force constants were calculated by the anomeric correction for the same conformer of a compound of the class RC(OR')$_3$. The only difference was that alternative numberings were used for the atoms. These bond and force constant differences resulted in different SE values for *the same conformer*, the value being dependent upon the atom numbering, that is, upon the order in which the coordinates were presented. It appears that the algorithm used in adjusting the bond lengths and force constants for anomeric corrections is sensitive to the order in which the components of the anomeric system are introduced. Since the force field is modified relatively extensively "on-the-fly", differences of SE values do not correspond to differences of enthalpies. If the MM2 program is applied to carbohydrates, these matters deserve consideration.

Treatment of Charged Molecules. There are obvious serious problems in performing valid computations with charged molecules. If the dipoles of amides, for example, are represented by point charges, then the very long range and very strong coulombic forces tend to dominate the nonbonded interactions. One consequence is that convergence may fail. A technique that has been used is to turn off Coulombic terms during minimization and then to turn them on for getting the final SE value.[55] If the treatment is extended to ions, the interactions are much larger. Equations 2-6 provide a fundamental statement of the thermodynamics. The equations may be extended to systems of molecules, but it is necessary to take care to define the thermodynamic states correctly. Unless the calculations conform to the requirements of thermodynamics as represented by these equations, the results of any molecular mechanics calculation will be questionable. It may be possible to obtain appropriate averaging of ionic interactions by Monte Carlo or other techniques.

Supplementary Material Available: Tables II, VII, and VIII (4 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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New Diels-Alder Reactions of (*E*/*Z*)-2'-Methoxy-Substituted 3-Vinylindoles with Carbo- and Heterodienophiles: Regio- and Stereoselective Access to [*b*] Annelated Indoles and Functionalized or [*a*] Annelated Carbazoles

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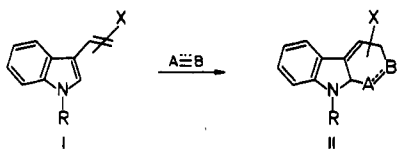
The (*E*/*Z*)-2'-methoxy-substituted 3-vinylindoles **1a,b** react with some carbo- and azodienophiles to furnish new carbazoles and pyridazinoindoles. The conservation of the *E* and *Z* stereochemistry of **1** in these Diels-Alder reactions was investigated, and a mechanistic rationalization is given for the stereoselective and regioselective results observed.

Introduction

Diels-Alder reactions of 2- and 3-vinylindoles as 4π-components are now well-established as versatile procedures for regio- and stereocontrolled syntheses of [*b*] annelated indoles, indole alkaloids,[1-3] and/or carbazoles.[4-8] This methodology should also constitute an interesting synthesis of heteroatom-functionalized carbazoles bearing, e.g., alkoxy, trialkylsiloxy, alkylthio, or amino functional groups. In contrast, the introduction of such polar functionalities onto annelated indoles or carbazoles is generally a tedious task by the more conventional methods known to date. Moreover, compounds of the type II (Scheme I), accessible via Diels-Alder reactions of I, have attracted considerable general interest as building blocks in alkaloid chemistry[9] and, in particular, for the development of pharmacologically active lead substances with antitumor and/or antibiotic properties.[10] The syntheses and exploitation of the Diels-Alder reactivity of heteroatom-functionalized 3-vinylindoles have, as yet, only been sparsely investigated with regard to alkoxy-,[11,12] trialkylsiloxy-,[13] alkylthio-,[14] or amino-functionalized[15,16] 3-vinylindoles.

Scheme I



I II

i.e. X = OAlk, OSiAlk$_3$, SAlk, NR'$_2$
R = H, Alk, SO$_2$Ph

Thus, in continuation of our investigations on pericyclic 6-electron processes involving indole derivatives,[4-8,10,11,16]

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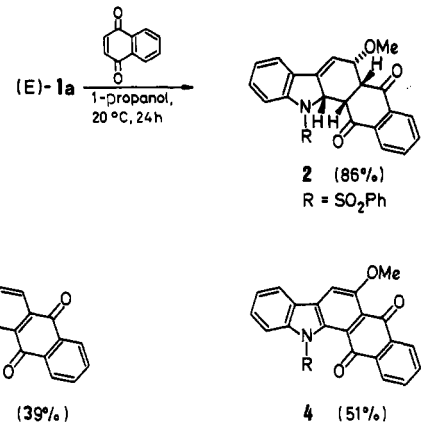
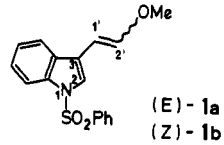
Scheme II



we now report on new Diels–Alder reactions of the (*E*)- and (*Z*)-2′-methoxy-substituted 3-vinylindoles **1a,b** with some carbo- and heterodienophiles. The influence of the *E*/*Z* stereochemistry of **1** with regard to the Diels–Alder reactivity is discussed.

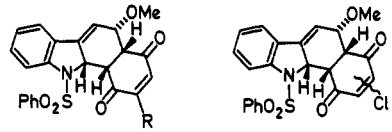
Synthetic Results

The 3-vinylindoles **1a,b** are readily accessible from the appropriate indole-3-carbaldehyde as a 3:2 *E*/*Z* mixture by a Wittig procedure first described[17] using methoxymethyl(triphenyl)phosphonium chloride/*n*-butyllithium in dimethoxyethane as solvent. The pure isomers were isolated by flash chromatography. However, equilibration studies on **1** have revealed that (*E*)-**1a** is the thermodynamically more stable form. The pure (*Z*)-isomer **1b** undergoes isomerization, e.g. on intimate contact with acidic materials (silica gel, $CHCl_3$), and the equilibrium mixture starting from (*Z*)-**1b** (24 h, 20 °C, in $CHCl_3$) exhibited an *E*/*Z* ratio of 3:1.



Compound (*E*)-**1a** reacts stereospecifically with 1,4-naphthoquinone to furnish the "endo" adduct **2** (Scheme II). In the presence of 2,3-dichloro-5,6-dicyano-1,4-benzoquinone as a dehydrogenation catalyst, compound **2** is easily converted into the fully aromatized carbazole **3** or **4** by elimination processes that depend on the reaction conditions.

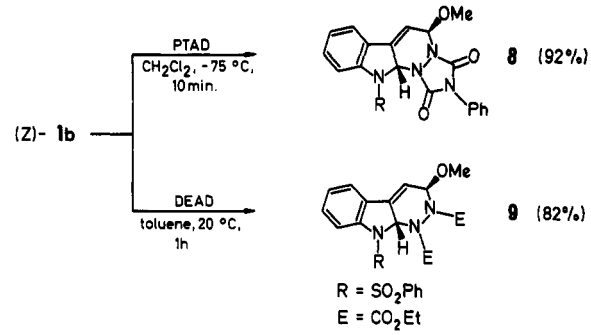
Similarly, 1,4-benzoquinone or 2-phenyl- and 2-chloro-1,4-benzoquinones react with (*E*)-**1a** to form the "endo" cycloadducts **5a–d**.



5	R	yield [%]
a	H	24
b	Ph	22

5c, 5d (31%)

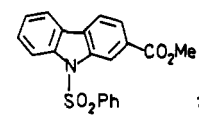
Scheme III



Although the Diels–Alder reaction with 2-phenyl-1,4-benzoquinone takes place regioselectively, probably as a result of steric factors, the analogous reaction with the chloro-substituted carbodienophile does not and gives rise to a 1:1 mixture of the regioisomers **5c,d** (preparatively separated). On the other hand, the (*Z*)-isomer **1b** does not react with the benzoquinone dienophiles to furnish any cycloadducts.

Interestingly, the more reactive tetracyanoethylene (TCNE) reacted with both isolated isomers, (*Z*)- and (*E*)-**1**, to produce the cycloadducts **6a** (exclusively from (*Z*)-**1**), **6b** (exclusively from (*E*)-**1**), as well as, in both cases, a cis/trans mixture of the indolylcyclobutane **6c** (ratio of **6a,b**:**6c** = 1:1 from both reactions). The cycloadduct **6a** was isolated in pure form, whereas product **6b** and the unstable stereoisomeric cyclobutane derivatives **6c** from both reactions could not be purified further. However, these compounds have been characterized adequately within the limits of detection by 400-MHz ^1H NMR spectroscopy. The nonstereoselective formation of **6c** is probably the result of a two-step process.

Several other acyclic carbodienophiles were tested, but only (*E*)-**1a** [and not (*Z*)-**1b**] reacted regioselectively with methyl propynoate in the presence of a molecular sieve catalyst to furnish the carbazole **7** directly by way of a [4 + 2] cycloaddition and subsequent elimination of methanol.



In the context of hetero-Diels–Alder processes, (*Z*)-**1b** reacted stereospecifically with 4-phenyl-4*H*-1,2,4-triazoline-3,5-dione (PTAD) to furnish **8** while diethyl azodicarboxylate (DEAD) reacted in a similar manner to yield the pyridazinoindole **9** (Scheme III).

The reaction of (*E*)-**1a** with PTAD merely gave rise to unstable and noncharacterizable products whereas the Diels–Alder reaction of (*E*)-**1a** with DEAD furnished not only the primarily expected cycloadduct **10** but also the epimer **9** (no isomerization of pure (*E*)-**1a** was as yet detected in the reaction mixture by TLC monitoring; Scheme IV). The third, and main, product of this reaction was compound **11**, resulting from a subsequent elimination

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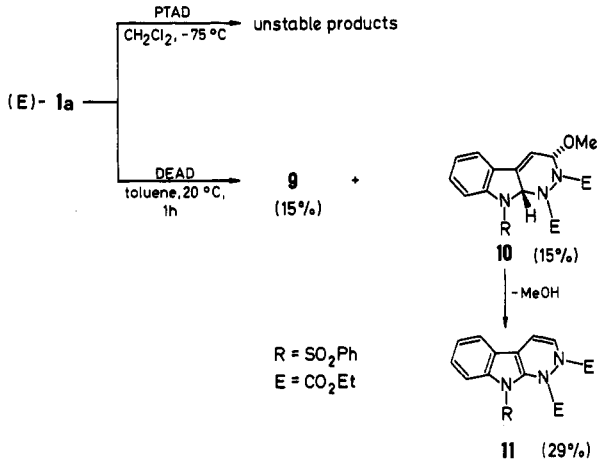
Scheme IV



reaction of the Diels–Alder adduct **10** (Scheme IV).

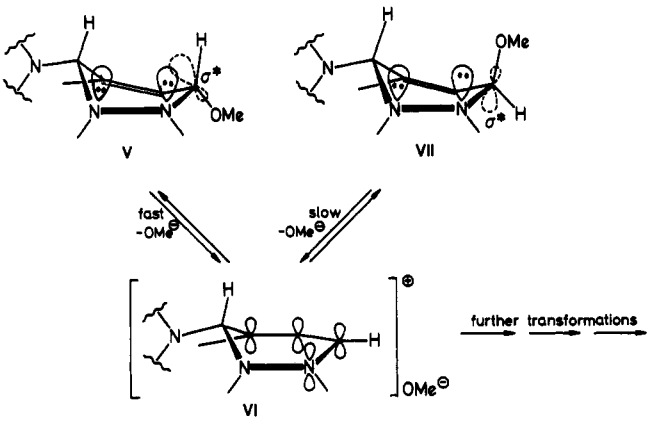
Mechanistic Rationalization

Conformational analyses of **1a,b** by means of MMX molecular mechanics calculations[18] reveal two energetically low conformations from rotation about the indole-C3–vinyl-C1′ σ-bond with C2,C3,C1′,C2′ torsional angles of 0° and 140° for (*E*)-**1a** and of 30° and 130° for (*Z*)-**1b**. However, the s-cis (**1a**) or s-cis synperiplanar (**1b**) conformer, respectively, is energetically favored by 2.60 kcal·mol^{-1} for **1a** or 2.20 kcal·mol^{-1} for **1b**. Thus, in the cases of both the (*E*)- and the (*Z*)-isomers of **1**, sufficient populations of the "reactive" conformers should be present in the equilibrium for the build up of the $[_4\pi_s + _2\pi_s]$ transition state (TS) in a concerted step.

On the other hand, MNDO–PM3 calculations[19] exemplarily performed on **1a** [*E*(HOMO) = −8.22 eV] demonstrate, on the basis of eigenvalues and eigenvectors, that a principally HOMO(diene)–LUMO(dienophile) interaction in the TS should control the Diels–Alder reactivity. In addition, secondary orbital overlap should favor the "endo" TS in all Diels–Alder reactions of **1a,b** with carbo- and heterodienophiles bearing a neighboring CO group.[8,20] Furthermore, MMX calculations[18] on the s-cis-*E*-endo and s-cis-*E*-exo TS's in the reaction of the *N*-acetyl analogue of **1a** with 1,4-benzoquinone are in favor of the s-cis-*E*-endo geometry by 0.5 kcal·mol^{-1} (for these calculations a bond order of 0.3 was used throughout).

The stereospecific Diels–Alder reactions leading to products **2**, **5**, **8**, and **9** are indicative of a concerted mechanism. A zwitterionic or diradical intermediate with a long lifetime (which can neither be detected analytically nor captured in the reactions leading to these cycloadducts) can be discounted since rotation about the C1′–C2′ σ-bond (referred to the numbering of the starting material **1**) of such an intermediate would lead to a stereoisomeric mixture of products. In addition, the cycloadducts **2**, **5**, **8**, and **9** are stable to epimerization under the Diels–Alder reaction conditions.

Scheme V



For the prediction of the preferred orientation of the reaction partners in Diels-Alder reactions with 2-phenyl- and 2-chloro-1,4-benzoquinones, MNDO calculations[19] were carried out for these quinones. Thus, the LUMO's (E = −1.48 and −1.77 eV, respectively) are weakly "polarized" at the reacting 5- and 6-positions on the basis of the magnitudes of the coefficients (2-phenyl-1,4-benzoquinone: c at C5 = −0.3446, c at C6 = 0.3493; 2-chloro-1,4-benzoquinone: c at C5 = −0.3543, c at C6 = 0.3453) and, according to the FMO concept, therefore, no preferred orientation exists. The absence of selectivity in the reaction of **1a** with 2-chloro-1,4-benzoquinone is in full agreement with these predictions. On the other hand, the regioselectivity in the cycloaddition of **1a** with 2-phenyl-1,4-benzoquinone to furnish **5b** is probably controlled by simple steric effects, as can be seen from observations of Dreiding models.

The results of the competition experiments (HPLC analysis of the educts) in the reaction of (*E*/*Z*)-**1** (1:1 mixture) with 1,4-naphthoquinone demonstrate the pronounced reactivity and selectivity of (*E*)-**1a** in the quinone dienophile series ($k_E/k_Z > 50$). In contrast, the product spectrum obtained indicates that the (*Z*)-isomer **1b** is probably the more reactive form in reactions with azodienophiles.

We propose the following general rationalization for the apparent different reactivities of the (*E*)- and (*Z*)-isomers toward carbo- and heterodienophiles. It seems reasonable that (*E*)-**1a** should exhibit an increased reactivity toward azodienophiles; this can readily be attributed to the higher stability of the s-cis-*E*-endo TS IV owing to n/σ^* stabilization. Namely, as a consequence of the boat TS of the [4 + 2] cycloaddition reaction, the lone electron pair at the "2" nitrogen atom of the azodienophile and the C–O σ-bond of the diene moiety have a transperiplanar orientation to each other in TS IV.[21] The related n/σ^* stabilization in the s-cis-*Z*-endo TS III with azodienophiles is less favored due to "configurational" changes. In accord with MNDO calculations, this rationalization is based on a HOMO(diene)–LUMO(dienophile) controlled endo orientation of the reactants throughout. Furthermore, the lower steric requirements for the build up of TS IV in the reactions of (*E*)-**1a** with azodienophiles should also accelerate the Diels–Alder reactions considerably; this is also valid for carbodienophiles.

(18) MMX is a π-SCF molecular mechanics program and was obtained from Serena Software Ltd., Bloomington, IN. The version by K. E. Gilbert and J. J. Gajewski based on MM2 (Allinger QCPE 395) and MMP1 Pi (Allinger 318) modified by K. Steliou was employed. Gajewski, J. J.; Gilbert, K. E.; McKelvey, J. *Adv. Mol. Model.* **1990**, *2*, 65.

(19) The MOPAC version 5.0 (QCPE 581) was used for PM3 and MNDO calculations: Dewar, M. J. S.; Thiel, W. J. *J. Am. Chem. Soc.* **1977**, *99*, 4899, 4907. Dewar, M. J. S.; Zoebisch, E. G.; Healy, E. F.; Stewart, J. J. P. *J. Am. Chem. Soc.* **1985**, *107*, 3902. Stewart, J. J. P. *J. Comp. Chem.* **1989**, *10*, 209. PM3 HOMO coefficients of **1a** at C2 = 0.3915, at C3 = 0.4510, at C1′ = −0.3050, at C2′ = −0.4310; PM3 net atomic charges at C2 = −0.1261, at C3 = −0.0628, at C1′ = −0.1393, at C2′ = −0.0062.

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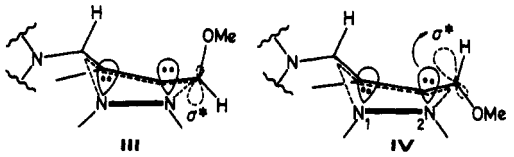

In addition to this kinetic effect for characterizing the outcome of hetero-Diels–Alder reactions, product-stabilizing factors also play a significant role. In the cycloaddition reactions of (*E*)-**1a** with PTAD and with DEAD, the primarily formed cycloadducts, especially in the reaction with PTAD, are not sufficiently stable. By a comparison of the two alternative product structures derivable from **1a,b** and azodienophiles, V should undergo heterolysis more rapidly than VII (Scheme V) as a result of the stronger (synperiplanar) n/σ^* interaction in the boatlike 1,2-diazine conformation of V (see X-ray structural analysis of **8**, supplementary material). This stereoelectronic effect is probably the driving force for the more rapid heterolysis of V to VI in comparison to the cycloadduct VII.

In summary, it can now be assumed that the differing product spectra obtained from Diels–Alder reactions of **1** with carbo- and azodienophiles are the result of a sensitive balance of steric, stereoelectronic, and FMO interactions.

The constitutions and stereochemistry of all Diels–Alder adducts were clarified above all by $^1H,^1H$ NMR decoupling and NOE experiments (400 MHz). In the case of product **8**, an X-ray crystallographic analysis provided valuable information on the geometry of the 1,2-diazine ring, which adopts a twisted boat conformation and thus unambiguously confirmed the "endo" selectivity of the stereospecific Diels–Alder step.

Experimental Section

Apparatus for melting points, C,H,N analyses, and spectroscopic measurements are given in ref 8.

Flash chromatographic separations were performed on silica gel 60 (Merck, grain size 0.040–0.063 mm). HPLC analyses were carried out with a Merck Hitachi L 6200 apparatus with a UV detector L 4000 (254 nm) and a Lichro-Spher 100 RP-18 column (5 μm, 125 × 4 mm).

All reactions were performed under anhydrous conditions using highly pure solvents under an argon atmosphere. For all racemic products, the nomenclature for only one enantiomer is given exemplarily.

12-(Benzenesulfonyl)-6α-methoxy-5aβ,6β,12aβ,12bβ-tetrahydro-12*H*-naphtho[2,3-*a*]carbazole-5,13-dione (2). The 3-vinylindole **1a**[17] (400 mg, 1.28 mmol) was dissolved in ethanol (120 mL), and a solution of 1,4-naphthoquinone (400 mg, 2.53 mmol) in ethanol (10 mL) was added. The mixture was stirred at 20 °C for 12 h. The formed precipitate was separated and recrystallized from toluene: yield 0.52 g (86%); mp 180 °C (toluene); ^1H NMR (DMSO-d_6) δ 3.33 (s, 3 H, OCH_3), 3.87 (pseudo t, $J_{5aH\beta,6H\beta}$ = 5.98 Hz, $J_{5aH,12H\beta}$ = 5.56 Hz, 1 H, C5a-H$_\beta$), 4.24 (m, $J_{6H\beta,7H}$ = 5.98 Hz, 1 H, C6-H$_\beta$), 4.43 (dd, $J_{12aH\beta,12bH\beta}$ = 3.75 Hz, $^4J_{12aH\beta,7H}$ = 3.01 Hz, 1 H, C12a-H$_\beta$), 4.51 (pseudo t, $J_{12bH\beta,12aH\beta}$ = 3.75 Hz, $^4J_{12bH\beta,5aH\beta}$ = 5.56 Hz, 1 H, C12b-H$_\beta$), 6.24 (pseudo t, $J_{7H,6H\beta}$ = 3.31 Hz, $J_{7H,12aH\beta}$ = 3.01 Hz, 1 H, C7-H), 7.10 (pseudo t, *J* = 7.0 Hz, 1 H, C9-H), 7.36 (pseudo t, *J* = 7.0 Hz, 1 H, C10-H), 7.56 (m, 3 H_{Ar}), 7.70 (m, 3 H_{Ar}), 7.92 (d, *J* = 7.5 Hz, 2 H, benzene-SO_2-C2/5-H), 8.00 (m, 1 H_{Ar}); EIMS (*m/z*, rel intensity) 471 ($M^{\bullet+}$, 3), 296 (100). Anal. Calcd for $C_{27}H_{21}NO_5S$ (471.53): C, 68.78; H, 4.49; N, 2.97; S, 6.80. Found: C, 68.81; H, 4.43, N, 2.96; S, 6.92.

12-(Benzenesulfonyl)-12*H*-naphtho[2,3-*a*]carbazole-5,13-dione (3). Compound **2** (100 mg, 0.21 mmol) was dissolved in toluene (50 mL), a solution of 2,3-dichloro-4,5-dicyano-1,4-benzoquinone (100 mg, 0.44 mmol) in toluene (10 mL) was added dropwise, and the mixture was heated under reflux for 12 h. Toluene (50 mL) was added to the hot mixture. After cooling, the mixture was extracted twice with 40-mL portions of saturated aqueous sodium hydrogen carbonate solution, and the organic phase was dried with magnesium sulfate, filtered, and concentrated. The residue was purified by flash chromatography (40–60 °C petroleum ether/ethyl acetate, 1/1): yield 35 mg (39%); mp 340 °C dec; ^1H NMR ($CDCl_3$) δ 7.17 (pseudo t, 2 H_{Ar}), 7.34 (m, 4 H_{Ar}), 7.45 (m, 1 H_{Ar}), 7.80 (m, 3 H_{Ar}), 8.02 (d, *J* = 8.38 Hz, 1 H_{Ar}), 8.15 (pseudo t, *J* = 8.38 Hz, 1 H_{Ar}), 8.31 (m 2 H_{Ar}), 8.44 (d, *J* = 7.94 Hz, 1 H_{Ar}); EIMS (*m/z*, rel intensity) 437 ($M^{\bullet+}$, 18), 326 (100), 296 (73). Anal. Calcd for $C_{26}H_{15}NO_4S$ (437.47): C, 71.38; H, 3.46; N, 3.20; S, 7.33. Found: C, 71.27; H, 3.31; N, 3.02; S, 7.18.

12-(Benzenesulfonyl)-6-methoxy-12*H*-naphtho[2,3-*a*]carbazole-5,13-dione (4). 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone (100 mg, 0.44 mmol) was added in small portions to a solution of carbazole **2** (80 mg, 0.17 mmol) in toluene (20 mL), and the mixture was stirred at 80–90 °C for 3 h. It was then diluted with toluene (20 mL) and extracted 3 times with 20-mL portions of saturated aqueous sodium hydrogen carbonate solution. The organic phase was neutralized, dried with magnesium sulfate, filtered, and concentrated to a volume of 5 mL. Orange-colored crystals formed: yield 41 mg (51%); mp 255 °C (toluene); ^1H NMR (DMSO-d_6) δ 4.07 (s, 3 H, OCH_3), 7.12–7.43 (m, 6 H_{Ar}), 7.57 (pseudo t, ^3J = 7.75 Hz, 1 H, C8-H or C9-H), 7.91–8.20 (m, 7 H_{Ar}); EIMS (*m/z*, rel intensity) 467 ($M^{\bullet+}$, 6), 327 (36), 300 (29), 94 (100), 93 (100). Anal. Calcd for $C_{27}H_{17}NO_5S$ (467.50): C, 69.37; H, 3.67; N, 3.00; S, 6.86. Found: C, 69.40; H, 3.86; N, 3.11; S, 6.85.

11-(Benzenesulfonyl)-5α-methoxy-4aβ,5β,11aβ,11bβ-tetrahydro-11*H*-benzo[2,3-*a*]carbazole-1,4-dione (5a). A solution of 1,4-benzoquinone (70 mg, 0.64 mmol) in ethanol (5 mL) was added dropwise to a solution of 3-vinylindole **1a** (200 mg, 0.64 mmol) in ethanol (20 mL). The mixture was stirred at 20 °C for 12 h, and the precipitate that formed was separated and recrystallized from toluene: yield 65 mg (24%); mp 191–192 °C (toluene); ^1H NMR ($CDCl_3$) δ 3.14 (s, 3 H, OCH_3), 3.37 (pseudo t (dd), $^3J_{4aH\beta,11bH\beta}$ = 5.95 Hz, 1 H, C4a-H$_\beta$), 4.11 (ddd, $^4J_{11aH\beta,6H}$ = 3.09 Hz, $^3J_{11aH\beta,11bH\beta}$ = 5.17 Hz, 1 H, C11a-H$_\beta$), 4.17 (ddd, $^3J_{5H\beta,6H}$ = 6.04 Hz, $^4J_{5H\beta,11aH\beta}$ = 2.70 Hz, 1 H, C5-H$_\beta$), 4.23 (pseudo t, $^3J_{11bH\beta,11aH\beta}$ = 5.12 Hz, 1 H, C11b-H$_\beta$), 6.21 (pseudo t, $^3J_{6H,11aH\beta}$ = 2.80 Hz, 1 H, C6-H), 6.72 (d, ^3J = 10.35 Hz, 1 H, C2-H or C3-H), 6.77 (d, ^3J = 10.35 Hz, 1 H, C3-H or C2-H), 7.07 (pseudo t, ^3J = 7.50 Hz, 1 H, C8-H or C9-H), 7.34 (pseudo t, ^3J = 7.77 Hz, 1 H, C9-H or C8-H), 7.52–7.58 (m, 3 H_{Ar}), 7.65–7.68 (m, 2 H_{Ar}), 7.90 (d, ^3J = 7.79 Hz, 2 H, C2'-H and C6'-H); EIMS (*m/z*, rel intensity) 421 ($M^{\bullet+}$, 0.7), 172 (100). Anal. Calcd for $C_{23}H_{19}NO_5S$ (421.47): C, 65.54; H, 4.54; N, 3.32; S, 7.61. Found: C, 65.60; H, 4.93; N, 3.13; S, 7.58.

11-(Benzenesulfonyl)-5α-methoxy-2-phenyl-4aβ,5β,11aβ,11bβ-tetrahydro-11*H*-benzo[2,3-*a*]carbazole-1,4-dione (5b). A solution of 2-phenyl-1,4-benzoquinone (60 mg, 0.33 mmol) in ethanol (2 mL) was added slowly to a solution of 3-vinylindole **1a** (100 mg, 0.32 mmol) in ethanol (6 mL), and the mixture was stirred at 20 °C for 48 h. The product separated as a yellow solid: yield 35 mg (22%); mp 140 °C (ethanol); ^1H NMR ($CDCl_3$) δ 3.23 (s, 3 H, OCH_3), 3.42 (pseudo t, $^3J_{4aH\beta,11bH\beta}$ = 6.16 Hz, 1 H, C4a-H$_\beta$), 4.16 (ddd, $^3J_{11aH\beta,11bH\beta}$ = 3.28 Hz, $^4J_{11aH\beta,6H}$ = 2.22 Hz, $^5J_{11aH\beta,5H\beta}$ = 1.20 Hz, 1 H, C11a-H$_\beta$), 4.22 (ddd, $^3J_{5H\beta,6H}$ = 3.17 Hz, $^3J_{5H\beta,4aH\beta}$ = 2.69 Hz, 1 H, C5-H$_\beta$), 4.43 (pseudo t, $^3J_{11bH\beta,4aH\beta}$ = 5.15 Hz, 1 H, C11b-H$_\beta$), 5.97 (pseudo t, $^3J_{6H,5H\beta}$ = 3.27 Hz, 1 H, C6-H), 6.83 (d, $^4J_{3H,4aH\beta}$ = 1.14 Hz, 1 H, C3-H), 7.04 (pseudo t, ^3J = 7.16 Hz, 1 H, C8-H or C9-H), 7.30–7.85 (m, 13 H_{Ar}); EIMS (*m/z*, rel intensity) 497 ($M^{\bullet+}$, 0.4), 270 (55), 186 (100). Anal. Calcd for $C_{29}H_{23}NO_5S$ (497.56): C, 70.01; H, 4.66; N, 2.82; S, 6.44. Found: C, 69.80; H, 4.71; N, 2.70; S, 6.64.

11-(Benzenesulfonyl)-2-chloro-5α-methoxy-4aβ,5β,-11aβ,11bβ-tetrahydro-11*H*-benzo[2,3-*a*]carbazole-1,4-dione (5c) and 11-(Benzenesulfonyl)-3-chloro-5a-methoxy-4aβ,5β,11aβ,11bβ-tetrahydro-11*H*-benzo[2,3-*a*]carbazole-1,4-dione (5d). A solution of 2-chloro-1,4-benzoquinone (320 mg, 2.24 mmol) in 2-propanol (10 mL) was added slowly to a solution of 3-vinylindole **1a** (690 mg, 2.2 mmol) in 2-propanol (40 mL), and the mixture was stirred at 20 °C for 8 h. The formed precipitate was separated and purified by flash chromatography (40–60 °C petroleum ether/ethyl acetate, 3/1).

The constitutions of the pure, isolated regioisomers **5c** and **5d** could not be clarified with respect to the position of the chlorine

atom at the 2–3 bond. In the following, the compounds are designated as I and II.

Compound I: yield 155 mg (16%); mp 201 °C (petroleum ether/ethyl acetate); ^{1}H NMR (DMSO-d_6) δ 3.15 (s, 3 H, OCH_3), 3.79 (pseudo t, $^3J_{4aH\beta,11bH\beta}$ = 5.70 Hz, 1 H, C4a-H$_\beta$), 4.15 (ddd, $^3J_{5H\beta,6H}$ = 3.05 Hz, 1 H, C5-H$_\beta$), 4.43 (ddd, $^4J_{11aH\beta,6H}$ = 1.68 Hz, 1 H, C11a-H$_\beta$), 4.49 (pseudo t, $^3J_{11bH\beta,4aH\beta}$ = 5.50 Hz, 1 H, C11b-H$_\beta$), 6.25 (pseudo t, $^3J_{6H,5H\beta}$ = 2.83 Hz, 1 H, C6-H), 7.09 (pseudo t, ^3J = 7.42 Hz, 1 H, C8-H or C9-H), 7.21 (s, 1 H, C2-H or C3-H), 7.36 (pseudo t, ^3J = 7.52 Hz, 1 H, C9-H or C8-H), 7.53–7.68 (m, 5 H$_{Ar}$), 7.91 (d, ^3J = 7.51 Hz, 2 H, C2′-H and C6′-H); EIMS for I and II (*m/z*, rel intensity) 455 (M$^{\bullet+}$, 4.4; 1.1), 314 (16; 13), 172 (100; 100). Anal. Calcd for $C_{23}H_{18}NO_5SCl$ (455.91): C, 60.59; H, 3.98; N, 3.07; S, 7.03; Cl, 7.78. Found: C, 60.29; H, 4.03; N, 3.05; S, 7.14; Cl, 7.80.

Compound II: yield 142 mg (15%); mp 179–180 °C (petroleum ether/ethyl acetate); ^{1}H NMR (DMSO-d_6) δ 3.14 (s, 3 H, OCH_3), 3.89 (pseudo t, $^3J_{4aH\beta,11bH\beta}$ = 6.01 Hz, 1 H, C4a-H$_\beta$), 4.17 (pseudo t, $^3J_{5H\beta,6H}$ = 3.13 Hz, 1 H, C5-H$_\beta$), 4.37 (ddd, not completely resolved, 1 H, C11a-H$_\beta$), 4.50 (pseudo t, $^3J_{11bH\beta,4aH\beta}$ = 5.10 Hz, 1 H, C11b-H$_\beta$), 6.24 (pseudo t, not completely resolved, 1 H, C6-H), 7.08 (pseudo t, ^3J = 7.48 Hz, C8-H or C9-H), 7.23 (s, 1 H, C2-H or C3-H), 7.35 (pseudo t, ^3J = 7.68 Hz, 1 H, C9-H or C8-H), 7.52–7.69 (m, 5 H$_{Ar}$), 7.89 (d, ^3J = 7.59 Hz, 2 H, C2′-H and C6′-H). Anal. Calcd for $C_{23}H_{18}NO_5SCl$ (455.91): C, 60.59; H, 3.98; N, 3.07; S, 7.03; Cl, 7.78. Found: C, 60.37; H, 4.17; N, 3.08; S, 7.22; Cl, 7.83.

9-(Benzenesulfonyl)-3β-methoxy-1,1,2,2-tetracyano-1,2,3a,9aβ-tetrahydro-9*H*-carbazole (6a) and *cis*/*trans*-1-(Benzenesulfonyl)-3-(4-methoxy-2,2,3,3-tetracyanocyclobutyl)-1*H*-indole (6c). A solution of tetracyanoethylene (327 mg, 2.55 mmol) in tetrahydrofuran (7 mL) was added dropwise at 20 °C to a solution of the 3-vinylindole **1b** (495 mg, 1.58 mmol) dissolved in tetrahydrofuran (20 mL). The mixture was stirred at 20 °C for 4 h and evaporated to dryness, and the residue was dissolved in toluene (50 mL). The toluene solution was concentrated to a volume of 10 mL and cooled to 4 °C, whereupon a precipitate formed. The solid was separated and washed with *n*-hexane (ratio of **6a** to *cis*/*trans*-**6c** by HPLC = 1:1). Several recrystallizations from CH_2Cl_2, *n*-hexane gave 290 mg (42%) of **6a**: mp 147 °C (CH_2Cl_2, *n*-hexane); ^{1}H NMR ($CDCl_3$) δ 3.67 (s, 3 H, OCH_3), 4.81 (dd, $^3J_{3H\alpha,4H}$ = 4.57 Hz, $^5J_{3H\alpha,9aH\beta}$ = 1.58 Hz, 1 H, C3-H$_\alpha$), 5.07 (pseudo t, *J* not resolved, 1 H, C9a-H$_\beta$), 6.18 (pseudo t, $^3J_{4H,3H\alpha}$ = 4.31 Hz, 1 H, C4-H), 7.18–7.93 (m, 9 H$_{Ar}$); EIMS (*m/z*, rel intensity) 441 (M$^{\bullet+}$, 3), 313 (71), 174 (100). Anal. Calcd for $C_{23}H_{15}N_5O_3S$ (441.46): C, 62.58; H, 3.42; N, 15.86; S, 7.26. Found: C, 62.30; H, 3.71; N, 15.61; S, 6.99.

Compound **6c** was obtained in a solid mixture with **6a** and characterized by its ^{1}H NMR spectrum: ^{1}H NMR (CD_3OD; only one epimer is detectable within the ^{1}H NMR detection limits) δ 3.70 (s, 3 H, OCH_3), 5.84 (d, ^3J = 13 Hz, 1 H, C1′-H or C4′-H), 7.16 (d, ^3J = 13 Hz, 1 H, C4′-H or C1′-H, according to INDOR experiments), 7.13–7.99 (m, 11 H, 10 H$_{Ar}$ and C4′-H or C1′-H).

9-(Benzenesulfonyl)-3α-methoxy-1,1,2,2-tetracyano-1,2,3β,9aβ-tetrahydro-9*H*-carbazole (6b) and *cis*/*trans*-1-(Benzenesulfonyl)-3-(4-methoxy-2,2,3,3-tetracyanocyclobutyl)-1*H*-indole (6c). Tetracyanoethylene (115 mg, 0.9 mmol) dissolved in toluene (5 mL) was added dropwise at 20 °C to a solution of the 3-vinylindole **1a** (100 mg, 0.32 mmol) in toluene (30 mL). The mixture was stirred at 20 °C for 2 h, concentrated to a volume of 12 mL, and cooled to 4 °C. The precipitate formed was filtered and washed several times with ether. HPLC analysis (eluent: acetonitrile/water/methanol, 30/30/40) showed the presence of three components [**6b** and *cis*/*trans*-**6c**, ratio 1:1 (*cis*/*trans*-**6c**)]; combined yield 80 mg (57%).

Analytical data for the mixture: FDMS (*m/z*, rel intensity) 441 (M$^{\bullet+}$, 0.14), 313 (100), 128 (0.28).

Compound 6b: ^{1}H NMR (CD_2Cl_2) δ 3.77 (s, 3 H, OCH_3), 4.54 (dd, $^4J_{3H\beta,9aH\beta}$ = 1.99 Hz, $^3J_{3H\beta,4H}$ = 2.91 Hz, 1 H, C3-H$_\beta$), 4.89 (dd, $^4J_{9aH\beta,4aH}$ = 3.03 Hz, $^5J_{9aH\beta,3H\beta}$ = 1.93 Hz, 1 H, C9a-H$_\beta$), 6.26 (pseudo t, $^4J_{4H,9aH}$ = 3.10 Hz, 1 H, C4-H), 7.10–7.89 (m, 9 H$_{Ar}$); ^{13}C NMR ($CDCl_3$) δ 57 (OCH_3), 64 (C3), 78 (C9a), 95 (C4); sp^2-C (tertiary) 118, 123, 128, 129 (2 C), 132, 149; sp^2-C (quaternary) 107, 108 (2 C), 110 (2 C), 111, 119, 126, 134, 144, 149 (C2′/C6′ of $PhSO_2$), 144 (C1′ of $PhSO_2$).

Compound 6c ($CDCl_3$; only one epimer observable within the detection limits of ^{1}H NMR spectroscopy): δ 3.87 (s, 3 H, OCH_3), 5.40 (d, ^3J = 6.43 Hz, 1 H, C1′-H or C4′-H), 6.28 (d, ^3J = 6.45 Hz, 1 H, C4′-H or C1′-H), 7.18–7.97 (m, 10 H$_{Ar}$).

Mixture of 6b and *cis*/*trans*-6c. Anal. Calcd for $C_{23}H_{15}N_5O_3S$ (441.46): C, 62.48; H, 3.42; N, 15.86; S, 7.26. Found: C, 62.30; H, 3.71; N, 15.61; S, 6.99.

Methyl 9-(Benzenesulfonyl)-9*H*-carbazole-2-carboxylate (7). Methyl propynoate (510 mg, 6 mmol) was added dropwise to a solution of **1a** (260 mg, 0.83 mmol) in toluene (20 mL). After addition of highly activated molecular sieve (4 Å; 7 g), the mixture was heated with stirring under reflux for 12 h. After filtration, the solid residue was extracted with dichloromethane (3 × 20 mL) and then with toluene (2 × 20 mL). The combined organic phases were concentrated under vacuum, and the residue obtained was purified by flash chromatography (40–60 °C petroleum ether/ethyl acetate, 4/1) to furnish 35 mg (12%) of **7** as yellow crystals: mp 198 °C (dichloromethane/*n*-hexane); ^{1}H NMR (CD_2Cl_2) δ 3.95 (s, 3 H, $COOCH_3$), 7.45–7.70 (m, 5 H$_{Ar}$), 7.82–7.85 (m, 2 H$_{Ar}$), 8.02–8.06 (d, ^3J = 7.98 Hz, 1 H, C3-H or C4-H), 8.22–8.32 (m, 3 H$_{Ar}$), 8.88 (s, 1 H, C1-H). Anal. Calcd for $C_{20}H_{15}NO_4S$ (365.40): C, 65.74; H, 4.14; N, 3.83; S, 8.77. Found: C, 65.48; H, 3.98; N, 3.66; S, 8.47.

11-(Benzenesulfonyl)-5β-methoxy-2-phenyl-5a,11aβ-dihydro[1,2,4]triazolo[1,2-*a*]pyridazino[3,4-*b*]indole-1,3-dione (8). PTAD (0.140 g, 0.8 mmol) was added to a solution of 3-vinylindole **1b** (0.250 g, 0.8 mmol) in dichloromethane (20 mL) at −75 °C, and the mixture was stirred at this temperature for 10 min and then concentrated under vacuum. The residue obtained was separated by flash chromatography (40–60 °C petroleum ether/ethyl acetate, 1/1): yield 0.36 g (92%); mp 171 °C (dichloromethane/petroleum ether); ^{1}H NMR (DMSO-d_6) δ 3.49 (s, 3 H, OCH_3), 5.84 (d, ^3J = 6.1 Hz, 1 H, C5-H$_\alpha$), 6.45 (d, ^4J = 2.6 Hz, 1 H, C11a-H$_\beta$), 6.70 (dd, ^3J = 6.1 Hz, ^4J = 2.6 Hz, 1 H, C6-H), 7.18 (dd, ^3J = 7.6 Hz, 1 H$_{Ar}$), 7.55 (mc, 11 H$_{Ar}$), 7.79 (d, ^3J = 7.8 Hz, 2 H, phenyl-SO_2-C2/6-H); EIMS (*m/z*, rel intensity) 488 (M$^{\bullet+}$, 6), 314 (40), 219 (100). Anal. Calcd for $C_{25}H_{20}N_3O_5S$ (488.52): C, 61.47; H, 4.13; N, 11.47. Found: C, 61.37; H, 3.99; N, 11.28.

Diethyl 9-(Benzenesulfonyl)-3β-methoxy-1,2,3a,9aβ-tetrahydropyridazino[3,4-*b*]indole-1,2-dicarboxylate (9). Diethyl azodicarboxylate (0.174 g, 1 mmol) was added to a solution of 3-vinylindole **1b** (0.250 g, 0.8 mmol) in toluene (10 mL) at 20 °C, and the mixture was stirred at this temperature for 1 h. The colorless crystals formed upon cooling the mixture to 4 °C were separated by filtration, yield 0.312 g (82%): mp 150–152 °C (toluene); ^{1}H NMR ($CDCl_3$) δ 1.35 (2 t, ^3J = 6.1 Hz, 6 H, 2 CH_2CH_3), 3.48 (s, 3 H, OCH_3), 4.23 (m, 2 H, CH_2CH_3), 4.32 (m, 1 H, CH_2CH_3), 4.43 (m, 1 H, CH_2CH_3), 5.72 (d, ^3J = 6.1 Hz, 1 H, C3-H$_\alpha$), 6.25 (dd, ^3J = 6.1 Hz, ^4J = 2.8 Hz, 1 H, C4-H), 6.38 (d, ^4J = 2.8 Hz, C9a-H$_\beta$), 6.98 (dt, ^3J = 7.5 Hz, 1 H$_{Ar}$), 7.34 (mc, 5 H$_{Ar}$), 7.66 (br d, ^3J = 7.8 Hz, 1 H, C5-H), 8.29 (br d, ^3J not resolved, 2 H, phenyl-SO_2-C2/6-H); EIMS (*m/z*, rel intensity) 487 (M$^{\bullet+}$, 22), 456 (31), 251 (31), 251 (100). Anal. Calcd for $C_{23}H_{25}N_3O_7S$ (487.53): C, 56.66; H, 5.17; N, 8.62. Found: C, 56.45; H, 5.19; N, 8.61.

Diethyl 9-(Benzenesulfonyl)-3β-methoxy-1,2,3α,9aβ-tetrahydropyridazino[3,4-*b*]indole-1,2-dicarboxylate (9), Diethyl 9-(Benzenesulfonyl)-3α-methoxy-1,2,3β,9aβ-tetrahydropyridazino[3,4-*b*]indole-1,2-dicarboxylate (10), and Diethyl 9-(Benzenesulfonyl)-1,2-dihydropyridazino[3,4-*b*]-indole-1,2-dicarboxylate (11). The mixture of the three compounds was obtained from 3-vinylindole **1a** (0.300 g, 0.96 mmol) and diethyl azodicarboxylate (0.200 g, 1.15 mmol) as described for the synthesis of **9** from **1b**. The products were separated and purified by flash chromatography (40–60 °C petroleum ether/ethyl acetate, 7/3).

Compound 9: yield 0.07 g (15%).

Compound 10: yield 0.07 g (15%); mp 92 °C (40–60 °C petroleum ether); ^{1}H NMR (DMSO-d_6) δ 1.06 (t, ^3J = 7.0 Hz, 3 H, CH_2CH_3), 1.33 (t, ^3J = 6.9 Hz, 3 H, CH_2CH_3), 3.36 (s, 3 H, OCH_3), 3.92 (q, ^3J = 7.0 Hz, 2 H, CH_2CH_3), 4.22 (m, 1 H, CH_2CH_3), 4.31 (m, 1 H, CH_2CH_3), 5.65 (br d, ^3J not resolved, 1 H, C3-H$_\beta$), 5.74 (br d, ^3J not resolved, 1 H, C4-H), 6.00 (d, ^4J = 2.6 Hz, 1 H, C9a-H$_\beta$), 7.07 (dd, ^3J = 7.3 Hz, 8.0 Hz, 1 H$_{Ar}$), 7.34 (dd, ^3J = 8.3 Hz, 8.4 Hz, 1 H$_{Ar}$), 7.53 (m, 4 H$_{Ar}$), 7.67 (m, 1 H$_{Ar}$), 7.89 (d, ^3J = 7.4 Hz, 2 H, phenyl-SO_2-C2/6-H); EIMS (*m/z*, rel intensity) 487 (M$^{\bullet+}$, 25), 313 (100). Anal. Calcd for $C_{23}H_{25}N_3O_7S$ (487.53):

C, 56.66; H, 5.17; N, 8.62. Found: C, 56.46; H, 5.19; N, 8.69.

Compound 11: yield 0.127 g (29%); mp 91 °C (40–60 °C petroleum ether); ^{1}H NMR (DMSO-d_6) δ 1.20 (t, ^3J = 7.0 Hz, 3 H, CH_2CH_3), 1.30 (br s, 3 H, CH_2CH_3), 4.24 (m, 2 H, CH_2CH_3), 4.35 (br s, 2 H, CH_2CH_3), 6.61 (br d, ^3J = 6.3 Hz, 1 H, C4-H), 7.06 (br s, 1 H, C3-H), 7.47 (mc, 6 H_{Ar}), 7.97 (br d, ^3J = 8.0 Hz, 2 H, phenyl-SO_2-C2/6-H), 8.08 (d, ^3J = 8.4 Hz, 1 H, C5-H); EIMS (m/z, rel intensity) 455 ($M^{\bullet+}$, 1), 310 (31), 169 (100). Anal. Calcd for $C_{22}H_{21}N_3O_6S$ (455.49): C, 58.01; H, 4.65; N, 9.26. Found: C, 58.27; H, 4.61; N, 9.06.

Supplementary Material Available: Full details of the X-ray analysis of compound 8 and 400-MHz ^{1}H NMR spectra of a mixture of **6a** and **7** (from (*E*)-**1a**) and a mixture of **6b** and **7** (from (*Z*)-**1b**) (9 pages). Ordering information is given on any current masthead page.

Synthesis of α-Methyl 1′,2′-Dideoxycellobioside: A Novel *C*-Disaccharide

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Bromonium ion induced 6-*endo-trig* cyclizations of *E* olefins derived from D-arabinose provide a stereoselective route to 2′-deoxyglucono-β-*C*-glycosides. Use of δ-alkenols containing allylic isopropylidenes (i.e., **1**) prevents formation of furan products due to the highly strained transition state necessary for formation of the trans [3.3.0] bicyclic systems. Because the exo-anomeric carbon is not involved in the cyclization, previously established stereocenters at this carbon are left intact. Application of this methodology to the synthesis of α-methyl 1′,2′-dideoxycellobioside (**22**) is presented. The restricted rotation about the bond connecting the two sugars affords a unique staggared conformation of the disaccharide.

Because of the ubiquitous role carbohydrates play in biology, carbohydrate analogues are valuable tools for the study of biochemical systems. Since the chemistry of sugars is dominated by the reactivity of the glycosidic bond, a great deal of effort has gone into the synthesis and study of *C*-glycosides in which the acetal linkage has been replaced by a hydrolytically stable carbon–carbon bond. The best understood *C*-glycosides are a series of *C*-disaccharides synthesized and studied by Kishi[2] and coworkers in which the bridging oxygen of the glycosidic linkage is replaced by a methylene group. They found that the solution conformations of these molecules are similar to those of the corresponding *O*-disaccharides. A general model based on a diamond-lattice analysis[3] has since been developed to predict solution conformations of disaccharides. We became interested in developing a series of *C*-oligosaccharides in which the "floppy" glycosidic linkage has been reengineered to produce a linkage with a predictable restricted conformation. Analysis of molecular models showed that direct connectivity of the two rings (to form a β-1′-deoxydisaccharide) should result in restricted rotation about the connecting bond, due to steric interaction between substituents on the two rings. We therefore set out to synthesize α-methyl 1′,2′-dideoxycellobioside (**22**) which can be considered a prototype for this class of compounds.

Methodology for the generation of *C*-glycosides has found wide application in natural products synthesis[4] and in the synthesis of biologically active carbohydrate analogues.[5] Methods which exploit the steric and/or stereoelectronic effects of pyranose or furanose substrates involve the intermediacy of cations, radicals, anions, or organometallic reagents at the anomeric carbon.[6] Equally productive approaches make use of the de novo synthesis of furanose or pyranose rings via cycloaddition or cyclization reactions on cyclic[7] or acyclic intermediates.[8] We desired a pyranose β-*C*-glycoside synthesis that would allow coupling of preformed glycoside units without disrupting the stereochemistry at the exo carbon adjacent to the anomeric position.[9] The extensive literature describing the electrophile-induced cyclization of carbohydrate-derived alkenols[10] encouraged us to pursue this methodology for the generation of the acyclic precursors. However, we realized that attaining selective 6-endo (versus 5-exo)[11] cyclization would be a problem. Both steric and electronic (inductive) effects can influence the stereo- and regiochemical outcome of the cyclization reaction. For example,

(1) Taken from the Ph.D. thesis of B.R.T.

(2) (a) Babirad, S. A.; Wang, Y.; Kishi, Y. *J. Org. Chem.* **1987**, *52*, 1370. (b) Wu, T.-C.; Goekjian, P. G., Kishi, Y. *J. Org. Chem.* **1987**, *52*, 4819. (c) Goekjian, P. G.; Wu, T.-C.; Kang, H.-Y.; Kishi, Y. *J. Org. Chem.* **1987**, *52*, 4823. (d) Babirad, S. A.; Wang, Y.; Goekjian, P. G.; Kishi, Y. *J. Org. Chem.* **1987**, *52*, 4825. (e) Wang, Y.; Goekjian, P. G.; Ryckman, D. M.; Kishi, Y. *J. Org. Chem.* **1988**, *53*, 4151.

(3) Miller, W. H.; Ryckman, D. M.; Goekjian, P. G.; Wang, Y.; Kishi, Y. *J. Org. Chem.* **1988**, *53*, 5580.

(4) Examples include showdomycin: Barton, D. H. R.; Ramesh, M. *J. Am. Chem. Soc.* **1990**, *112*, 891 and references therein. Palytoxin: Armstrong, R. W.; Beau, J. M.; Cheon, S. H.; Christ, W. J.; Fujioka, H.; Ham, W. H.; Hawkins, L. D.; Kishi, Y.; Jin, H.; Kang, S. H.; Tino, J. A.; Taniguchi, M.; Uenishi, J.; Ueda, K.; Talamas, F. X.; Stutz, A. E.; White, J. B.; Yonaga, M.; Mcwhorter, W. W.; Nakata, M.; Martinelli, M. J.; Mizuno, M. *J. Am. Chem. Soc.* **1989**, *111*, 7525.

(5) (a) Peseke, K.; Abrosi, H. D.; Michalik, M. *Carbohydr. Res.* **1989**, *194*, 87. (b) Bamford, M. J.; Coe, P. L.; Walker, R. T. *J. Med. Chem.* **1990**, *33*, 2494. (c) Related compounds: Danishefsky, S. J.; Pearson, W. H.; Harvey, D. F.; Maring, C. J.; Spring, J. P. *J. Am. Chem. Soc.* **1985**, *107*, 1256.

(6) For a comprehensive listing of methods for C-glycosidation, see: Herscovici, J.; Muleka, K.; Boumaiza, L.; Antonakis, K. *J. Chem. Soc., Perkin Trans. 1* **1990**, 1995.

(7) Ireland, R. E.; Thaisrivongs, S.; Wilcox, C. S. *J. Am. Chem. Soc.* **1980**, *102*, 1155. Burke, S. D.; Armistead, D. M.; Schoenen, F. J. *J. Org. Chem.* **1984**, *49*, 4320. Curran, D. P.; Suh, Y. G. *Carbohydr. Res.* **1987**, *171*, 161.

(8) Myles, D. C.; Danishefsky, S. J.; Schulte, G. *J. Org. Chem.* **1990**, *55*, 1636 and references cited therein.

(9) In general, many previously developed methods meet this criteria (i.e., Diels–Alder reactions, Claissen rearrangements, any 6-endo cyclization). However, construction of C-oligosaccharides using carbohydrate precursors provides a complementary route to these targets (vide infra).

(10) Sinay provided one of the first examples of a 6-*exo-trig* cyclization of a glucose-derived δ-hydroxyalkene, with predominant formation of the α-anomer. In general, the directing effect of allylic hydroxy groups in 5- and 6-exo cyclizations result in products with cis relationship between the alcohol and the carbon on the newly formed stereocenter: Pougny, J. R.; Nassr, M. A. M.; Sinay, P. *J. Chem. Soc., Chem. Commun.* **1981**, 375. For comprehensive studies on carbohydrate substrates, see: Reitz, A. B.; Nortey, S. O.; Maryanoff, B. E.; Liotta, D.; Monahan, R. *J. Org. Chem.* **1987**, *52*, 4191 and references cited therein.

(11) Baldwin, J. E. *J. Chem. Soc., Chem. Comm.* **1976**, 734.

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