over Na_2SO_4. Removal of solvent in vacuo, followed by column chromatography (silica gel, 40% ethyl acetate–hexane) of the crude product, provided 54 mg (93%) of **57**: R_f 0.07 (20% ethyl acetate–hexane); $[\alpha]^{22}_D$ +41° (*c* 0.24, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 7.40–7.24 (m, 16 H), 7.01 (d, *J* = 2.0 Hz, 1 H), 6.93 (d, *J* = 2.0 Hz, 1 H), 5.38 (s, 2 H), 5.36 (s, 2 H), 5.25 (m, 2 H), 4.86–4.71 (m, 6 H), 4.10 (m, 1 H), 3.58 (s, 3 H), 3.54–3.40 (m, 2 H), 3.22 (d, *J* = 10.0 Hz, 1 H), 2.94 (m, 1 H), 2.63 (d, *J* = 10.0 Hz, 1 H), 2.50 (m, 2 H), 2.21 (d, *J* = 7.0 Hz, 1 H), 1.55 (m, 10 H), 1.38 (d, *J* = 5.6 Hz, 3 H); IR ($CDCl_3$) 3650–3150 (br), 2940, 1675, 1620, 1565 cm^{-1}; mass spectrum *m/e* 832 (parent ion).

3-[1′[[1′(*S*),2′(*R*),3′(*S*),4′(*R*)]-3′,4′-[Cyclohexylidenebis(oxy)]-1′-methoxy-2′-oxopentyl]]-6,8,9-tris[(benzyloxy)methoxy]-1,2,3,4-tetrahydro-1(2*H*)-anthracenone (58). DMSO (0.07 mL, 1.0 mmol) was added dropwise to a −78 °C solution of oxalyl chloride (0.06 mL, 0.74 mmol) in CH_2Cl_2 (3 mL) under Ar. This solution was stirred for 10 min, and then a −78 °C solution of alcohol **57** (52 mg, 0.062 mmol) in CH_2Cl_2 (1.5 mL) was added dropwise via cannula. The cloudy mixture was stirred at −78 °C for 1.25 h, treated with triethylamine (0.21 mL, 1.48 mmol), and then allowed to warm to −5 °C over 2 h. The resulting mixture was poured into water and extracted three times with CH_2Cl_2 (3 × 30 mL). The combined extracts were dried over Na_2SO_4, and the solvent was removed in vacuo. The residue was triturated three times with ether (3 × 15 mL), and the combined triturate was filtered through a Kimwipe plug and then concentrated. The residue was purified by column chromatography (silica gel, 1:1 ether–hexane) to give 47 mg (91%) of diketone **58**: R_f 0.19 (1:1 ether–hexane); $[\alpha]^{22}_D$ −33° (*c* 0.03, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 7.40–7.24 (m, 16 H), 6.99 (d, *J* = 2.0 Hz, 1 H), 6.93 (d, *J* = 2.0 Hz, 1 H), 5.38 (s, 2 H), 5.36 (s, 2 H), 5.23 (m, 2 H), 4.86–4.71 (m, 6 H), 4.10 (m, 3 H), 3.42 (s, 3 H), 3.04–2.60 (m, 5 H), 1.55 (m, 10 H), 1.38 (d, *J* = 8.8 Hz, 3 H); IR ($CDCl_3$) 2940, 1720, 1675, 1618, 1566 cm^{-1}.

3-[1′-[[1′(*S*),2′(*R*),3′(*S*),4′(*R*)]-3′,4′-[Cyclohexylidenebis(oxy)]-1′-methoxy-2′-oxopentyl]]-6,8,9-tris[(benzyloxy)methoxy]-1,2,3,4-tetrahydro-2-[(*tert*-butyldimethylsilyl)oxy]-1(2*H*)-anthracenone, Protected Olivin 59. To a solution of diketone **58** (15.5 mg, 0.018 mmol) in dry CH_2Cl_2 (1.5 mL) under N_2 were added sequentially Et_3N (0.07 mL, 0.50 mmol) and TBDMS-OTf (0.04 mL, 0.17 mmol). After being stirred for 10 min, the reaction was diluted with CH_2Cl_2 and washed with saturated aqueous $NaHCO_3$. The organic layer was dried over Na_2SO_4 and concentrated, and the residue was purified by column chromatography (silica gel, 50:50:1 ether–hexane–triethylamine). The silyl enol ether [R_f 0.57 (1:1 ether–hexane)] so obtained was immediately dissolved in CH_2Cl_2 (1 mL), cooled to −20 °C, and treated successively with solid NaH_2PO_4 (46 mg, 0.32 mmol) and 97% *m*CPBA (46 mg, 0.32 mmol). The reaction mixture was stirred at −20 °C for 25 min and then quenched with a cold 1:1 mixture of saturated aqueous $NaHSO_3$ and $NaHCO_3$ solutions. The aqueous layer was further extracted with CH_2Cl_2, and the combined extracts were washed with saturated aqueous $NaHCO_3$ and dried over Na_2SO_4. Purification of the crude product by column chromatography (silica gel, 150:50:1 hexane–ether–triethylamine) afforded 11.6 mg (76%) of protected olivin **59**: R_f 0.55 (1:1 ether–hexane); $[\alpha]^{22}_D$ −35° (*c* 0.15, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 7.41–7.26 (m, 15 H), 7.22 (s, 1 H), 6.99 (d, *J* = 2.4 Hz, 1 H), 6.95 (d, *J* = 2.4 Hz, 2 H), 5.41–5.39 (m, 4 H), 5.31 (s, 2 H), 4.95–4.50 (m, 8 H), 4.10 (d, *J* = 8.9 Hz, 1 H), 3.98 (m, 1 H), 3.41 (s, 3 H), 3.32 (m, 1 H), 2.47–2.67 (m, 2 H), 1.61 (m, 10 H), 1.40 (d, *J* = 5.8 Hz, 3 H), 1.03 (s, 9 H), 0.32 (s, 3 H), 0.12 (s, 3 H); IR ($CDCl_3$) 2940, 1715, 1700, 1620, 1565 cm^{-1}; mass spectrum *m/e* 960 (parent ion).

Synthetic Olivin (1). Protected olivin **59** (9.1 mg, 0.008 mmol) was dissolved in dry MeOH (2 mL) and treated with 20 mg of activated Dowex 50W-X8 resin. The resulting mixture was stirred at room temperature for 6 days. Workup consisted of filtering the suspension through a Kimwipe plug and removal of MeOH in vacuo. The residue was crystallized from hexane–ether to afford 3.1 mg (95%) of olivin as a yellow solid. The material so obtained was indistinguishable from natural olivin by all of the usual criteria: R_f 0.15 (94:5:1 CH_2Cl_2–MeOH–HCOOH); mp 139–141 °C; $[\alpha]^{22}_D$ +53° (*c* 0.04, EtOH); ^1H NMR (300 MHz, CD_3CN) δ 6.77 (s, 1 H), 6.50 (d, *J* = 1.1 Hz, 1 H), 6.34 (d, *J* = 1.1 Hz, 1 H), 4.72 (d, *J* = 2.2 Hz, 1 H), 4.39 (d, *J* = 11.4 Hz, 1 H), 4.17–4.13 (m, 2 H), 3.36 (s, 3 H), 2.98–2.93 (m, 1 H) 2.69–2.53 (m, 2 H), 1.20 (d, *J* = 7.0 Hz, 3 H); IR ($CHCl_3$) 3500–3200 (br), 2920, 2850, 1730, 1635 cm^{-1}; mass spectrum *m/e* 406 (parent ion).

Natural Olivin. A solution of olivomycin A (32.9 mg, 0.028 mmol) in 3 mL of 0.05 N methanolic HCl was refluxed under nitrogen for 4 h. After being cooled to room temperature, the reaction mixture was neutralized with Ag_2CO_3. The resulting silver salts were filtered off, and the filtrate was concentrated in vacuo. The residue was then dissolved in 10 mL of water and extracted four times with EtOAc (4 × 5 mL). The combined extracts were concentrated to give a yellow oil which was crystallized from chloroform–ethanol–hexane. The yellow solid so obtained was further purified by column chromatography (silica gel, 94:5:1 CH_2Cl_2–MeOH–HCOOH) to afford 0.7 mg of olivin that was recrystallized from ether–hexane. The yield of olivin could be increased if the mother liquor from the initial crystallization was subjected to additional purification: R_f 0.15 (94:5:1 CH_2Cl_2–MeOH–HCOOH); mp 136–139 °C; $[\alpha]^{22}_D$ +56° (*c* 0.07, EtOH); ^1H NMR (300 MHz, CD_3CN) δ 6.77 (s, 1 H), 6.50 (d, *J* = 1.1 Hz, 1 H), 6.34 (d, *J* = 1.1 Hz, 1 H), 4.72 (d, *J* = 2.2 Hz, 1 H), 4.39 (d, *J* = 11.4 Hz, 1 H), 4.17–4.13 (m, 2 H), 3.36 (s, 3 H), 2.98–2.93 (m, 1 H) 2.69–2.53 (m, 2 H), 1.20 (d, *J* = 7.0 Hz, 3 H); IR ($CHCl_3$) 3500–3200 (br), 2920, 2850, 1730, 1635 cm^{-1}; mass spectrum *m/e* 406 (parent ion).

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Supplementary Material Available: General experimental details and procedures for synthesis of **20** (from **14**), **20b** (from **19**), **23** and **24** (from **14**), and **34b** (from **20b**) (4 pages). Ordering information is given on any current masthead page.

[4 + 2] Cycloaddition Reaction of Dibenzyl Azodicarboxylate and Glycals

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Abstract: The [4 + 2] cycloaddition reaction of dibenzyl azodicarboxylate and glycals allows the stereoselective introduction of an amino function at C-2 of a carbohydrate. Very good results were obtained with both furanoid and pyranoid glycals, except when triacetylglucal (TAG) was used as the substrate. In some instances the course of the reaction was found to be concentration dependent.

Recently, we reported a new and efficient method for the preparation of 2-aminoglycosides.[1,2] This method combines the amination and glycosidation steps into a single strategy, the key step being the highly stereoselective [4 + 2] cycloaddition reaction of dibenzyl azodicarboxylate and glycals (Scheme I). The adducts

† Merck Frosst Canada Inc.
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(1) Fitzsimmons, B. J.; Leblanc, Y.; Rokach, J. *J. Am. Chem. Soc.* **1987**, *109*, 285–286.

0002-7863/89/1511-2995$01.50/0

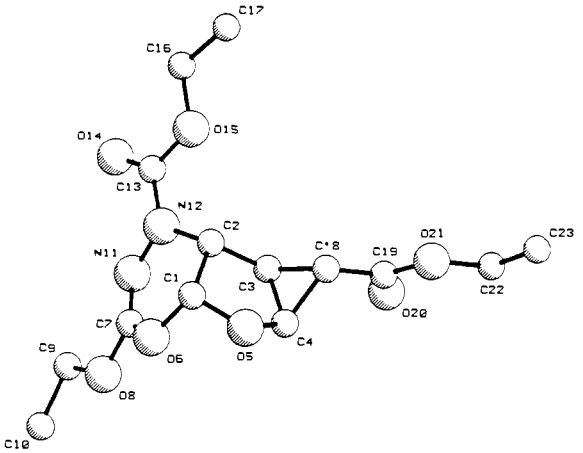
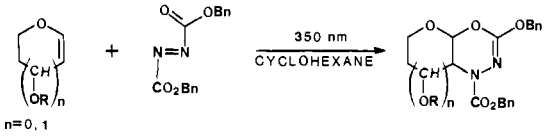


Figure 1. Computer-generated drawing of **13** derived from the X-ray coordinates with hydrogens omitted for clarity.

Scheme I



obtained by this reaction are powerful and versatile glycosylating agents and can thus be used to prepare a variety of complex 2-aminoglycosides. Herein we report further examples, experimental details, and some mechanistic aspects of this reaction.

At the outset, it was important to determine the structure of the cycloadducts. It is reported in the literature that the reaction of azodicarboxylate with acyclic vinyl ethers can produce [4 + 2] and/or [2 + 2] adducts.[3,4] Unfortunately it was difficult on the basis of NMR data to determine with absolute certainty which of the adducts we had obtained due to their structural similarity, although the adducts showed an IR band at 1675 cm^{-1} for a C=N, suggesting [4 + 2] cycloadducts. The final proof rested on X-ray crystallographic analysis of adduct **13**, obtained in 94% yield by reaction of diethyl azodicarboxylate (DEAD) on cyclopropylfuran ester **1**[5] (Table I), confirming that compound **13** was a [4 + 2] cycloadduct (Figure 1). The chemical shifts in the ^1H and ^{13}C NMR spectra of the adducts prepared for this study were comparable to those observed for compound **13**, thus indicating that [4 + 2] adducts were consistently obtained.

As reported in our first paper, the C-3 substituent of furanoid glycals has a strong directing effect, only one diastereoisomer being detected in all cases studied. However, the amino sugars present in natural products are usually in the pyranoside form. Therefore, even though some 2-aminofuranosides such as methyl L-2-aminoglucofuranoside (**26**)[6] can be easily converted to their pyranoside form (**31**), it was desirable to investigate the applicability of this method on pyranoid glycals.

Under the standard conditions used for furanoid glycals, no transformation to the cycloadduct was observed when triacetylglucal (TAG) (**3**) was used as the substrate, even after many weeks of irradiation. However, the reaction did proceed slowly when heated at 90 °C, to give after 2 weeks a diastereomeric mixture of cycloadduct **15** (3/2) with a 20% conversion. Two hypotheses were considered to rationalize this result: a lower ground state energy of pyranoid glycals compared to furanoid glycals or the result of an unfavorable effect of the acetoxy units on the ring. To test these hypotheses, the reaction was first attempted on the simplest case; dihydropyran **7**. After 3 days of irradiation under the same conditions as utilized for the furanoid glycals, a 70% yield of cycloadduct **19** was obtained. Thus it appeared that the latter hypothesis might explain the poor reactivity of TAG. Indeed, when the three acetoxy groups were replaced by three silyloxy groups (entry 4, Table I), the cycloaddition reaction took place under the standard conditions to produce cycloadduct **16** in good yield. Surprisingly, only one diastereoisomer was produced even though glycal **4** is expected to be in a half-chair conformation where the three silyl ethers are in a quasi-equatorial orientation. It is also interesting to note that no trans-diaxial coupling was observed in the ^1H NMR spectra for the *N*-acetyl trisilyl glucopyranoside derivative **32**, which suggested a preferential boat or $^1C_4$ conformation. The strong gauche interaction between the C-3 and the C-4 silyloxy substituents must be responsible for the conformational change. By the same reasoning, the half-boat could be a favorable conformation for glycal **4** and thus the axial C-3 silyl ether would hinder the cycloaddition from the top face of the molecule. It is noteworthy that the same degree of selectivity was obtained with pentasilyl lactal **8** as a substrate. A single isomer (**20**) was isolated in 94% yield and was converted to trisaccharide **36**, which is an analogue of the blood group determinant previously prepared by Lemieux et al.[7] Galactosamine,[8] an important amino sugar, was prepared from galactal derivative **9**[9] by the same sequence; in this case the cycloaddition reaction afforded only one isomer (**21**).

In the previous examples of pyranoid glycals, the orientation of the C-3 substituent was not fixed due to the conformational flexibility of the molecules. Therefore, to make the glycals more rigid and thus observe the directing effect of the C-3 substituent on the stereoselectivity of the reaction in the case of pyranoid glycals, the three 4,6-benzylidene glycals **10–12** were prepared[10–12] and subjected to the cycloaddition conditions. With compound **10** possessing an equatorial silyl ether, the cycloaddition reaction produced a 15/1 mixture of isomers (**22**). The major isomer was found to be that in which the cycloaddition had occurred on the lower face of the molecule, trans to the C-3 substituent. This isomer was converted to tetraacetylglucosamine (**33**), proving the stereochemistry of the compound. As expected, with compound **11**, in which the silyl ether is axial, the reaction gave one isomer (**23**) corresponding to an addition from the top face of the glycal, again opposite to the C-3 substituent. Obviously, for deoxy compound **12**, no selectivity was anticipated due to the remoteness of the chiral centers from the double bond and the general planarity of the molecule. However, the reaction gave a 4/1 mixture of isomers (**24**, **25**), with the major isomer (**24**) corresponding to the formation of an axial carbon–nitrogen at C-2 giving rise directly to a quasi-chair conformation in the transition state of the reaction. In this case, the major isomer precipitated from the reaction mixture, allowing an easy separation of the diastereoisomers.

Having shown the stereocontrol exerted by the C-3 substituent of six-membered glycals on the cycloaddition reaction, we next focused our attention on the inhibitory effect of acyl groups. It was reasoned that the acetoxy groups at C-3 and C-6 should exhibit the most pronounced effect on the double bound. Thus compounds **5** and **6** were prepared and subjected to the standard

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(6) For D isomer, see: Jacquinet, J. C.; Sinay, P. *Carbohydr. Res.* **1974**, *32*, 101–114. Konstas, S.; Photaki, I.; Zervas, L. *Chem. Ber.* **1959**, *92*, 1288–1293.
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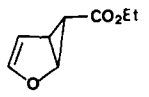
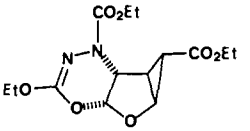
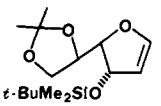
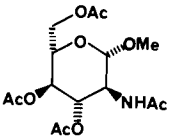
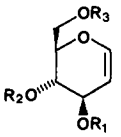
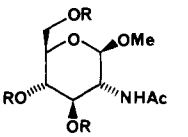
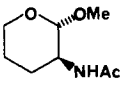
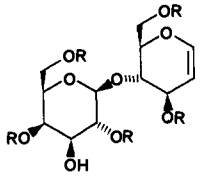
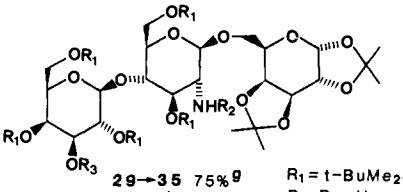
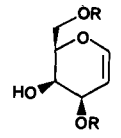
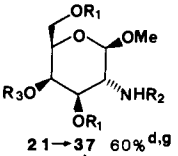
(12) Fraser-Reid, B.; Radatus, B. *J. Am. Chem. Soc.* **1970**, *92*, 6661–6663.

Table I[a]

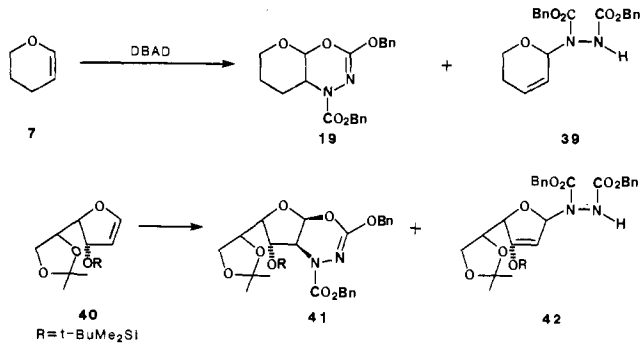
	substrate	adduct	glycoside[15]	amine
1		 **13** 94%[a]	—	—
2		**14** 70%[b]	**26** 80%[d]	 **26**→**31** 42%[f,g,h]
3	 R_1, R_2, R_3=Ac	**15** 20% (3/2)[c]	—	 **27**→**32** 72%[g,h] R = t-BuMe$_2$Si
4	R_1, R_2, R_3=t-BuMe$_2$Si	**16** 70%[b]	**27** 88%[d]	
5	R_1, R_2=Ac R_3= t-BuMe$_2$Si	**17** 0%[b]	—	[i,h] → **33** R = Ac
6	R_1 R_2=Me R_3=Ac	**18** 60% (4/1)[b]	—	
7		**19** 70%[b]	**28** 80%[d]	 **28**→**34** 75%[g,h]
8	 R = t-BuMe$_2$Si	**20** 94%[b]	**29** 82%[e]	 **29**→**35** 75%[g] R_1 = t-BuMe$_2$Si R_2, R_3 = H [j,k,l] → **36** 70% R_1, R_3 = Ac R_2=Phth
9	 R = t-BuMe$_2$Si	**21** 86%[b]	—	 **21**→**37** 60%[d,g] R_1= t-BuMe$_2$Si R_2, R_3 = H [l,l] → **38** R_1, R_2, R_3 = Ac
10	R_1= t-BuMe$_2$SiO R_2=H	**22** 70%[b](15/1)	**30** 82%[d]	**30** →**33**[g,l,m,h]
11	R_1=H R_2= t-BuMe$_2$SiO	**23** 70%[b]	—	—
12	R_1,R_2=H	**24** 70%[b] 4 : 1 TOP / **25** BOTTOM	—	—

[a] (a) DEAD, cyclohexane, CH_2Cl_2, 350 nm; (b) DBAD, cyclohexane, CH_2Cl_2, 350 nm; (c) DBAD, cyclohexane, 90 °C, 2 weeks; (d) MeOH, *p*-TsOH, room temperature; (e) diacetonide galactose, BF_3·Et_2O, −78 → −5 °C; (f) MeOH, AcCl, 0 °C → room temperature; (g) Rancy nickel/MeOH/AcOH/40 psi H_2, 118 h; (h) acetic anhydride/pyridine/room temperature; (i) *n*-Bu_4NF/THF/0 °C → room temperature; (j) phthalic anhydride, pyridine, Et_3N, 75 °C, 2 h; (k) *n*-Bu_4NF, THF, 50 °C (5 h) → room temperature (6 h); (l) Ac_2O, pyridine, 90 °C, 3 h; (m) H_2SO_4, THF, H_2O, room temperature, 3 h.

cycloaddition conditions. With the acetoxy group at C-3 and the silyloxy at C-6, no cycloadduct formation was observed. However, with a methyl ether at C-3 and an acetoxy group at C-6, a diastereomeric mixture of the adducts **18** was produced. From these findings, it appeared that an electron-withdrawing group at C-3, such as an acetoxy, depolarized the vinyl ether to an extent that it cannot undergo the cycloaddition reaction. These findings are consistent with an inverse electron demand Diels–Alder reaction.

During this study, it was found that in some instances the course of the reaction was concentration dependent. According to the literature, the irradiation of azodicarboxylates resulted in the conversion of the trans isomer to the cis isomer.[4] In addition, the rate constant for the [4 + 2] reaction of vinyl ethers with the cis isomer is approximately 10^4 times higher than in the case of the trans isomer.[4] Presumably when the isomerization is a relatively slow process, other reactions arising from the trans isomer could

Scheme II



occur. From the results, it appears that the reaction of *trans*-DBAD with the substrates gave predominantly the product of an ene type reaction rather than the [4 + 2] adduct. For example, a solution 0.2 M in dihydropyran (DHP) and 1 M in DBAD gave mostly the [4 + 2] adduct **19** in 70% yield under irradiation. However, a 5 M solution of the substrate and 1 M in DBAD produced 60% of the ene product **39** and 10% of the [4 + 2] adduct **19** (Scheme II). These latter conditions, without irradiation, gave the ene product in 77% yield with <5% of the adduct, due to the absence of the cis isomer of DBAD in solution. A more pronounced concentration-dependent ene/[4 + 2] ratio was observed with glycal **40**.[1] With a 0.1 M solution of substrate, the [4 + 2] adduct **41** was produced in 75% yield with about 5% of the ene compound **42**,[13] whereas a 0.3 M solution gave a 50% yield of the adduct and 25% yield of the ene compound. As anticipated, following the reaction of TLC, it was observed that the product ratio [4 + 2]/ene increases as the reaction progresses with the disappearance of starting material. Therefore the isomerization of the DBAD is rate limiting under these conditions, and at high concentrations the bimolecular ene reaction becomes faster than this unimolecular process.

In summary, the [4 + 2] cycloaddition reaction of dibenzyl azodicarboxylate and glycals is a convenient method to stereospecifically introduce an amino function at the C-2 position of carbohydrates. The cycloaddition reaction proceeds well with both furanoid and pyranoid glycals, except when an electron-withdrawing group is attached at C-3. In the case of pyranoid glycals, the selectivity of the reaction depends on the orientation and on the nature of the C-3 substituent. For the future, our attention will be focused on the electronic and steric factors controlling that [4 + 2] cycloaddition reaction.

Experimental Section

NMR spectra were recorded on a Bruker AM 250 (250 MHz) and on a Bruker AM 300 (300 MHz) spectrometer.[14] Numbers in the spectral assignments refer to carbohydrate numbering. High-resolution mass spectra (HRMS) were obtained by O. A. Mamer of McGill University. Elemental analyses were performed by Galbraith Laboratories, Knoxville, and by Guelph Chemical Laboratories Ltd., Guelph. X-ray diffraction analyses were carried out on an Enraf-Nonius CAD4 diffractometer with Cu radiation (λ = 1.54178 Å). The cycloaddition reactions were performed in a Rayonet apparatus using 3500-Å tubes.

1,5-Anhydro-2-deoxy-3,6-bis-*O*-[(1,1-dimethylethyl)dimethylsilyl]-4-*O*-[2,4,6-tris-*O*-[(1,1-dimethylethyl)dimethylsilyl]-β-D-galactopyranosyl]-D-*arabino*-hex-1-enitol (8). To a solution of lactose-derived lactal[15] (465 mg, 1.50 mmol) in DMF (8 mL) were added *tert*-butyldimethylsilyl chloride (6.00 g, 39.4 mmol) and imidazole (3.00 g, 44.1 mmol). The resulting mixture was stirred at 100 °C for 24 h. After the reaction mixture cooled to room temperature, an aqueous solution of 25% ammonium acetate was added (50 mL), and the mixture was extracted with ether in the usual manner. Flash chromatography (5% ether in hexanes) of the crude mixture afforded the title product (1.07 g, 1.20 mmol, 80%) as a white foam: $[\alpha]^{22}_D$ −10.5° (*c* 1.0, acetone); ^{1}H NMR (250 MHz, $CDCl_3$) δ 0.10 (m, 30 H, 10 CH_3); 0.91 (m, 45 H, 5 $(CH_3)_3C$); 1.96 (d, 1 H, *J* = 6.0 Hz, OH); 3.30 (dd, 1 H, *J* = 5.4, 9.5 Hz, H-5′); 3.38 (m, 1 H, H-3′); 3.63 and 3.76 (2 m, 5 H, H-2′, H-6a, H-6b, H-6′a, H-6′b); 3.96 (bt, 1 H, *J* = 8.3 Hz, H-4); 4.08 (m, 2 H, H-4′, H-5); 4.28 (dd, 1 H, *J* = 1.0, 6.2 Hz, H-3); 4.55 (d, 1 H, *J* = 7.29, H-1′); 4.60 (dd, 1 H, *J* = 1.0, 7.4 Hz, H-2); 6.30 (d, 1 H, *J* = 7.4 Hz, H-1). Anal. Calcd for $C_{42}H_{90}O_9Si_5$: C, 57.35; H, 10.31. Found: C, 57.38; H, 10.48.

Typical Procedure for the Preparation of Cycloadducts. [4a*R*-(4aα,6α,8α,8aα)]-7,8-Bis[[(1,1-dimethylethyl)dimethylsilyl]oxy]-6-[[[(1,1-dimethylethyl)dimethylsilyl]oxy]methyl]-4a,7,8,8a-tetrahydro-3-(phenylmethoxy)-1*H*,6*H*-pyrano[3,2-*e*][1,3,4]oxadiazine-1-carboxylic Acid Phenylmethyl Ester (16). To a solution of glycal **4** (300 mg, 0.61 mmol) in cyclohexane (2 mL) was added dibenzyl azodicarboxylate (941 mg, 3.05 mmol). The suspension was solubilized by the addition of CH_2Cl_2 ($\simeq$500 μL) and then irradiated at 350 nm for 4 days at 35 °C. Hexanes (30 mL) together with a DBAD crystal were added, and the mixture was stored at −5 °C.[16] The DBAD was filtered off and washed with hexanes. The filtrate was evaporated and submitted 3 times to the same treatment. Flash chromatography of the residue (15% ether in hexanes) afforded the desired cycloadduct **16** (332 mg, 0.42 mmol, 71%) as a white foam: $[\alpha]^{22}_D$ −74.6° (*c* 1.13, acetone); IR (KBr) 1710 (C=O), 1670 (C=N) cm^{-1}; ^{1}H NMR (250 MHz, acetone-d_6) δ 0.10, 0.12, 0.13, 0.16, and 0.20 (5 s, 18 H, 6 CH_3); 0.86, 0.88, and 0.92 (3 s, 27 H, 3 $(CH_3)_3C$); 3.66–4.00 (m, 5 H, H-3, H-4, H-5, H-6, H-6′); 4.60 (dd, 1 H, *J* = 4.2, 8.3 Hz, H-2); 5.25 (m, 4 H, 2 CH_2Ph); 5.73 (d, 1 H, *J* = 4.2 Hz); 7.25–7.55 (m, 10 H, 2 Ph); ^{13}C NMR (62 MHz, $CDCl_3$) δ −4.07, −2.59, −2.22, 14.78, 16.32, 16.67, 17.12, 17.34, 18.07, 18.34, 25.95, 26.45, 53.53, 61.77, 67.82, 70.23, 70.99, 71.42, 76.41, 76.49, 94.83 (OCO), 128.11, 128.43, 128.81, 129.23, 133.58, 135.38, 136.28, 148.96 (C=N), 153.77 (OCON). Anal. Calcd for $C_{40}H_{66}N_2O_8Si_3$: C, 61.07; H, 8.46; N, 3.56. Found: C, 60.89; H, 8.52; N, 3.72.

3-Ethoxy-4a,5a,6a,6b-tetrahydro-1*H*,6*H*-cyclopropa[4,5]furo[3,2-*e*]-[1,3,4]oxadiazine-1,6-dicarboxylic acid diethyl ester (13): mp 92–94 °C (ether–hexane); IR (KBr) 1730 (C=O), 1670 (C=N) cm^{-1}; ^{1}H NMR (250 MHz, $CDCl_3$) δ 1.18 (t, 3 H, *J* = 8.3 Hz, OCH_2CH_3); 1.26 (2 t, 6 H, *J* = 6.2, 7.1 Hz, $CO_2CH_2CH_3$); 1.85 (d, 1 H, $CHCO_2$); 2.16 (m, 1 H, NCH*CH*CHO); 4.08 (q, 2 H, *J* = 8.3 Hz, OCH_2CH_3); 4.26 (2 q, 4 H, *J* = 6.2, 7.1 Hz, $CO_2CH_2CH_3$); 4.50 (d, 1 H, *J* = 10 Hz, NCHCH*CH*O); 4.86 (bd, 1 H, *J* = 4.1 Hz, N*CH*CHCHO); 5.58 (d, 1 H, *J* = 5 Hz, O*CH*O); ^{13}C NMR (62 MHz, $CDCl_3$) δ 13.97, 14.05, 14.49 (3 CH_3); 26.49, 32.73, 55.15, and 65.86 (4 CH); 60.98, 62.67, and 64.77 (3 CH_2); 105.20 (OCHO); 152.02 and 153.55 (OCON and C=N); 168.43 (OCOEt). Anal. Calcd for $C_{14}H_{20}N_2O_7$: C, 51.21; H, 6.13; N, 8.53. Found: C, 51.14; H, 6.29; N, 8.54.

Suitable crystals of **13** for X-ray diffraction studies formed from ether with space group symmetry $P2_1/n$ and cell constants of *a* = 17.035 (4) Å, *b* = 5.016 (2) Å, *c* = 20.172 (4) Å, and β = 114.16 (2)° for *Z* = 4 and a calculated density of 1.387 g/cm^3. Of the 2161 reflections measured on an automatic four-circle diffractometer equipped with Cu radiation, 1351 were observed ($I \geq 3\sigma(I)$). The structure was solved with a direct-methods approach and difference Fourier analysis and was refined by full-matrix least-squares techniques.[17] Hydrogens were assigned isotropic temperature factors corresponding to their attached atoms. The function $\sum w(|F_o| - |F_c|)^2$ with $w = 1/(\sigma F_o)^2$ was minimized to give an unweighted residual of 0.043. There are no short intermolecular contacts. Tables I, II, and III containing the final fractional coordinates, temperature parameters, bond distances, and bond angles are available as supplementary material. Figure 1 is a computer-generated perspective drawing of **13** from the final X-ray coordinates.

[4a*S*-[4aβ,6β(*S),7β,7aβ]]-6-(2,2-Dimethyl-1,3-dioxolan-4-yl)-7-[[(1,1-dimethylethyl)dimethylsilyl]oxy]-4a,6,7,7a-tetrahydro-3-(phenylmethoxy)-1*H*-furo[3,2-*e*][1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (14)**: R_f = 0.4 (40% ether in hexanes); $[\alpha]^{22}_D$ +111.7° (*c* 0.7, $CHCl_3$); IR (neat) 1710 (C=O), 1660 (C=N) cm^{-1}; ^{1}H NMR (250 MHz, acetone-d_6) δ 0.13 and 0.15 (2 s, 6 H, 2 CH_3); 0.82 (s, 9 H, $(CH_3)_3C$); 1.20 and 1.25 (2 s, 6 H, $(CH_3)_2C$); 3.82 and 4.02 (2 t, 2 H, $J_{6,6'}$ = 8.0 Hz, $J_{6,5}$ = 8.0 Hz, H-6, H-6′); 4.10–4.25 (m, 2 H, H-4, H-5); 4.42 (t, 1 H, $J_{3,2}$ = 4.0 Hz, $J_{3,4}$ = 4.0 Hz, H-3); 4.73 (t, 1 H, $J_{2,1}$ = 4.0 Hz, $J_{2,3}$ = 4.0 Hz, H-2); 5.07–5.25 (m, 4 H, 2 CH_2Ph); 5.95 (d, 1 H, $J_{1,2}$

(13) The stereochemistry at C-1 of compound **41** has not been established.

(14) The ^{1}H NMR spectra of the glycosides were recorded at high temperature in benzene-d_6 or toluene-d_8 due to broad signals at lower temperature. However, for compound **29**, the ^{1}H NMR spectrum showed broad signals even at 373 K, making its interpretation of little practical value.

(15) Haword, W. H.; Hirst, E. L.; Plant, M. M. T.; Reynolds, R. J. W. *J. Chem. Soc.* **1930**, 2644–2653.

(16) Except for the adducts **16** and **20**, the crude mixture was directly chromatographed on silica gel without removing the excess of DBAD.

(17) The following library of crystallographic programs was used: SHELXS-86, G. M. Sheldrick, University of Gottingen, Gottingen, West Germany, 1986; PLUTO, W. D. S. Motherwell and W. Glegg, University of Cambridge, Cambridge, England, 1978; SDP PLUS V1.1, Y. Okaya and B. A. Frenz, B. A. Frenz and Associates, College Station, TX, 1984.

= 4 Hz, H-1); 7.23–7.48 (m, 10 H, 2 Ph). Anal. Calcd for $C_{31}H_{42}N_2O_8Si$: C, 62.18; H, 7.07; N, 4.67. Found: C, 62.62; H, 7.09; N, 4.72.

***cis*-4a,7,8,8a-Tetrahydro-3-(phenylmethoxy)-1*H*,6*H*-pyrano[3,2-*e*]-[1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (19)**: IR (CH_2Cl_2) 1730 (C=O), 1670 (C=N) cm^{-1}; ^1H NMR (250 MHz, acetone-d_6) δ 1.50–1.91 (m, 4 H, H-3, H-3′, H-4, H-4′); 3.66–3.83 (m, 2 H, H-5, H-5′); 4.41 (td, 1 H, J = 5.1, 11.7 Hz, H-2); 5.23 (m, 4 H, 2CH_2Ph); 5.60 (d, 1 H, J = 5.1 Hz, H-1); 7.16–7.53 (m, 10 H, 2 Ph). High-resolution mass spectrum m/z calcd for $C_{21}H_{23}N_2O_5$ $(M + H)^+$: 383.1602. Found: 383.1602.

[4a*R*-(4aα,6aα,7β,8aα,8aα)]-6,8-Bis[[(1,1-dimethylethyl)dimethylsilyl]-oxy]-4a,7,8,8a-tetrahydro-3-(phenylmethoxy)-7-[[2,4,6-tris-*O*-[(1,1-dimethylethyl)dimethylsilyl]-β-D-galactopyranosyl]oxy]-1*H*,6*H*-pyrano-[3,2-*e*][1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (20): $[\alpha]^{22}_D$ −43.5° (*c* 1.0, acetone); IR (KBr) 1715 (C=O), 1665 (C=N) cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 0.10 (m, 30 H, 10 CH_3); 0.83 (m, 45 H, 5 $(CH_3)_3C$); 1.90 (d, 1 H, J = 7.0 Hz, OH); 3.23 (dd, 1 H, J = 5.4, 10.4 Hz, H-5′); 3.35 (m, 1 H, H-3′); 3.45–3.76 (m, 6 H); 3.88 (t, 1 H, J = 10.4 Hz); 4.01 (d, 1 H, J = 2.0 Hz, H-4′); 4.06 (d, 1 H, J = 6.0 Hz); 4.50 (d, 1 H, J = 7.5 Hz, H-1′); 4.61 (bd, 1 H, J = 8.7 Hz, H-2); 5.08–5.30 (m, 4 H, 2 CH_2Ph); 5.46 (d, 1 H, J = 3.0 Hz, H-1); 7.20–7.45 (m, 10 H, 2 Ph); ^{13}C NMR (62 MHz, $CDCl_3$) δ −5.55, −4.81, −4.44, −3.33, −2.96, 17.77, 18.14, 18.51, 26.29, 26.47, 26.66, 54.07, 60.74, 60.78, 68.51, 68.88, 69.99, 70.74, 72.96, 73.33, 74.07, 75.55, 75.73, 76.20, 77.03, 95.92 (OCO), 101.85 (OCO), 128.51, 128.88, 129.06, 129.25, 132.92, 136.66, 149.62 (C=N), 154.07 (OCON). Anal. Calcd for $C_{58}H_{104}N_2O_{13}Si_5$: C, 59.14; H, 8.89; N, 2.37. Found: C, 58.82; H, 8.78; N, 2.29.

[4a*R*-(4aα,6α,7α,8β,8aβ)]-8-[[(1,1-Dimethylethyl)dimethylsilyl]-oxy]-6-[[[(1,1-dimethylethyl)dimethylsilyl]oxy]methyl]-4a,7,8,8a-tetrahydro-7-hydroxy-3-(phenylmethoxy)-1*H*,6*H*-pyrano[3,2-*e*][1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (21): $[\alpha]^{22}_D$ −79.6° (*c* 1.15, acetone); ^1H NMR (250 MHz, acetone-d_6) δ 0.08 (m, 12 H, 4 CH_3); 0.88 and 0.90 (2 s, 18 H, 2 $(CH_3)_3C$); 3.74–4.05 (m, 6 H); 4.90 (dd, 1 H, J = 3.6, 10.0 Hz, H-2); 5.16–5.27 (m, 4 H, 2 CH_2Ph); 5.74 (bs, 1 H, H-1); 7.31–7.45 (m, 10 H, 2 Ph). Anal. Calcd for $C_{34}H_{52}N_2O_8Si_2$: C, 60.68; H, 7.79; N, 4.16. Found: C, 60.50; H, 7.88; N, 3.98.

[4a*R*-(4aα,5aβ,8β,9α,10aα)]-10-[[(1,1-Dimethylethyl)dimethylsilyl]-oxy]-4a,5a,6,9a,10,10a-hexahydro-8-phenyl-3-(phenylmethoxy)-1*H*-[1,3]dioxino[4′,5′:5,6]pyrano[3,2-*e*][1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (22): $[\alpha]^{22}_D$ −79.8° (*c* 4, acetone); ^1H NMR (250 MHz, acetone-d_6) δ 0.83 (s, 9 H, $(CH_3)_3C$); 3.71–3.91 (m, 4 H); 4.23 (m, 1 H); 4.73 (dd, 1 H, J = 9.5, 3.6 Hz, H-2); 5.10–5.33 (m, 4 H, 2CH_2Ph); 5.66 (s, 1 H, OCHO); 5.80 (d, 1 H, J = 3.6 Hz, H-1); 7.26–7.55 (m, 15 H, 3 Ph). Anal. Calcd for $C_{35}H_{42}N_2O_8Si$: C, 64.99; H, 6.54; N, 4.33. Found: C, 65.26; H, 6.60; N, 4.41.

[4a*S*-(4aα,5aα,8α,9aβ,10α,10aα)]-10-[[(1,1-Dimethylethyl)dimethylsilyl]oxy]-4a,5a,6,9a,10,10a-hexahydro-8-phenyl-3-(phenylmethoxy)-1*H*-[1,3]dioxino[4′,5′:5,6]pyrano[3,2-*e*][1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (23): $[\alpha]^{22}_D$ +34.5 (*c* 0.7, acetone); IR 1700 (C=O) cm^{-1}; ^1H NMR (250 MHz, acetone-d_6) δ 0.11 and 0.15 (2 s, 6 H, 2 CH_3); 0.95 (s, 9 H, $(CH_3)_3C$); 3.73 (m, 1 H); 3.83 (dd, 1 H, J = 12.5, 2.2 Hz, H-4); 3.93 (t, 1 H, J = 2.2, 3.7 Hz, H-2); 4.25 (m, 2 H); 5.20 (m, 4 H, 2 CH_2Ph); 5.38 (t, 1 H, J = 3.7, 2.2 Hz, H-3); 5.66 (s, 1 H, OCHO); 5.86 (d, 1 H, J = 2.2 Hz, H-1); 7.25–7.33 (m, 15 H, 3 Ph); ^{13}C NMR (62 MHz, $CDCl_3$) δ −4.07, −3.10, 26.66, 57.40, 64.81, 67.77, 68.51, 69.25, 94.44 (OCO), 102.22 (OCO), 126.29, 128.51, 128.69, 128.88, 129.25, 135.92, 136.66, 138.14, 147.4 (C=N), 154.81 (OCON). Anal. Calcd for $C_{35}H_{42}N_2O_8Si$: C, 64.99; H, 6.54; N, 4.33. Found: C, 65.06; H, 6.62; N, 4.20.

[4a*S*-(4aα,5aα,8α,9aβ,10aα)]-4a,5a,6,9a,10,10a-Hexahydro-8-phenyl-3-(phenylmethoxy)-1*H*-[1,3]dioxino[4′,5′:5,6]pyrano[3,2-*e*]-[1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (24): mp 175 °C (ethyl acetate–hexane); $[\alpha]^{22}_D$ +85.4° (*c* 0.57, acetone); IR (KBr) 1700 (C=O), 1660 (C=N) cm^{-1}; ^1H NMR (250 MHz, acetone-d_6) δ 2.06 (m, 1 H, H-3); 2.56 (dt, 1 H, J = 13.8, 5.8 Hz, H-3′); 3.68–3.93 (m, 2 H, H-6 and H-6′); 4.00 (m, 1 H, H-4); 4.30 (dd, 1 H, J = 9.4, 4.4 Hz, H-5); 4.78 (m, 1 H, J = 2.9, 5.8, 7.3 Hz, H-2); 5.26 (m, 4 H, 2 CH_2Ph); 5.65 (s, 1 H, OCHO); 5.73 (d, 1 H, J = 2.9 Hz, H-1); 7.33–7.51 (m, 10 H, 2 Ph); ^{13}C NMR (62 MHz, $CDCl_3$) δ 28.14, 46.29, 68.51, 69.25, 70.37, 71.48, 73.33, 95.92 (OCO), 102.22 (OCO), 125.92, 128.32, 128.51, 128.69, 128.76, 129.25, 135.92, 137.03, 138.14, 148.51 (C=N), 153.33 (OCON). Anal. Calcd for $C_{29}H_{28}N_2O_7$: C, 67.43; H, 5.46; N, 5.42. Found: C, 67.25; H, 5.42; N, 5.55.

[4a*R*-(4aα,5aβ,8β,9aα,10aα)]-4a,5a,6,9a,10,10a-Hexahydro-8-phenyl-3-(phenylmethoxy)-1*H*-[1,3]dioxino[4′,5′:5,6]pyrano[3,2-*e*]-[1,3,4]oxadiazine-1-carboxylic acid phenylmethyl ester (25): mp 145–147 °C (ethyl acetate–hexanes); $[\alpha]^{22}_D$ −78.0° (*c* 0.4, acetone); IR (KBr) 1700 (C=O), 1670 (C=N) cm^{-1}; ^1H NMR (250 MHz, acetone-d_6) δ 1.70 (m, 1 H, J = 11.6 Hz, H-3); 2.13 (td, 1 H, J = 2.9, 11.7 Hz, H-3′); 3.70 (m, 2 H, H-6 and H-6′); 3.83 (m, 1 H, H-4); 4.25 (dd, 1 H, J = 4.0, 10.0 Hz, H-5); 4.70 (btd, 1 H, J = 2.9, 4.4, 11.7 Hz, H-2); 5.15–5.33 (m, 4 H, 2 CH_2Ph); 5.65 (s, 1 H, OCHO); 5.73 (d, 1 H, J = 2.2 Hz, H-1); 7.33–7.51 (m, 15 H, 3 Ph). Anal. Calcd for $C_{29}H_{28}N_2O_7$: C, 67.43; H, 5.46; N, 5.42. Found: C, 67.45; H, 5.16; N, 5.17.

***O*-2,4,6-Tris-*O*-[(1,1-dimethylethyl)dimethylsilyl]-β-D-galacto-pyranosyl-(1→4)-*O*-2-[1,2-bis[(phenylmethoxy)carbonyl]hydrazino]-2-deoxy-3,6-bis-*O*-[(1,1-dimethylethyl)dimethylsilyl]-β-D-glucopyranosyl-(1→6)-1,2:3,4-bis-*O*-(1-methylethylidene)-α-D-galactopyranose (29)**. Adduct **20** (200 mg, 0.16 mmol) and diacetonide galactose (65 mg, 0.25 mmol) dissolved in CH_2Cl_2 (560 mL) containing powdered 4-Å molecular sieves at −78 °C were treated with $BF_3{\cdot}Et_2O$ (26 μL, 0.25 mmol). After 3 h at −78 °C, the temperature was slowly raised to −40 °C. The temperature was maintained for 4 h at −40 °C, and the mixture was then allowed to warm to −5 °C. Then the temperature was brought down to −78 °C, 7 mL of an ether–aqueous 25% solution of ammonium acetate (1/1) mixture was added, and the resulting mixture was extracted with ether in the usual manner. Flash chromatography (30% ether in hexanes) of the crude mixture gave the desired compound **29** (198 mg, 0.14 mmol, 82%): $[\alpha]^{22}_D$ −21.1° (*c* 3.3, acetone). Anal. Calcd for $C_{70}H_{124}N_2O_9Si_5$: C, 58.46; H, 8.69; N, 1.95. Found: C, 58.48; H, 8.73; N, 1.68.

***O*-2,4,6-Tris-*O*-[(1,1-dimethylethyl)dimethylsilyl]-β-D-galacto-pyranosyl-(1→4)-*O*-2-amino-2-deoxy-3,6-bis-*O*-[(1,1-dimethylethyl)di-methylsilyl]-β-D-glucopyranosyl-(1→6)-1,2:3,4-bis-*O*-(1-methyl-ethylidene)-α-D-galactopyranose (35)**. To trisaccharide **29** (153 mg, 0.11 mmol) dissolved in MeOH (5 mL) were added Raney nickel (≃1 g) and a few drops of acetic acid. The mixture was placed on a Parr apparatus at 50 psi of hydrogen for 20 h. Then solid sodium bicarbonate was added and the mixture was filtered on Celite. The solvent was removed at reduced pressure, and the residue was then chromatographed (40% ethyl acetate in hexanes) to give amino trisaccharide **35** (92 mg, 75%): $[\alpha]^{22}_D$ −36.7° (*c* 1.7, acetone); ^1H NMR (500 MHz, $CDCl_3$) δ 0.10 (m, 30 H, 10 CH_3); 0.90 (m, 45 H, 5 $(CH_3)_3C$); 1.33, 1.40, and 1.53 (3 s, 12 H, 2 $(CH_3)_2C$); 1.89 (d, 1 H, J = 6.0 Hz, OH); 2.73 (t, 1 H, J = 8.5 Hz, H-2′); 3.11 (d, J = 9.4 Hz, 1 H); 3.22 (dd, 1 H, J = 5.2, 9.0 Hz, H-5″); 3.32 (m, 1 H, H-3″); 3.46 (t, J = 8.5 Hz, 1 H); 3.52–3.77 (m, 6 H); 3.90–4.07 (m, 4 H); 4.20 (dd, 1 H, J = 0.5, 8.0 Hz, H-4); 4.28 (dd, 1 H, J = 2.4 and 5.0 Hz, H-2); 4.36 (m, 1 H, H-1′); 4.48 (d, 1 H, J = 7.7 Hz, H-1″); 4.56 (dd, 1 H, J = 2.3, 7.9 Hz, H-3); 5.50 (d, 1 H, J = 5.0 Hz, H-1). Anal. Calcd for $C_{54}H_{111}NO_{15}Si_5$: C, 56.16; H, 9.69; N, 1.21. Found: C, 56.37; H, 9.78; N, 1.25.

***O*-2,3,4,6-Tetra-*O*-acetyl-β-D-galactopyranosyl-(1→4)-*O*-2-phthal-imido-2-deoxy-3,6-bis-*O*-acetyl-β-D-glucopyranosyl-(1→6)-1,2:3,4-bis-*O*-(1-methylethylidene)-α-D-galactopyranose (36)**. Phthalic anhydride (4 mg) was added to a solution of amine **35** (43 mg, 0.04 mmol) in pyridine (100 μL). The mixture was heated in a sealed tube at 75 °C for 30 min. Then a few drops of triethylamine and more phthalic anhydride (4 mg) were added. After 2 h at 75 °C, the solution was evaporated at reduced pressure. Flash chromatography (30% ethyl acetate in hexanes) of the crude mixture gave the amide (40 mg, 90%). Then the amide was dissolved in THF (200 μL), and a solution of *n*-tetrabutylammonium fluoride in THF (1 M) (311 mL, 0.4 mmol) was added. After 5 h at room temperature, the mixture was heated at 50 °C for 5 h. After a subsequent period of 6 h at room temperature, the solvent was removed by a flow of nitrogen, and excess acetic anhydride (300 μL) and pyridine (300 μL) were added. The mixture was kept at 90 °C for 3 h. The solvent was removed at reduced pressure and the mixture was purified by flash chromatography (70% ethyl acetate in hexanes) to give the title compound (22 mg, 70%), which was recrystallized from ethanol: mp 203 °C; $[\alpha]^{22}_D$ −19.4° (*c* 1.0, $CHCl_3$) (lit.[7] mp 201–202 °C), $[\alpha]^{22}_D$ −19.6° (*c* 0.8, $CHCl_3$).

Methyl 2-Amino-2-deoxy-3,6-bis-*O*-[(1,1-dimethylethyl)dimethyl-silyl]-β-D-galactopyranoside (37). To adduct **21** (249 mg, 0.37 mmol) dissolved in MeOH (≃5 mL) was added a crystal of *p*-TSOH. The reaction mixture was kept at 25 °C until completion (≃10 min) (TLC, 20% ether in hexanes, double elution). Then solid sodium bicarbonate was added and the solvent was evaporated. Flash chromatography of the crude mixture (30% ether in hexanes) gave the methyl pyranoside (250 mg, 0.36 mmol). The pyranoside was then dissolved in MeOH and treated with Raney nickel (≃1 g) and a few drops of acetic acid. The mixture was placed on a Parr apparatus at 40 psi of hydrogen for a period of 18 h. Solid sodium bicarbonate was then added, and the mixture was filtered on Celite. After evaporation of the solvent and flash chromatography (5% 2-propanol in ethyl acetate) of the residue, the title compound was obtained as an oil (95 mg, 0.22 mmol, 60%): ^1H NMR (250 MHz, $CDCl_3$) δ 0.08 (m, 12 H, 4 CH_3); 0.83 and 0.91 (2 s, 18 H, 2 $(CH_3)_3C$); 2.96 (t, 1 H, J = 8.2 Hz, H-2); 3.46 (m, 1 H); 3.50 (s, 3 H, CH_3O); 3.58 (dd, 1 H, J = 3.5, 8.2 Hz, H-3); 3.81 (d, 1 H, J = 3.5 Hz, H-4); 3.83–3.95 (m, 2 H); 4.08 (d, 1 H, J = 8.2 Hz, H-1). High-reso-

lution mass spectrum m/z calcd for $C_{19}H_{44}NO_5Si_2$ $(M + H)^+$: 422.2758. Found: 422.2758.

Methyl 3,4,6-Tris-*O*-acetyl-2-amino-2-deoxy-β-D-galactopyranoside (38). To a stirred solution of amine **37** (70 mg, 0.17 mmol) in THF (830 μL) at 0 °C was added a solution of tetra-*n*-butylammonium fluoride in THF (1 M) (830 μL, 0.85 mmol). The resulting mixture was allowed to warm to room temperature. After 0.5 h the solvent was removed at reduced pressure and excess pyridine (≃500 μL) and excess acetic anhydride (≃500 μL) were added. After a day the solvents were evaporated and the crude mixture was purified by flash chromatography (ethyl acetate) to procure the tetraacetylgalactosamine **38** (44 mg, 0.12 mmol, 69%) as a white solid: mp 216 °C; $[\alpha]^{22}_D$ −17.4° (*c* 0.5, $CHCl_3$) (lit.[8] mp 216–217 °C), $[\alpha]^{22}_D$ −17.0° (*c* 1, $CHCl_3$).

Methyl 2-[1,2-bis[(phenylmethoxy)carbonyl]hydrazino]-2-deoxy-3,4,6-tris-*O*-[(1,1-dimethylethyl)dimethylsilyl]-β-D-glucopyranoside (27): $[\alpha]^{22}_D$ −24.0 (*c* 1.1, acetone); IR (CH_2Cl_2) 1760, 1720 (C=O) cm^{-1}; ^1H NMR (300 MHz, 383 K, toluene-d_8) δ 0.17, 0.19, 0.22, 0.29, and 0.35 (5 s, 18 H, 6 CH_3); 1.02, 1.03, and 1.05 (3 s, 27 H, 3 $(CH_3)_3C$); 3.33 (s, 3 H, CH_3O), 3.97 (m, 1 H, H-6); 4.04 (m, 1 H, H-6′); 4.13 (bt, 1 H, H-4); 4.26 (m, 2 H, H-3 and H-5); 4.62 (t, 1 H, J = 4.2 Hz, H-2); 5.06–5.19 (m, 5 H, 2 CH_2Ph and H-1); 7.03–7.27 (m, 10 H, 2 Ph). Anal. Calcd for $C_{41}H_{70}Si_3N_2O_9$: C, 60.10; H, 8.61; N, 3.41. Found: C, 60.46; H, 8.78; N, 3.48.

Methyl 2-(acetylamino)-2-deoxy-3,4,6-tris-*O*-[(1,1-dimethylethyl)dimethylsilyl]-β-D-glucopyranoside (32): IR (neat) 1675 (C=O) cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 0.86 and 0.93 (2 s, 27 H, 3 $(CH_3)_3C$); 1.95 (s, 3 H, $NCOCH_3$); 3.36 (s, 3 H, CH_3O); 3.66–3.83 (m, 3 H); 3.91 (bd, 1 H, J = 1.5 Hz); 4.06 (d, 1 H, J = 8.0 Hz, H-2); 4.20 (t, 1 H, J = 8.0 Hz, H-5); 4.50 (s, 1 H, H-1); 4.75 (d, 1 H, J = 8.0 Hz, NH).

1-Methoxy-2-[1,2-bis[(phenylmethoxy)carbonyl]hydrazino]-3,4,5,6-tetrahydropyran (28). To adduct **19** (660 mg, 1.70 mmol) dissolved in methanol (3.4 mL) was added a crystal of *p*-TsOH. After a few minutes the reaction was complete and solid sodium bicarbonate was added. The solvent was removed at reduced pressure and the crude mixture was purified by flash chromatography (30% ethyl acetate in hexanes) to afford the title product (572 mg, 80%) as a solid. The compound was dissolved in hot methanol and after 0.5 h at 25 °C, ether was added until the solution was cloudy. Then the mixture was cooled at 0 °C to give a white solid: mp 112–113 °C; ^1H NMR (300 MHz, 350 K, benzene-d_6); 1.10–1.14 (m, 2 H, H-4 and H-4′); 1.70 and 2.00 (2 m, 2 H, H-3 and H-3′); 3.05 (dt, 1 H, J = 3.7, 11.2 Hz, H-5); 3.60 (m, 1 H, H-5′); 4.15 (m, 1 H, H-2); 4.32 (d, 1 H, J = 3.0 Hz, H-1); 5.15 (m, 4 H, 2CH_2Ph); 6.15 (s, 1 H, NH); 7.00–7.21 (m, 10 H, 2 Ph). Anal. Calcd for $C_{22}H_{26}N_2O_6$: C, 63.82; H, 6.33; N, 6.76. Found: C, 63.98; H, 6.46; N, 6.47.

2-Acetamido-2-methoxy-3,4,5,6-tetrahydropyran (34). To compound **28** (414 mg, 1.00 mmol) dissolved in MeOH (5 mL) were added Raney nickel (≃1 g) and a few drops of acetic acid. The mixture was placed on a Parr apparatus at 40 psi of hydrogen. After 18 h solid sodium bicarbonate (500 mg) was added, and the mixture was filtered through Celite. The solvent was removed at reduced pressure and excess acetic anhydride and pyridine were added. After 6 h the solvents were evaporated and the residue was purified by flash chromatography (10% acetone in ethyl acetate) to give compound **34** (130 mg, 0.95 mmol, 75%) as a white solid: mp 77–78 °C (hexanes–ether); IR (KBr) 1650 (C=O) cm^{-1}; ^1H NMR (250 MHz, acetone-d_6) δ 1.33 and 1.50 (2 m, 2 H); 1.75 and 1.96 (2 m, 2 H); 1.86 (s, 3 H, CH_3CON); 3.33 (s, 3 H, CH_3O); 3.41 (m, 1 H, H-5); 3.70 (m, 2 H, H-5′ and H-2); 4.30 (d, 1 H, J = 3.0 Hz, H-1). High-resolution mass spectrum m/z calcd for $C_8H_{16}NO_3$ $(M + H)^+$: 174.1130. Found: 174.1132.

1-(5,6-Dihydro-2*H*-pyran-2-yl)-1,2-hydrazinedicarboxylic Acid Bis(phenylmethyl) Ester (39). To a suspension of dibenzyl azodicarboxylate (1.0 g, 3.3 mmol) in cyclohexane (800 μL) was added dihydropyran (1.4 g, 16.6 mmol). The resulting solution was kept at 25 °C until the solution was colorless (3 days). The solvent was then removed at reduced pressure. Flash chromatography of the crude mixture gave the desired title compound as a white solid (1 g, 260 mmol, 77%): mp 94–95 °C (ether–hexanes); IR (KBr) 3280 (NH), 1730 (C=O) cm^{-1}; ^1H NMR (300 MHz, 350 K, benzene-d_6) δ 1.61 (m, 2 H, H-4 and H-4′); 3.44 and 3.62 (2 m, 2 H, H-5 and H-5′); 4.95–5.10 (m, 4 H, 2 CH_2Ph); 5.67 (m, 2 H, H-2 and H-3); 6.15 (s, 1 H, H-1); 6.22 (s, 1 H, NH); 7.01–7.20 (m, 10 H, 2 Ph). Anal. Calcd for $C_{21}H_{22}N_2O_5$: C, 65.95; H, 5.80; N, 7.32. Found: C, 66.22; H, 5.84; N, 7.26.

[4a*S*-[4aα,6α(*S),7α,7aα]]-6-(2,2-Dimethyl-1,3-dioxolan-4-yl)-7-[[(1,1-dimethylethyl)dimethylsilyl]oxy]-4a,6,7,7a-tetrahydro-3-(phenylmethoxy)-1*H*-furo[3,2-e][1,3,4]oxadiazine-1-carboxylic Acid Phenylmethyl Ester (41) and 1-[2-Deoxy-3-*O*-[(1,1-dimethylethyl)dimethylsilyl]-5,6-*O*-(1-methylethylidene)-D-*threo*-hex-2-enofuranosyl]-1,2-hydrazinedicarboxylic Acid Bis(phenylmethyl) Ester (42).** To glycal **40** (500 mg, 1.66 mmol) dissolved in cyclohexane (6 mL) (0.3 M) was added dibenzyl azodicarboxylate (2.48 g, 8.30 mmol). The mixture was solubilized by the addition of CH_2Cl_2 (300 μL). After irradiation (350 nm) for a period of 18 h, the solvent was evaporated under reduced pressure. The residue was purified by flash chromatography (30% ether in hexanes) and the cycloadduct **41** (500 mg, 0.83 mmol, 50%) was eluted first from the column followed by the ene product **42** (250 mg, 0.41 mmol, 25%).

Compound 41: $[\alpha]^{22}_D$ +44.0° (*c* 1, acetone); IR (neat) 1710 (C=O), 1670 (C=O) cm^{-1}; ^1H NMR (250 MHz, acetone-d_6) δ 0.13 and 0.15 (2 s, 6 H, 2 CH_3); 0.88 (s, 9 H, $(CH_3)_3C$); 1.30 and 1.36 (2 s, 6 H, $(CH_3)_2C$); 3.76 and 4.03 (2 t, 2 H, J = 8.0 Hz, H-6 and H-6′) 4.21–4.36 (m, 2 H, H-4 and H-5); 4.50 (t, 1 H, J = 6.0 Hz, H-3); 5.20 (m, 5 H, 2 CH_2Ph and H-2); 5.83 (d, 1 H, J = 4 Hz, H-1); 7.48 (m, 10 H, 2 Ph). Anal. Calcd for $C_{31}H_{42}N_2O_8Si$: C, 62.18; H, 7.07; N, 4.67. Found: C, 62.02; H, 7.17; N, 4.39.

Compound 42: IR (CH_2Cl_2) 3400 (NH), 1760, 1725 (C=O), 1660 cm^{-1}; ^1H NMR (300 MHz, 383 K, toluene-d_8) δ 0.13 and 0.15 (2 s, 6 H, 2 CH_3); 0.92 (s, 9 H, $(CH_3)_3C$); 1.31 and 1.42 (2 s, 6 H, $(CH_3)_2C$); 3.87 and 3.95 (2 t, 2 H, J = 8.7, 7.8 Hz, H-6 and H-6′); 4.10 (m, 1 H, H-5); 4.32 (m, 1 H, H-4); 4.72 (bs, 1 H, H-2); 4.98–5.10 (m, 4 H, 2 CH_2Ph); 6.01 (s, 1 H, NH); 6.88 (dd, 1 H, J = 4.7, 1.3 Hz, H-1); 7.10–7.20 (m, 10 H, 2 Ph). Anal. Calcd for $C_{31}H_{42}N_2O_8Si$: C, 62.18; H, 7.07; N, 4.67. Found: C, 62.02; H, 7.17; N, 4.39.

Methyl 2-Deoxy-3-*O*-[(1,1-dimethylethyl)dimethylsilyl]-5,6-*O*-(1-methylethylidene)-2-[1,2-bis[(phenylmethoxy)carbonyl]hydrazino]-β-L-glucofuranoside (26). To cycloadduct **14** (700 mg, 1.17 mmol) dissolved in MeOH (20 mL) was added a crystal of *p*-TsOH. After the TLC (40% ether in hexanes) showed completion of the reaction, sodium bicarbonate (500 mg) was added and the solvent removed at reduced pressure. Flash chromatography of the residue (40% ether in hexanes) afforded furanoside **26** (574 mg, 0.93 mmol 80%): R_f = 0.14 (40% ether in hexanes); $[\alpha]^{22}_D$ +18.7° (*c* 0.6, acetone); IR (neat) 3280 (NH_2), 1760, 1720 (C=O) cm^{-1}; ^1H NMR (250 MHz, 343 K, benzene-d_6) δ 0.21 and 0.22 (2 s, 6 H, 2CH_3); 1.00 (s, 9 H, $(CH_3)_3C$); 1.35 and 1.45 (2 s, 6 H, $(CH_3)_2C$); 3.24 (s, 3 H, CH_3O); 4.11–4.13 (m, 3 H, H-6, H-6′, and H-4); 4.53 (m, 1 H, H-5); 4.63 (dd, 1 H, $J_{3,2}$ = 2.1 Hz, $J_{3,4}$ = 5.8 Hz); 4.79 (t, 1 H, $J_{2,3}$ = 2.1 Hz, $J_{2,1}$ = 2.1 Hz, H-2); 4.96 and 4.97 (2 s, 2 H, CH_2Ph); 5.00 (d, 1 H, $J_{1,2}$ = 2.1 Hz, H-2); 5.02 (s, 2 H, CH_2Ph); 6.90–7.20 (m, 10 H, 2 Ph). Anal. Calcd for $C_{32}H_{46}N_2O_9Si$: C, 60.92; H, 7.35; N, 4.44. Found: C, 60.69; H, 7.43; N, 4.33.

Methyl 2-Acetamido-3,4,6-tris-*O*-acetyl-2-deoxy-β-L-glucopyranoside (31). Furanoside **26** (360 mg) was added to 0 °C to a solution containing MeOH (20 mL) and acetyl chloride (1.6 mL). The mixture was then kept at 22 °C for 24 h. The solution was then evaporated and to the resulting crude mixture (291 mg) were added 25 mL of MeOH, excess Raney nickel (≃1 g), and 6 drops of acetic acid. The mixture was placed on a Parr apparatus at 40 psi of hydrogen for 18 h. Then solid sodium bicarbonate was added and the solvent removed at reduced pressure after filtration of the reaction mixture on Celite. The residue was treated with an excess of pyridine (5 mL) and acetic anhydride (5 mL). After a day, the solvents were evaporated and the crude mixture was purified by flash chromatography (ethyl acetate) to give a white solid (87 mg, 42%): mp 160–162 °C; $[\alpha]^{22}_D$ +24.0 (*c* 1.0, methanol) (lit.[18] mp 163–164 °C (D isomer), $[\alpha]^{22}_D$ −24° (*c* 1.0, methanol) (D isomer).

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Supplementary Material Available: Tables of the atomic positional and thermal parameters, bond distances, and bond angles for **13** (3 pages). Ordering information is given on any current masthead page.

(18) Kuhn, R.; Kirschenlohr, W. *Chem. Ber.* **1953**, *86*, 1331–1333.