 (*d*, $J = 6.4$, exchange with D_2O, HO–C(4)). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 169.7 (*s*, 2 C); 137.8 (*s*); 134.2 (*d*, 2 C); 131.5 (*s*, 2 C); 128.4 (*d*, 2 C); 127.7 (*d*); 127.6 (*d*, 2 C); 123.4 (*d*, 2 C); 73.6 (*t*, PhCH_2). CI-MS (NH_3): 457.5 (37, $[M + NH_4]^+$), 399.4 (85, $[M - AllO + NH_3]^+$), 382.4 (100, $[M - AllO]^+$).

Glycosidation of **2**. A soln. of **2** [12] (50 mg, 0.114 mmol) in dioxane (1 ml) was treated with **1** (68.7 mg, 0.125 mmol) and stirred under Ar at r.t. for 4 h. The solvent was evaporated and the residue dissolved in the minimal amount of $CHCl_3$, adsorbed on silica gel, and submitted to FC. Elution with toluene/AcOEt 10:1 gave **11** (108.5 mg, 72%), elution with toluene/AcOEt 5:1 **12** (12 mg, 8%), and elution with toluene/AcOEt 1:1 **2** (8 mg, 16%).

Allyl 6-O-Benzyl-2-deoxy-2-phthalimido-3-O-(2,3,4,6-tetra-O-benzyl-α-D-glucopyranosyl)-α-D-allopyranoside (**11**): R_f (toluene/AcOEt 9:1) 0.27. $[\alpha]_D^{25} = -28.6$ ($c = 0.9$, $CHCl_3$). IR ($CHCl_3$): 3580*w* (sh), 3530*w* (sh), 3460*w* (br.), 3090*w*, 3070*w*, 3000*w*, 2920*w*, 2860*w*, 1780*w*, 1715*s*, 1610*w*, 1490*w*, 1450*w*, 1380*w* (sh), 1360*m*, 1330*m*, 1260*m*, 1140*m* (sh), 1090*s*, 1070*s*, 1050*s* (sh), 1020*s*, 910*w*, 885*w*, 860*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.71–7.69 (*m*, 2 arom. H); 7.59–7.63 (*m*, 2 arom. H); 7.41–7.23 (*m*, 17 arom. H); 7.21–7.13 (*m*, 6 arom.

Table 3. *Selected ^{1}H-NMR* (400 MHz, $CDCl_3$) *Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *for* **2**, **4**, **7**, **8**, *and* **11**–**21**

	2 [12]	**11**	**12**	**4**	**19**	**20**	**21**	**7**	**17**	**18**	**8**	**13**	**14**	**15**	**16**
H–C(1)	4.92	5.45	5.35	4.90	5.48	5.36	4.88	6.00	6.20	6.10	5.70	6.04	5.89	5.94	5.96
H–C(2)	4.57	4.57–4.50	4.45	4.50	4.45	4.35	4.50	4.37–4.32	4.32	4.37–4.29	4.10–4.01	4.30	4.23–4.13	4.17–4.12	4.24
H–C(3)	4.36	4.75	4.77	4.36	4.77	4.78	4.66	4.47–4.43	4.46	4.66	4.35–4.26	4.19	4.28	4.08–4.04	4.53–4.43
H–C(4)	3.88–3.80	3.84	3.82	3.76	3.69	3.68	3.94	3.80	3.80–3.75	3.84–3.81	3.83–3.77	3.70	3.73	3.80	3.94
H–C(5)	4.19	4.17–4.05	3.96–3.92	4.11	3.97	3.79	4.43	4.23	4.05–3.99	4.09	4.35–4.26	3.81–3.76	3.70–3.56	3.78–3.74	4.19–4.12
H_A–C(6)	3.88–3.80	3.69	3.49–3.45	3.97	3.76	3.58–3.51	3.89–3.84	4.47–4.43	4.36	4.37–4.29	3.83–3.77	3.62–3.56	3.70–3.56	3.63	3.78
H_B–C(6)	3.88–3.80	3.63	3.35	3.94–3.87	3.68	3.47	3.79	3.86	3.83	3.84–3.81	–	3.37	3.45	3.43	3.70
H–C(1′)	–	4.65	4.78	–	4.64	4.45	4.62	–	4.68	4.59	–	4.47–4.33	4.42	4.77	4.51
H–C(2′)	–	3.25	3.50	–	3.25	3.58–3.51	3.61–3.55	–	3.29	3.42	–	3.19	3.48	3.53	3.44–3.38
H–C(3′)	–	4.17–4.05	3.61	–	4.10	3.63	3.71–3.62	–	4.04	3.53	–	4.09–4.04	3.70–3.56	3.89	3.61–3.53
H–C(4′)	–	3.41	3.49–3.45	–	3.30	3.58–3.51	3.61–3.55	–	3.64	3.08	–	3.28	3.36	3.65	3.61–3.53
H–C(5′)	–	4.17–4.05	3.28–3.23	–	4.17–4.12	3.29–3.25	3.50	–	4.05–3.99	3.25–3.19	–	4.09–4.04	3.18	4.08–4.04	3.44–3.38
H_A–C(6′)	–	3.58	3.28–3.23	–	3.60	3.29–3.25	3.71–3.62	–	3.80–3.75	3.25–3.19	–	3.81–3.76	2.86	3.78–3.74	3.61–3.53
H_B–C(6′)	–	3.48	3.17	–	3.49	3.13	3.71–3.62	–	3.48	2.60	–	3.39	2.86	3.67	3.61–3.53
PhC*H*	–	–	–	–	–	–	–	5.63	5.57	5.57	–	–	–	–	–
PhCH_2 at highest field	4.67, 4.63	4.22, 3.88	3.96–3.92, 3.80	–	4.23, 3.89	3.93, 3.78	> 4.5	–	4.11, 3.58	4.14, 3.99	4.63	3.96, 3.62–3.56	3.89, 3.84	> 4.37	> 4.38
J(1,2)	3.7	3.7	3.7	3.7	3.6	3.7	3.7	8.7	8.7	8.7	8.5	8.7	8.7	8.7	8.7
J(2,3)	2.6	3.5	3.6	2.3	3.6	3.5	3.7	[a])	2.8	2.8	[a])	3.0	3.1	[a])	2.8
J(3,4)	2.8	3.3	3.6	2.9	2.5	3.5	2.3	2.5	2.5	2.8	[a])	2.6	3.1	3.0	3.0
J(4,5)	9.9	9.6	9.8	9.9	9.8	10.0	9.9	9.9	[a])	10.0	[a])	10.1	10.0	9.9	9.9
J(5,6*A*)	2.6	2.2	[a])	3.4	3.5	[a])	2.3	5.0	5.1	5.1	[a])	[a])	[a])	5.1	1.6
J(5,6*B*)	4.5	4.6	4.7	4.7	4.9	5.0	2.3	10.0	10.3	10.0	[a])	2.6	5.1	1.8	4.9
J(6*A*,6*B*)	[a])	10.7	10.6	11.8	11.8	11.8	11.9	10.3	10.1	[a])	[a])	10.0	10.3	10.8	11.0
J(1′,2′)	–	3.2	7.9	–	3.2	7.8	7.8	–	3.3	7.6	–	3.4	7.9	3.7	7.9
J(2′,3′)	–	9.8	9.1	–	9.7	9.1	[a])	–	9.6	9.0	–	9.9	9.3	9.4	[a])
J(3′,4′)	–	9.5	9.1	–	9.5	9.1	[a])	–	9.6	9.0	–	9.7	9.0	9.5	[a])
J(4′,5′)	–	9.5	[a])	–	9.4	[a])	9.7	–	9.6	9.0	–	9.7	9.8	9.6	[a])
J(5′,6′*A*)	–	1.8	[a])	–	2.9	[a])	2.1	–	[a])	[a])	–	[a])	3.0	[a])	[a])
J(5′,6′*B*)	–	6.2	[a])	–	6.4	[a])	5.0	–	1.9	6.0	–	6.9	3.0	5.5	[a])
J(6′*A*,6′*B*)	–	10.2	[a])	–	10.2	[a])	[a])	–	10.7	10.8	–	10.1	[a])	10.9	[a])

[a]) Not determined.

Table 4. *Selected* ^{13}C*-NMR* (50 MHz, $CDCl_3$) *Chemical Shifts* [ppm] *for* **2**, **4**, **7**, **8**, **11**, *and* **18**–**20**

	2 [12]	**4**[a])	**7**	**8**	**11**[b])	**18**	**19**[b])	**20**[b])
C(1)	96.7	96.4	96.4	95.3	95.8	97.2	95.8	95.7
C(2)	54.9	55.0	56.4	56.0	54.2	56.2	55.3	54.8
C(3)	68.4[c])	69.1[c])	69.4	72.6[c])	79.6	74.2[c])	79.8	76.6
C(4)	68.3[c])	68.7[c])	79.0	70.9[c])	67.4	78.8[d])	68.3	67.4
C(5)	67.9[c])	68.2[c])	63.7	69.6	69.3	64.4	69.2	68.5
C(6)	69.4[d])	60.8[d])	69.1	70.1[d])	69.5	69.3[e])	62.7	62.3
C(1′)	–	–	–	–	100.0	102.3	100.1	104.1
C(2′)	–	–	–	–	79.1	82.7	79.0	82.3
C(3′)	–	–	–	–	81.3	84.5	81.3	84.9
C(4′)	–	–	–	–	77.9	78.0[d])	77.9	77.9
C(5′)	–	–	–	–	71.9	72.6[c])	72.1	74.9
C(6′)	–	–	–	–	69.0	69.2[e])	69.0	69.0
PhCH	–	–	102.0	–	–	102.3	–	–
Allyl	68.8[d]), 133.5, 116.8	68.0[d]), 134.7, 115.7	70.7, 133.7, 117.5	70.6[d]), 133.8, 117.2	69.2, 134.5, 116.8	70.8, 133.9, 117.4	69.4, 134.4, 117.0	68.7, 134.3, 116.2

[a]) In (D_6)DMSO. [b]) Assignments based upon $^1H,^{13}C$-HMQC spectrum. [c])[d])[e]) Assignments may be interchanged.

H); 7.02–7.00 (*m*, 2 arom. H); 6.01 (*ddt*, $J \approx 17.2, 10.4, 5.3$, 1 olef. H); 5.36 (*dq*, $J \approx 17.3, 1.5$, 1 olef. H); 4.98 (*dq*, $J \approx 10.4, 1.2$, 1 olef. H); 4.78 (*d*, $J = 11.2$, PhC*H*); 4.68 (*d*, $J = 11.0$, PhC*H*); 4.60 (*d*, $J = 11.0$, PhC*H*); 4.45 (*d*, $J = 12.1$, PhC*H*); 4.41 (*d*, $J = 11.2$, PhC*H*); 4.37 (*d*, $J = 12.1$, PhC*H*); 4.31 (*ddt*, $J \approx 12.2, 5.5, 1.4$, 1 allyl. H); 4.22 (*d*, $J = 12.5$, PhC*H*); 3.97 (*d*, $J = 12.3$, exchange with D_2O, HO–C(4)); 3.88 (*d*, $J = 12.5$, PhC*H*); 3.87–3.81 (*m*, with D_2O *dd*, $J = 9.6, 3.3$, H–C(4)). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 168.2 (*s*, 2 C); 138.8 (*s*); 138.5 (*s*); 138.4 (*s*); 138.1 (*s*); 137.8 (*s*); 133.5 (*d*, 2 C); 132.1 (*s*, 2 C); 128.4–127.4 (several *d*); 122.8 (*d*, 2 C); 75.4 (*t*); 74.5 (*t*); 73.4 (*t*); 73.3 (*t*); 72.9 (*t*). ESI-MS: 985 (100, $[M + Na]^+$). Anal. calc. for $C_{58}H_{59}NO_{12}$ (962.12): C 72.41, H 6.18, N 1.46; found: C 72.19, H 6.38, N 1.43.

*Allyl 6-*O*-Benzyl-2-deoxy-2-phthalimido-3-*O*-(2,3,4,6-tetra-*O*-benzyl-β-*D*-glucopyranosyl)-α-*D*-allopyranoside* (**12**): R_f (toluene/AcOEt 9:1) 0.17. ^1H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.77–7.74 (*m*, 2 arom. H); 7.60–7.57 (*m*, 2 arom. H); 7.35–7.19 (*m*, 21 arom. H); 7.10–7.07 (*m*, 4 arom. H); 6.01 (*dddd*, $J = 17.2, 10.5, 5.3, 4.8$, 1 olef. H); 5.51 (*dq*, $J \approx 17.2, 1.5$, 1 olef. H); 5.18 (*dq*, $J \approx 10.5, 1.2$, 1 olef. H); 4.93 (*d*, $J = 11.2$, PhC*H*); 4.88 (*d*, $J = 11.2$, PhC*H*); 4.86 (*d*, $J = 11.2$, PhC*H*); 4.80 (*d*, $J = 11.2$, PhC*H*); 4.69 (*d*, $J = 10.8$, PhC*H*); 4.55 (*d*, $J = 12.1$, PhC*H*); 4.47 (*d*, $J = 12.1$, PhC*H*); 4.41 (*d*, $J = 10.8$, PhC*H*); 4.29 (*ddt*, $J \approx 13.2, 4.9, 1.2$, 1 allyl. H); 4.13 (*ddt*, $J \approx 13.2, 5.3, 1.3$, 1 allyl. H); 3.80 (*d*, $J = 12.0$, PhC*H*); 3.61 (*t*, $J = 9.1$, H–C(3′)); 3.37 (*d*, $J = 11.7$, exchange with D_2O, HO–C(4)); 3.35 (*dd*, $J = 10.6, 4.7$, H–C(6)); 3.28–3.23 (*AB* of *ABM*, H–C(5′), H–C(6′)); 3.17 (*M* of *ABM*, H–C(6′)).

Glycosidation of **8**. As described for the glycosidation of **2**, with **8** (10 mg, 0.023 mmol), dioxane (0.2 ml), and **1** (16.5 mg, 0.030 mmol). FC (toluene/AcOEt 9:1 → 5:1) yielded pure fractions of **13**, **15**, **16**, and **14** and **13**/**15**, **15**/**16**, and **16**/**14**, of which the ratios were determined by anal. HPLC. The yields (**13**: 12.5%; **15**: 13%; **16**: 20.5%; **14**: 16%) were calculated from the pure fractions and the HPLC proportions of the mixtures. Elution with toluene/AcOEt 1:1 gave **8** (3 mg, 30%).

*Allyl 6-*O*-Benzyl-2-deoxy-2-phthalimido-3-*O*-(2,3,4,6-tetra-*O*-benzyl-α-*D*-glucopyranosyl)-β-*D*-allopyranoside* (**13**): R_f (toluene/AcOEt 9:1) 0.24. Anal. HPLC (CH_2Cl_2/0.2% MeOH, 1.5 ml/min): t_R 7.2 min. ^1H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.78–7.75 (*m*, 2 arom. H); 7.64 (*m*, 1 arom. H); 7.58 (*m*, 1 arom. H); 7.45–7.09 (*m*, 23 arom. H); 6.88–6.85 (*m*, 2 arom. H); 5.93 (*ddt*, $J = 17.2, 10.3, 5.9$, 1 olef. H); 5.23 (*dq*, $J \approx 17.2, 1.5$, 1 olef. H); 5.10 (*dq*, $J \approx 10.3, 1.3$, 1 olef. H); 4.93 (*d*, $J = 11.0$, PhC*H*); 4.85 (*d*, $J = 11.0$, PhC*H*); 4.79 (*d*, $J = 11.1$, PhC*H*); 4.54 (*AB*, PhCH_2); 4.21 (*ddt*, $J \approx 12.4, 6.1, 1.3$, 1 allyl. H); 3.96 (*d*, $J = 12.7$, PhC*H*).

*Allyl 6-*O*-Benzyl-2-deoxy-2-phthalimido-3-*O*-(2,3,4,6-tetra-*O*-benzyl-β-*D*-glucopyranosyl)-β-*D*-allopyranoside* (**14**): R_f (toluene/AcOEt 9:1) 0.11. Anal. HPLC (CH_2Cl_2/0.2% MeOH, 1.5 ml/min): t_R 15.4 min. ^1H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.74–7.67 (*m*, 2 arom. H); 7.58 (*m*, 1 arom. H); 7.47 (*m*, 1 arom. H); 7.38–7.14 (*m*, 23 arom. H); 7.02 (*m*, 2 arom. H); 5.88 (*ddt*, $J = 17.2, 10.3, 5.8$, 1 olef. H); 5.20 (*dq*, $J \approx 17.2, 1.5$, 1 olef. H); 5.09 (*dq*, $J \approx 10.3, 1.3$, 1 olef. H); 4.96 (*d*, $J = 11.0$, PhC*H*); 4.85 (*d*, $J = 11.0$, PhC*H*); 4.80 (*AB*,

PhCH_2); 4.64 (*d*, *J* = 10.8, PhC*H*); 4.58 (*d*, *J* = 12.2, PhC*H*); 4.52 (*d*, *J* = 12.2, PhC*H*); 4.36 (*ddt*, *J* ≈ 12.4, 5.7, 1.3, 1 allyl. H); 4.34 (*d*, *J* = 10.8, PhC*H*); 3.89 (*d*, *J* = 12.1, PhC*H*); 3.84 (*d*, *J* = 12.1, PhC*H*).

*Allyl 6-*O*-Benzyl-2-deoxy-2-phthalimido-4-*O*-(2,3,4,6-tetra-*O*-benzyl-α-*D*-glucopyranosyl)-β-*D*-allopyranoside* (**15**): R_f (toluene/AcOEt 9:1) 0.20. Anal. HPLC (CH_2Cl_2/0.2% MeOH, 1.5 ml/min): t_R 6.6 min. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.90–7.88 (*m*, 2 arom. H); 7.79–7.75 (*m*, 2 arom. H); 7.37 7.22 (*m*, 20 arom. H); 7.15–7.09 (*m*, 3 arom. H); 6.97–6.90 (*m*, 2 arom. H); 5.94 (*d*, *J* = 8.7, H–C(1)); 5.88 (*ddt*, *J* = 17.2, 10.3, 5.9, 1 olef. H); 5.19 (*dq*, *J* ≈ 17.2, 1.5, 1 olef. H); 5.08 (*dq*, *J* ≈ 10.3, 1.3, 1 olef. H); 4.83 (*AB*, PhCH_2); 4.79 (*d*, *J* = 10.9, PhC*H*); 4.76 (*d*, *J* = 11.3, PhC*H*); 4.59 (*d*, *J* = 12.0, PhC*H*); 4.54 (*d*, *J* = 12.0, PhC*H*); 4.53 (*d*, *J* = 12.1, PhC*H*); 4.48 (*m*, 2 PhC*H*); 4.37 (*d*, *J* = 12.1, PhC*H*); 4.35 (*ddt*, *J* ≈ 12.3, 5.7, 1.3, 1 allyl. H); 3.87 (br. *s*, exchange with D_2O, HO–C(3)).

*Allyl 6-*O*-Benzyl-2-deoxy-2-phthalimido-4-*O*-(2,3,4,6-tetra-*O*-benzyl-β-*D*-glucopyranosyl)-β-*D*-allopyranoside* (**16**): R_f (toluene/AcOEt 9:1) 0.15. Anal. HPLC (CH_2Cl_2/0.2% MeOH, 1.5 ml/min): t_R 11.2 min. IR ($CHCl_3$): 3590*w*, 3090*w*, 3060*w*, 3030*w*, 3000*w*, 2960*w*, 2930*m*, 2870*w*, 1780*w*, 1715*s*, 1490*w*, 1460*w* (sh), 1450*w*, 1385*m*, 1375*m* (sh), 1360*m*, 1090*s* (br.), 1070*s*, 1050*s* (sh), 1030*s*, 1015*s*, 930*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.83–7.81 (*m*, 2 arom. H); 7.71–7.68 (*m*, 2 arom. H); 7.33–7.24 (*m*, 18 arom. H); 7.19 7.14 (*m*, 6 arom. H); 7.10–7.06 (*m*, 1 arom. H); 5.88 (*ddt*, *J* = 17.2, 10.3, 5.9, 1 olef. H); 5.18 (*dq*, *J* ≈ 17.2, 1.5, 1 olef. H); 5.08 (*dq*, *J* ≈ 10.3, 1.3, 1 olef. H); 4.87 (*d*, *J* = 11.0, PhC*H*); 4.80 (*d*, *J* = 11.1, PhC*H*); 4.78 (*d*, *J* = 11.0, PhC*H*); 4.77 (*d*, *J* = 10.9, PhC*H*); 4.71 (*d*, *J* = 11.1, PhC*H*); 4.53–4.43 (*m*, H–C(3), 3 PhC*H*); 4.42 (*d*, *J* = 12.3, PhC*H*); 4.38 (*d*, *J* = 12.3, PhC*H*); 4.36 (*ddt*, *J* ≈ 12.5, 5.7, 1.3, 1 allyl. H); 3.10 (br. *s*, exchange with D_2O, HO–C(3)). CI-MS (NH_3): 980.5 (33, $[M + NH_4]^+$), 979.5 (52).

Glycosidation of **7**. A mixture of **7** (63 mg, 0.144 mmol) and 4-Å molecular sieves (80 mg) in dioxane (1.9 ml) was stirred under Ar for 30 min, treated with **1** (150 mg, 0.272 mmol), and stirred for 3 h. Filtration through *Celite*, evaporation of the filtrate, and FC (hexane/CH_2Cl_2 1:5) gave **17** (19.5 mg, 14%), **18** (72 mg, 52%), and **7** (20 mg, 32%).

*Allyl 4,6-*O*-Benzylidene-2-deoxy-2-phthalimido-3-*O*-(2,3,4,6-tetra-*O*-benzyl-α-*D*-glucopyranosyl)-β-*D*-allopyranoside* (**17**): R_f (hexane/CH_2Cl_2 1:6) 0.27. IR ($CHCl_3$): 3090*w*, 3070*w*, 3040*w*, 3000*w*, 2930*w*, 2910*w*, 2870*w*, 1775*w*, 1715*s*, 1495*w*, 1470*w* (sh), 1455*w*, 1390*m*, 1365*m* (sh), 1350*m* (sh), 1310*w*, 1175*m* (sh), 1155*m* (sh), 1145*m*, 1110*s*, 1090*s*, 1075*s* (sh), 1050*s*, 1030*s* (sh), 1015*s*, 940*w*, 920*w*, 875*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.74–7.72 (*m*, 1 arom. H); 7.68–7.65 (*m*, 1 arom. H); 7.62–7.52 (*m*, 4 arom. H); 7.36–7.21 (*m*, 16 arom. H); 7.19–7.15 (*m*, 3 arom. H); 7.12–7.09 (*m*, 2 arom. H); 6.90–6.87 (*m*, 2 arom. H); 6.20 (*d*, *J* = 8.7, H–C(1)); 5.88 (*dddd*, *J* = 17.2, 10.5, 5.9, 4.6, 1 olef. H); 5.57 (*s*, PhC*H*); 5.22 (*dq*, *J* ≈ 17.2, 1.5, 1 olef. H); 5.10 (*dq*, *J* ≈ 10.5, 1.3, 1 olef. H); 4.86 (*d*, *J* = 11.0, PhC*H*); 4.76 (*d*, *J* = 10.6, PhC*H*); 4.70 (*d*, *J* = 12.1, PhC*H*); 4.54 (*d*, *J* = 12.1, PhC*H*); 4.46 (*t*, *J* ≈ 2.5, H–C(3)); 4.43 (*d*, *J* = 10.6, PhC*H*); 4.39 (*ddt*, *J* ≈ 12.3, 4.6, 1.2, 1 allyl. H); 4.21 (*d*, *J* = 12.1, PhC*H*); 4.19 (*ddt*, *J* ≈ 12.3, 5.9, 1.3, 1 allyl. H); 4.11 (*d*, *J* = 12.6, PhC*H*); 3.58 (*d*, *J* = 12.6, PhC*H*).

*Allyl 4,6-*O*-Benzylidene-2-deoxy-2-phthalimido-3-*O*-(2,3,4,6-tetra-*O*-benzyl-β-*D*-glucopyranosyl)-β-*D*-allopyranoside* (**18**): R_f (hexane/CH_2Cl_2 1:6) 0.20. $[\alpha]_D^{25} = -46.1$ (*c* = 0.7, $CHCl_3$). IR ($CHCl_3$): 3090*w*, 3070*w*, 3000*w*, 2960*w*, 2870*w*, 1780*w*, 1720*s*, 1470*w* (sh), 1455*w*, 1390*m*, 1375*m* (sh), 1360*m*, 1310*w*, 1260*m*, 1170*m*, 1135*m* (sh), 1090*s* (br.), 1050*s* (sh), 1030*s* (sh), 1010*s*, 915*w*, 870*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.78–7.76 (*m*, 1 arom. H); 7.72–7.70 (*m*, 1 arom. H); 7.56–7.44 (*m*, 7 arom. H); 7.36–7.16 (*m*, 18 arom. H); 7.05–7.02 (*m*, 2 arom. H); 5.86 (*dddd*, *J* = 17.2, 10.3, 5.8, 4.5, 1 olef. H); 5.57 (*s*, PhC*H*); 5.21 (*dq*, *J* ≈ 17.2, 1.5, 1 olef. H); 5.19 (*d*, *J* = 11.1, PhC*H*); 5.10 (*dq*, *J* ≈ 10.3, 1.2, 1 olef. H); 4.85 (*d*, *J* = 11.2, PhC*H*); 4.84 (*d*, *J* = 10.8, PhC*H*); 4.67–4.65 (*m*, 2 PhC*H*); 4.16 (*ddt*, *J* ≈ 12.5, 5.9, 1.3, 1 allyl. H); 4.14 (*d*, *J* = 12.1, PhC*H*); 3.99 (*d*, *J* = 12.1, PhC*H*). ^{13}C-NMR (50 MHz, $CDCl_3$): see *Table 4*; additionally, 168.2 (*s*); 167.8 (*s*); 138.8 (*s*); 138.5 (*s*); 138.1 (*s*); 138.0 (*s*); 137.3 (*s*); 133.7 (*d*); 133.2 (*d*); 132.7 (*s*); 131.6 (*s*); 128.5–126.3 (several *d*); 122.9 (*d*, 2 C); 78.0 (*d*); 75.6 (*t*); 74.9 (*t*); 74.6 (*t*); 72.9 (*t*); 70.8 (*t*, 1 allyl. C); 69.3 (*t*). ESI-MS: 998.7 (70, $[M + K]^+$), 982.4 (100, $[M + Na]^+$). Anal. calc. for $C_{58}H_{57}NO_{12}$ (960.10): C 72.56, H 5.98, N 1.46; found: C 72.69, H 6.04, N 1.61.

Glycosidation of **4**. Under Ar at r.t., **4** (90 mg, 0.258 mmol) was dissolved in dioxane (4.7 ml) under stirring for 5 min. After the addn. of **1** (142 mg, 0.258 mmol), the soln. was stirred for 4 h and evaporated. The residue was dissolved in $CHCl_3$ (3 ml) and absorbed on silica gel. FC (toluene/AcOEt 4:1 → 3:1 → 2.5:1 → 2:1) yielded **21** (20.2 mg, 9%), **19** (92 mg, 41%), and **20** (36 mg, 16%). Elution with AcOEt gave **4** (28.5 mg, 32%).

*Allyl 2-Deoxy-2-phthalimido-3-*O*-(2,3,4,6-tetra-*O*-benzyl-α-*D*-glucopyranosyl)-α-*D*-allopyranoside* (**19**): R_f (toluene/AcOEt 2:1) 0.26. $[\alpha]_D^{25} = -37.1$ (*c* = 0.2, $CHCl_3$). IR ($CHCl_3$): 3595*w*, 3450*w* (br.), 3090*w*, 3070*w*, 3040*w*, 3000*w*, 2925*m*, 2870*m*, 1780*w*, 1715*s*, 1610*w*, 1495*w*, 1450*m*, 1385*m* (sh), 1365*m*, 1320*m*, 1150*m*, 1075*s*, 1045*s*, 1030*s*, 910*w*, 885*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.71 (*m*, 2 arom. H); 7.59–7.57 (*m*, 2 arom. H); 7.33–7.25 (*m*, 12 arom. H); 7.21–7.14 (*m*, 6 arom. H); 7.02–6.99 (*m*, 2 arom. H); 6.01 (*ddt*, *J* = 17.2, 10.4, 5.3, 1 olef. H); 5.38 (*dq*, *J* ≈ 17.2, 1.5, 1 olef. H); 4.99 (*dq*, *J* ≈ 10.4, 1.2, 1 olef. H); 4.79 (*d*, *J* = 11.6, PhC*H*); 4.67

(*d*, J = 11.1, PhC*H*); 4.62 (*d*, J = 11.1, PhC*H*); 4.50 (*d*, J = 12.0, PhC*H*); 4.43–4.40 (*m*, 2 PhC*H*); 4.28 (*ddt*, $J \approx$ 12.1, 5.6, 1.3, 1 allyl. H); 4.23 (*d*, J = 12.7, PhC*H*); 3.99 (*d*, J = 12.4, exchange with D_2O, HO–C(4)); 3.89 (*d*, J = 12.7, PhC*H*); 3.73–3.65 (*m*, with D_2O 3.69, *dd*, J = 9.8, 2.5, H–C(4)); 1.90 (br. *t*, $J \approx$ 6.0, exchange with D_2O, HO–C(6)). ^{13}C-NMR (HMQC, 100 MHz, $CDCl_3$): see *Table 4*; additionally, 133.5 (2 C); 129.0–126.0 (several arom. C); 122.7 (2 C); 75.4 (Ph*C*H_2); 74.6 (Ph*C*H_2); 73.5 (Ph*C*H_2); 72.9 (Ph*C*H_2); 69.4 (allyl. C). CI-MS (NH_3): 889 (45, $[M + NH_4]^+$), 872 (10, $[M + 1]^+$). Anal. calc. for $C_{51}H_{53}NO_{12}$ (871.99): C 70.25, H 6.12, N 1.61; found: C 70.20, H 6.31, N 1.53.

*Allyl 2-Deoxy-2-phthalimido-3-*O*-(2,3,4,6-tetra-*O*-benzyl-β-*D*-glucopyranosyl)-α-*D*-allopyranoside* (**20**): R_f (toluene/AcOEt 2:1) 0.17. $[\alpha]_D^{25} = +20.3$ (c = 0.3, $CHCl_3$). IR ($CHCl_3$): 3590*w*, 3420*w* (br.), 3090*w*, 3070*w*, 3040*w*, 3000*w*, 2930*w*, 2870*w*, 1780*w*, 1720*s*, 1605*w*, 1495*w*, 1455*w*, 1390*m*, 1360*m*, 1325*w*, 1145*m*, 1115*m*, 1085*s*, 1060*s*, 1050*s*, 1030*s*, 885*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.76–7.74 (*m*, 2 arom. H); 7.61–7.59 (*m*, 2 arom. H); 7.36–7.22 (*m*, 17 arom. H); 7.10–7.06 (*m*, 3 arom. H); 6.03 (*ddt*, J = 17.2, 10.3, 4.9, 1 olef. H); 5.54 (*dq*, $J \approx$ 17.2, 1.8, 1 olef. H); 5.21 (*dq*, $J \approx$ 10.3, 1.3, 1 olef. H); 4.97 (*d*, J = 11.3, PhC*H*); 4.87 (*d*, J = 11.0, PhC*H*); 4.85 (*d*, J = 11.3, PhC*H*); 4.83 (*d*, J = 11.0, PhC*H*); 4.69 (*d*, J = 10.8, PhC*H*); 4.43 (*d*, J = 10.8, PhC*H*); 4.28 (*ddt*, $J \approx$ 13.2, 4.9, 1.6, 1 allyl. H); 4.14 (*ddt*, $J \approx$ 13.2, 4.9, 1.6, 1 allyl. H); 3.93 (*d*, J = 11.8, PhC*H*); 3.78 (*d*, J = 11.8, PhC*H*); 3.34 (*d*, J = 11.8, exchange with D_2O, HO–C(4)); 1.66 (*t*, $J \approx$ 6.4, exchange with D_2O, HO–C(6)). ^{13}C-NMR (HMQC, 100 MHz, $CDCl_3$): see *Table 4*; additionally, 133.6 (2 C); 129.0–127.0 (several arom. C); 123.0 (2 C); 116.2 (1 olef. C); 75.5 (Ph*C*H_2); 75.4 (Ph*C*H_2); 74.7 (Ph*C*H_2); 72.9 (Ph*C*H_2). CI-MS (NH_3): 889 (100, $[M + NH_4]^+$), 742 (82).

*Allyl 2-Deoxy-2-phthalimido-4-*O*-(2,3,4,6-tetra-*O*-benzyl-β-*D*-glucopyranosyl)-α-*D*-allopyranoside* (**21**): R_f (toluene/AcOEt 2:1) 0.37. $[\alpha]_D^{25} = +45.0$ (c = 0.3, $CHCl_3$). IR ($CHCl_3$): 3590*w*, 3400*w* (br.), 3000*w*, 2925*w*, 2870*w*, 1770*w*, 1715*s*, 1470*w* (sh), 1450*w*, 1365*m*, 1330*m*, 1085*s*, 1060*s*, 1050*s*, 1030*s* (sh), 890*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): see *Table 3*; additionally, 7.91–7.88 (*m*, 2 arom. H); 7.80–7.77 (*m*, 2 arom. H); 7.37–7.23 (*m*, 15 arom. H); 7.19–7.14 (*m*, 4 arom. H); 7.05 (*m*, 1 arom. H); 5.95 (br. *s*, exchange with D_2O, HO–C(3)); 5.74 (*dddd*, J = 17.2, 10.4, 5.5, 4.7, 1 olef. H); 5.24 (*dq*, $J \approx$ 17.2, 1.7, 1 olef. H); 5.06 (*dq*, $J \approx$ 10.4, 1.5, 1 olef. H); 4.95 (*d*, J = 11.1, PhC*H*); 4.90 (*d*, J = 11.0, PhC*H*); 4.83 (*d*, J = 11.1, PhC*H*); 4.81 (*d*, J = 11.0, PhC*H*); 4.80 (*d*, J = 11.0, PhC*H*); 4.55 (*d*, J = 11.0, PhC*H*); 4.53 (*d*, J = 11.8, PhC*H*); 4.51 (*d*, J = 11.8, PhC*H*); 4.20 (*ddt*, $J \approx$ 13.5, 4.7, 1.7, 1 allyl. H); 1.87 (br. *s*, exchange with D_2O, HO–C(6)). CI-MS (NH_3): 889 (76, $[M + NH_4]^+$).

REFERENCES

[1] P. R. Muddasani, B. Bernet, A. Vasella, *Helv. Chim. Acta* **1994,** *77,* 334.
[2] P. Uhlmann, A. Vasella, *Helv. Chim. Acta* **1994,** *77,* 1175.
[3] A. Vasella, in 'Carbohydrates', Ed. S. M. Hecht, submitted.
[4] A. Vasella, *Pure Appl. Chem.* **1993,** *65,* 731.
[5] A. Vasella, *Pure Appl. Chem.* **1991,** *63,* 507.
[6] K. Briner, A. Vasella, *Helv. Chim. Acta* **1992,** *75,* 621.
[7] P. Uhlmann, A. Vasella, *Helv. Chim. Acta* **1992,** *75,* 1979.
[8] E. Bozó, A. Vasella, *Helv. Chim. Acta* **1992,** *75,* 2613.
[9] P. R. Muddasani, E. Bozó, B. Bernet, A. Vasella, *Helv. Chim. Acta* **1994,** *77,* 257.
[10] E. Bozó, A. Vasella, *Helv. Chim. Acta* **1994,** *77,* 745.
[11] K. Briner, A. Vasella, *Helv. Chim. Acta* **1990,** *73,* 1764.
[12] J.-L. Maloisel, A. Vasella, *Helv. Chim Acta* **1992,** *75,* 1491.
[13] J.-L. Maloisel, A. Vasella, B. M. Trost, D. L. van Vranken, *Helv. Chim. Acta* **1992,** *75,* 1515.
[14] H. Paulsen, D. Hadamczyk, W. Kutschker, A. Bünsch, *Liebigs Ann. Chem.* **1985,** 129.
[15] H. Paulsen, M. Heume, H. Nürnberger, *Carbohydr. Res.* **1990,** *200,* 127.
[16] H.-P. Wessel, D. R. Bundle, *J. Chem. Soc., Perkin Trans. 1* **1985,** 2251.
[17] P. J. Garegg, H. Hultberg, S. Wallin, *Carbohydr. Res.* **1982,** *108,* 97.
[18] M. Ek, P. J. Garegg, H. Hultberg, S. Oscarson, *J. Carbohydr. Chem.* **1983,** *2,* 305.
[19] H. Günther, 'NMR-Spektroskopie', Georg Thieme Verlag, Stuttgart, 1983, p. 91.
[20] F. Mohamadi, N. G. J. Richards, W. C. Guida, R. Liskamp, C. Caufield, M. Lipton, G. Chang, T. Hendrickson, W. C. Still, *J. Comput. Chem.* **1990,** *11,* 440.
[21] R. R. Fraser, M. Kaufman, P. Morand, G. Govil, *Can. J. Chem.* **1969,** *47,* 403.
[22] C. J. Easton, C. A. Hutton, E. R. T. Tiekink, *Z. Kristallogr.* **1993,** *203,* 310; *Tetrahedron Lett.* **1990,** *31,* 7059.

[23] a) W. Watt, R. Ghosh, T. Seal, B. Mukherjee, *Acta Crystallogr., Sect. C* **1993,** *49,* 171; b) A. Guggisberg, A. A. Gormann, B. W. Bycroft, H. Schmid, *Helv. Chim. Acta* **1969,** *52,* 76.
[24] K. Yamaguchi, G. Matsumura, M. Shimizu, H. Tanaka, T. Miyasaka, *Acta Crystallogr., Sect. C* **1992,** *48,* 384.
[25] A. Chiaroni, N. Langlois, C. Riche, *Acta Crystallogr., Sect. C* **1992,** *48,* 2194.
[26] R. Gericke, J. Harting, I. Lues, C. Schittenhelm, *J. Med. Chem.* **1991,** *34,* 3074.
[27] T. Itaya, N. Watanabe, A. Mizutani, *Tetrahedron Lett.* **1986,** *27,* 4043.
[28] G. Deffieux, M. Gardet, J. M. Leger, A. Carpy, *Acta Crystallogr., Sect. B* **1979,** *35,* 2358; *ibid.* **1977** *33,* 1977.
[29] J. Fridrichson, A. McL. Mathieson, *Acta Crystallogr.* **1967,** *23,* 439.
[30] B. Wang, F. Takusagawa, M. P. Mertes, K. Bowman-James, *Acta Crystallogr., Sect. C* **1993,** *49,* 1568.
[31] X. Cao, W. Pfleiderer, H. Rosemeyer, F. Seela, W. Bannwarth, P. Schönholzer, *Acta Crystallogr., Sect. B* **1992,** *75,* 1267; W. Saenger, G. Ritzmann, W. Pfleiderer, *ibid.* **1977,** *33,* 2989.
[32] W. J. Cook, S. E. Ealick, J. A. Sechrist III, *Acta Crystallogr., Sect. C* **1984,** *40,* 885; G. I. Birnbaum, F. E. Hruska, W. P. Niemczura, *J. Am. Chem. Soc.* **1980,** *102,* 5586; D. Suck, W. Saenger, *ibid.* **1972,** *94,* 6520.
[33] J. Gorski, P. Tollin, *Cryst. Struct. Commun.* **1982,** *11,* 543.
[34] H. L. De Winter, N. M. Blaton, OI. M. Peeters, C. J. De Ranter, A. Van Aerschot, P. Herdewijn, *Acta Crystallogr., Sect. C* **1991,** *47,* 838.
[35] L. D. Nord, N. K. Dalley, P. A. McKernan, R. K. Robins, *J. Med. Chem.* **1987,** *30,* 1044.
[36] G. A. Jeffrey, W. Saenger, in 'Hydrogen Bonding in Biological Structures', Springer-Verlag, Berlin, 1991.
[37] K. Bock, J. Ø. Duus, *J. Carbohydr. Chem.* **1994,** *13,* 513; J. Ø. Duus, Ph. D. Thesis, Technical University of Denmark, Copenhagen, 1993.
[38] A. Bax, M. Ikura, L. E. Kay, D. A. Torchia, R. Tschudin, *J. Magn. Reson.* **1990,** *86,* 304; A. Bax, R. H. Griffey, B. L. Hawkins, *ibid.* **1983,** *55,* 301.
[39] J. B. Fenn, M. Mann, C. K. Meng, S. F. Wong, C. N. Whitehouse, *Science* **1989,** *246,* 64.