Metal-Graphite Reagents in Carbohydrate Chemistry. 8.[1] The Scope and Limitations of the Use of Zinc/Silver-Graphite in the Synthesis of Carbohydrate-Derived Substituted Hex-5-enals and Pent-4-enals

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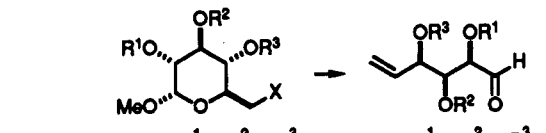
The compatibility of different organic functional groups with the use of the zinc/silver-graphite reagent was investigated, utilizing 23 6-bromo-6-deoxy- or 6-deoxy-6-iodohexopyranosides and 5-deoxy-5-iodopentofuranose derivatives. These compounds possessed *O*-acetyl, *O*-benzoyl, *O*-methyl-, or *O*-*p*-tolylsulfonyl, *O*-benzyl, *O*-methyl, *O*-isopropylidene, epoxy, acetamido deoxy, azido deoxy, chloro deoxy, and deoxy fluoro groups and included a mono and a dideoxy derivative. Reductive dealkoxyhalogenation of these compounds gave, in most instances, a single product, a hex-5- or pent-4-enal, which could be considered a precursor for carbocyclization reactions. Iodides reacted faster than bromides, and pyranose derivatives reacted faster and more cleanly than furanose derivatives. The kinetic or thermodynamic stability of the product enal was found to be structure-dependent. Reduction of the carbon-halogen bond was one of the few side reactions observed. A mechanism for the reductive ring cleavage is proposed.

Introduction

In the constantly and rapidly expanding field of natural product synthesis, there is an ever increasing demand for carbohydrate-derived synthons.[2] Those compounds possessing a carbonyl group tethered to an olefinic bond, such as hex-5-enals or pent-4-enals, are of particular interest. Such compounds can be converted to homochiral cyclopentanoids by either radical-mediated cyclization[3,4] or cycloaddition.[5] Exploiting Vasella's fundamental discovery,[5] we recently improved and extended the scope of the zinc-induced ring-opening reaction of 6-deoxy-6-halopyranose and 5-deoxy-5-halofuranose derivatives by employing either zinc/silver-graphite or potassium-graphite laminate (C_8K)[6-8] under aprotic conditions. The use of these highly reactive reagents not only completely inhibited the formation of byproducts such as enal acetals,[5] but also allowed the synthesis of hitherto inaccessible[7] cyclic and acyclic olefinic sugar derivatives. In order to further expand the scope and to determine the limitations of the synthesis of carbohydrate-derived enals by reduction with highly reactive metals,[9] the reductive dealkoxyhalogenation of a number of Ω-deoxy halo sugars differing in ring size, configuration, and substitution pattern was attempted.

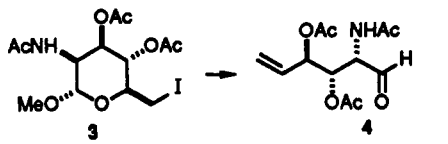
Results and Discussion

With the exception of the methyl 6-bromo-6-deoxyhexopyranosides **1d**, **5c**, **9**, and **28**, which were obtained from 4,6-*O*-benzylidene precursors by reaction with *N*-bromosuccinimide,[10] and compounds **12**, **14**, **15**, **18e**, and **18g**, which were prepared by the displacement of a sulfonyloxy group by iodide,[11] the starting materials were prepared by iodination of the corresponding 5-O- or 5-O-protected sugars with the triphenylphosphine/imidazole/iodine reagent.[12] Interestingly, these iodinations proceeded substantially faster than originally reported[12] and invariably gave good yields, even at ambient temperature.

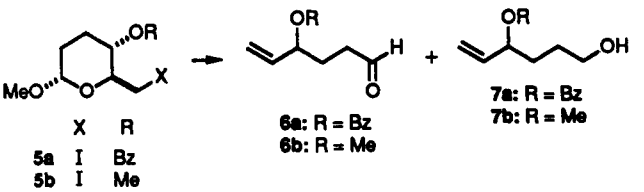


	X	R^1	R^2	R^3
1a	I	Ac	Ac	Ac
1b	I	Bz	Bz	Bz
1c	I	Me	Me	Bz
1d	Br	Me	Me	Bz
1e	I	Me	Me	Ce
1f	I	Ts	Ts	Me

	R^1	R^2	R^3
2a	Ac	Ac	Ac
2b	Bz	Bz	Bz
2c	Me	Me	Bz
2e	Me	Me	Ce



3 **4**



	X	R
5a	I	Bz
5b	I	Me

6a: R = Bz
6b: R = Me

7a: R = Bz
7b: R = Me

(1) For part VII, see ref 7. Presented in part at the Fifth European Symposium on Carbohydrates, Prague, Czechoslovakia, August 21-25, 1989.

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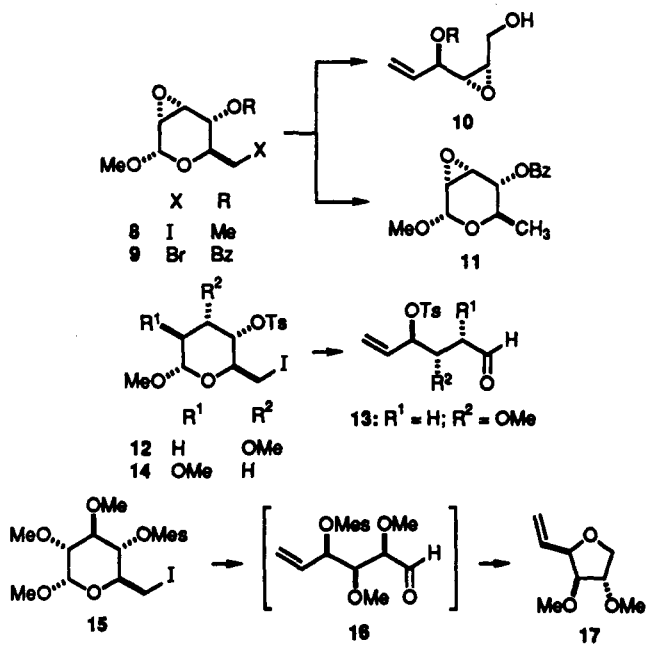
The results of this study of the scope and limitations of the zinc/silver–graphite-induced elimination reaction can be summarized as follows:

A. The limited results previously reported[3] were substantially extended. The reaction of zinc/silver–graphite with a great variety of Ω-deoxy halo sugars proceeded smoothly and rapidly in anhydrous tetrahydrofuran or dimethoxyethane at, or slightly above, room temperature. The results were superior to those obtained with less reactive zinc reagents, which invariably required protic solvents and higher reaction temperatures.[5,14]

B. With only a few exceptions, the rate of dealkoxyhalogenation was high and was nearly independent of the substitution pattern of the sugars. In a few cases, reduction of the carbon–halogen bond competed with dealkoxyhalogenation at temperatures below 0 °C.[7] However, the kinetic or thermodynamic stability of the resulting enal was clearly a function of the nature of the protecting groups present and their locations. This was clearly demonstrated by the elimination reaction of the *O*-sulfonyl derivatives **1f**, **12**, **14**, and **15**. Thus, although the products formed from **1f**, **14**, and **15** decomposed immediately, compound **13** was sufficiently stable to allow its isolation and characterization. The spontaneous formation of compound **17**, after sodium borohydride treatment of the reaction mixture resulting from **15**, indicated the intermediacy of enals. There is, at present, no plausible explanation for the limited stability of the *O*-sulfonyl enals.



Attempts to induce similar spontaneous consecutive reactions following dealkoxyhalogenation by placing leaving groups at appropriate sites, as in compounds **18c**, **18f**, and **18g**, failed.

Because of their high volatility, compounds **6b** and **25** could not be separated from the solvent. Their isolation was accomplished in the form of compounds **7b** and **26**, which resulted from the sodium borohydride reduction of **6b** and **25**, respectively.

Table I. Dealkoxyhalogenation of Ω-Deoxy Halo Sugars by Zn/Ag–Graphite

entry	compd	conditions	product (yield, %)
1	**1a**	25 °C, 10 min	**2a** (87)
2	**1b**	25 °C, 5 min	**2b** (81)[a,b,j]
3	**1c**	25 °C, 10 min	**2c** (77)
4	**1d**	30 °C, 4 h[c]	**2c** (66)[d,j]
5	**1e**	25 °C, 10 min	**2e** (83)
6	**1f**	25 °C, 10 min	–[e]
7	**3**	25 °C, 10 min	**4** (76)
8	**5a**	25 °C, 5 min	**6a** (1), **7a** (85)
9	**5a**	25 °C, 15 min[c]	**6a** (5), **7a** (85)
10	**5a**	25 °C, 12 h[f]	**6a** (70), **7a** (10)
11	**5b**	25 °C, 10 min	**7b** (84)[g]
12	**8**	25 °C, 10 min	**10** (90)[g]
13	**9**	40 °C, 12 h	**11** (70)
14	**12**	25 °C, 10 min	**13** (75)[h]
15	**14**	25 °C, 5 min	–[e]
16	**15**	25 °C, 10 min	**17** (71)[g]
17	**27**	25 °C, 3 h	–[i]
18	**28**	30 °C, 12 h	–[i]
19	**18a**	30 °C, 30 min	**19a** (41),[g,j] **20a** (8)
20	**18b**	60 °C, 12 h	**20b** (71)
21	**18c**	60 °C, 12 h	**20c** (46)[k]
22	**18d**	30 °C, 60 min	**19d** (57)[g]
23	**18e**	60 °C, 12 h	**20e** (68)
24	**18f**	30 °C, 60 min	–[d]
25	**18g**	30 °C, 60 min	–[d]
26	**21**	30 °C, 3 h	**22** (48), **23** (20)
27	**24**	30 °C, 60 min	**26** (69)[g]

[a] One equivalent of pyridine was added before workup to avoid decomposition of the product. [b] No reaction observed at −78 °C. [c] Rieke Zn/THF/methanol. [d] Sluggish reaction with Zn/Ag–graphite in THF. [e] Product decomposed on attempted workup. [f] Zn dust/THF. [g] After reduction with $NaBH_4$. [h] Approximate half-life: <20 min (determined by ^1H NMR). [i] No reaction observed. [j] Isolated as the 1,2-*O*-isopropylidene derivative. [k] Trace amounts of unidentified byproducts also detected. [l] Decomposed on prolonged exposure to air.

Apart from their distinct tendency toward glycoside hydrolysis, deoxy sugars[21] not only showed unusually high rates of dealkoxyhalogenation, but also underwent further reduction to mixtures of hex-5-enals **6** and hex-5-enitols **7**. The ratio of **6** to **7** was a function of the activity of the zinc reagent employed (cf. Table I).

The following order of reactivity in zinc/silver–graphite-induced ring-opening dealkoxyhalogenation was observed: 6-deoxy-6-iodohexopyranosides > 6-bromo-6-deoxy hexopyranosides. The latter were also prone to dehalogenation (cf. entries **13**, **14**, Table I). 5-Deoxy-5-iodopentofuranoses or -furanosides were the least reactive. The reaction rate, as well as the kind of product formed, depended on the configuration and substitution pattern of the parent sugar. Thus, the 3-deoxy fluoro (**18d**) or the 3-*O*-methyl derivative (**18a**), after borohydride reduction, afforded the 4-enitols **19d** and **19a**, respectively. The influence of steric and configurational effects was shown by the products from compounds **18b**, **21**, and **18c**. The ring-opening reactions of **18b** and **18c** were completely inhibited by the presence of the *O*-benzyl and *O*-*p*-tolylsulfonyl groups, respectively. In the case of the less sterically crowded compound **21**, a mixture of **22** and **23**, in a ratio of 5:2, was formed. Interestingly, the reaction of **18c** resulted in the reduction of both the carbon–halogen bond and the azido group.

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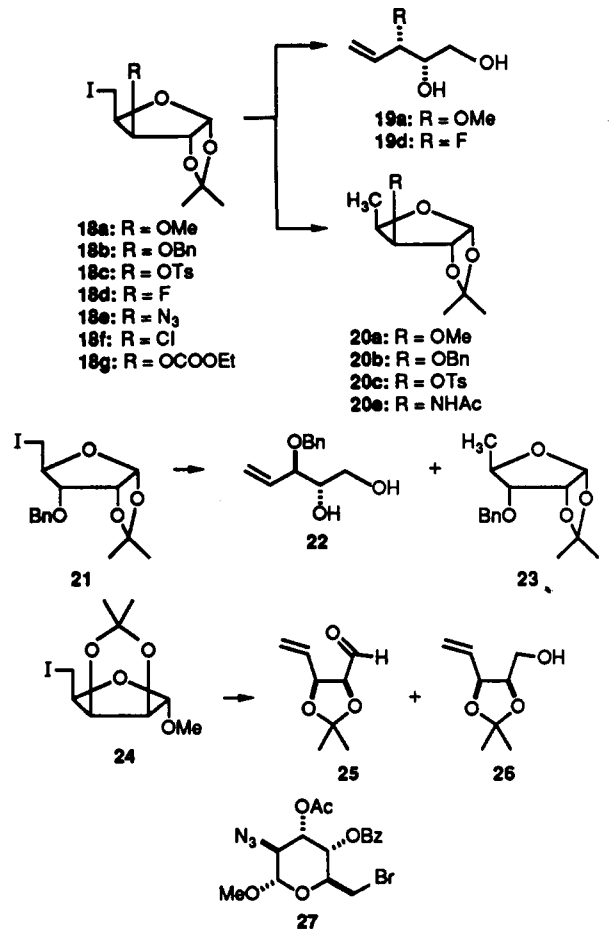

From these results it appears that dealkoxyhalogenation under either protic[5] or aprotic conditions requires, in the transition state, an unrestrained coordination of the zinc reagent with both the ring oxygen and the halogen of the sugar. Coordination is apparently retarded by bulky or strongly electron donating substituents. Finally, the protic solvents[5,13,14] required for the reaction employing less active zinc reagents may perhaps enhance the necessary Lewis acid–Lewis base interactions. However, under the reaction conditions employed, a mechanism involving a single-electron transfer, or carbanionic intermediates, as previously proposed,[15] can be excluded. This view is strongly supported by the exclusive Wurtz-type coupling of methyl 6-deoxy-6-iodo-2,3,4-tri-*O*-methyl-α-D-glucopyranoside induced by magnesium–graphite,[6] known to be a very efficient single-electron donor.

Experimental Section

General. ^1H, ^{13}C, and ^{19}F NMR spectra were taken in $CDCl_3$ solutions, with tetramethylsilane added as an internal standard. Dry tetrahydrofuran (THF) or dimethoxyethane (DME) were used exclusively. Unless stated otherwise, optical rotations were measured in CH_2Cl_2 solution.

Preparation of 5-Deoxy-5-iodopentofuranose and 6-Deoxy-6-iodohexopyranoside Derivatives. To a solution or suspension of the 5-O- or 6-O-unprotected sugar (20 mmol) in toluene (150 mL) were added, with vigorous stirring, imidazole (70 mmol), triphenylphosphine (21 mmol), and iodine (25 mmol). After 20 min at ambient temperature, the solution was decanted from the gummy precipitate. The decantate was decolorized by shaking it with aqueous $Na_2S_2O_3$ and water, dried (Na_2SO_4), and evaporated to dryness. Column chromatography of the residue yielded the product in 75–90% yield. Compounds **1c**, **1e**, **1f**, **5a**, **5b**, and **8** were obtained by iodination at C-6, followed by protection of the hydroxyl group at C-4. The physical properties and other analytical data of the products are summarized in Table II.

Zinc/Silver–Graphite-Induced Dealkoxyhalogenation of Deoxy Halo Sugars. General Procedure. A solution of the Ω-deoxy halo sugar (15 mmol) in anhydrous THF (10 mL) was rapidly added drop-by-drop to a stirred suspension of zinc/silver–graphite[6] in THF (35 mL) under argon at the temperature given in Table I. After reaction was complete (cf. Table I), the mixture was filtered. The solvent was evaporated from the filtrate, and column chromatography of the residue gave the pure 5-enal in good yield (cf. Table I).

To isolate the products from compounds **8**, **18a**, **18d**, **21**, and **24** the reaction mixture was treated with 1.2 equiv of sodium borohydride until reduction was complete. After filtration and evaporation of solvent from the filtrate, the residue was purified by column chromatography. In the case of the reaction product of compound **15**, borohydride reduction led to spontaneous cyclization to **17**.

2,3,4-Tri-*O*-acetyl-5,6-dideoxy-D-*xylo*-hex-5-enose (2a): oil; $[\alpha]^{20}_D$ 3.9° (*c* 13.3); IR 1760, 1740, 1735 cm^{-1} (s); ^1H NMR δ 9.48 (s, 1 H, CHO), 5.75 (d, X part of an ABX, 1 H, H-5, *J*(4,5) = 7, *J*(5,6a) = 9.5, *J*(5,6b) = 15), 5.55 (AB part of the ABX, 2 H, H-6a, H-6b), 5.22–5.39 (m, 3 H, H-2, H-3, H-4), 2.24, 2.11, 2.06 (s, 3 H each, MeCOOR); ^{13}C NMR δ 194.05 (C-1), 169.76, 169.58, 169.41 (COOR), 131.29 (C-5), 120.56 (C-6), 75.85, 72.36, 70.74 (C-2, C-3, C-4), 20.83, 20.66, 20.29 (MeCOOR);

2,3,4-Tri-*O*-benzoyl-5,6-dideoxy-D-*xylo*-hex-5-enose (2b): oil; $[\alpha]^{20}_D$ −21.2° (*c* 39); IR 1735, 1730 cm^{-1} (s); ^1H NMR δ 9.71 (s, 1 H, CHO), 7.20–8.15 (m, 15 H, aromatic H), 6.17 (vd, 2 H, H-2, H-3), 6.00 (dd, 1 H, H-5, *J*(4,5) = 10.6), 5.81 (vs, 1 H, H-4), 5.50 (d, 1 H, H-6a, *J*(5,6a) = 17.1), 5.33 (d, 1 H, H-6b, *J*(5,6b) = 10.6); ^{13}C NMR δ 194.28 (CHO), 165.42, 165.19, 165.04 (COOR), 133.73, 133.54, 133.25, 131.23, 129.93, 129.60, 128.94, 128.77, 128.47, 128.14 (aromatic C, C-5), 121.00 (C-6), 76.46, 73.25, 71.54 (C-2, C-3, C-4).

4-*O*-Benzoyl-5,6-dideoxy-2,3-di-*O*-methyl-D-*xylo*-hex-5-enose (2c): oil; $[\alpha]^{20}_D$ 65.9° (*c* 1.0); IR 1735, 1730 cm^{-1} (s); ^1H NMR δ 9.81 (d, 1 H, CHO, *J*(CHO,H-2) = 1.0), 7.40–8.07 (m, 5 H, aromatic H), 5.95 (ddd, 1 H, H-5, *J*(4,5) = 6.7, *J*(5,6a) = 19.1, *J*(5,6b) = 10.4), 5.81 (dd, 1 H, H-4, *J*(3,4) = 6.7), 5.45 (d, 1 H, H-6a), 5.32 (d, 1 H, H-6b), 3.84 (dd, 1 H, H-3, *J*(2,3) = 2.4), 3.74 (dd, 1 H, H-2), 3.49, 3.45 (s, 3 H each, OMe); ^{13}C NMR δ 203.02 (C-1), 165.30 (COOR), 133.30, 132.95, 129.82, 128.73 (aromatic C, C-5), 119.44 (C-6), 85.12, 82.87, 74.70 (C-2, C-3, C-4), 60.74, 59.30 (OMe).

5,6-Dideoxy-4-(ethoxycarbonyl)-2,3-di-*O*-methyl-D-*xylo*-hex-5-enose (2e): oil; $[\alpha]^{20}_D$ 53.8° (*c* 15.4); IR 1730, 1700 cm^{-1} (s); ^1H NMR δ 9.63 (s, 1 H, CHO), 5.72 (ddd, 1 H, H-5, *J*(4,5) = 6.9, *J*(5,6a) = 17.1, *J*(5,6b) = 10.4), 5.28 (dd, 1 H, H-6a, *J*(6a,6b) = 1.1), 5.17 (dd, 1 H, H-6b), 4.03 (q, 2 H, OCH_2CH_3, *J* = 7.0), 3.52–3.58 (m, 2 H, H-2, H-3), 3.36 (dd, 1 H, H-4, *J*(3,4) = 6), 3.33, 3.29 (s, 3 H each, OMe), 1.14 (t, 3 H, OCH_2CH_3); ^{13}C NMR δ 202.56 (CHO), 132.55 (C-5), 119.68 (C-6), 84.66, 82.44, 76.96 (C-2, C-3, C-4), 64.05 (OCH_2), 60.53, 59.04 (OMe), 14.19 (OCH_2CH_3).

2-Acetamido-3,4-di-*O*-acetyl-2,5,6-trideoxy-D-*arabino*-hex-5-enose (4): oil; $[\alpha]^{20}_D$ +50.8° (*c* 1.8, acetone); IR 3150–3620 (bs), 1750, 1740, 1720, 1640 cm^{-1} (s); ^1H NMR (acetone-d_6) δ 7.61 (s, 1 H, CHO), 5.84 (d, X part of an ABX, 1 H, H-5, *J*(4,5) = 7.0, *J*(5,6a) = 17.2, *J*(5,6b) = 10.4), 5.59 (dd, 1 H, H-3, *J*(2,3) = 2.0, *J*(3,4) = 7.4), 5.36 (dd, 1 H, H-4), 5.30 and 5.26 (AB part of the ABX, 2 H, H-6a, H-6b), 5.04 (dd, 1 H; H-2, *J*(NH,H-2) = 8.9), 2.10, 2.02, 2.00 (s, 3 H each, MeCO), NH not detected; ^{13}C NMR (acetone-d_6) δ 198.19 (CHO), 171.73, 169.97, 169.59 (CONH, COOR), 133.61 (C-5), 119.92 (C-6), 72.60, 71.29 (C-3, C-4), 59.14 (C-2), 22.60, 20.94, 20.55 (MeCO).

4(*S*)-(Benzoyloxy)hex-5-enal (6a): oil; $[\alpha]^{20}_D$ +50.6° (*c* 1.5); IR 1740, 1735 cm^{-1} (s); ^1H NMR δ 9.30 (s, 1 H, CHO), 7.08–8.15 (m, 5 H, aromatic H), 5.62 (ddd, 1 H, H-5, *J*(4,5) = 6.1, *J*(5,6a) = 17.9, *J*(5,6b) = 9.2), 5.48 (dt, 1 H, H-4, *J*(3,4) = 6), 5.17 (dd, H-6a, *J*(6a,6b) = 1.0), 5.00 (dd, 1 H, H-6b), 1.75–1.99 (m, 4 H, H-2, H-3); ^{13}C NMR δ 199.99 (CHO), 165.75 (COOR), 136.64, 131.34, 130.40, 129.01, 128.75 (aromatic C), 133.35 (C-5), 117.32 (C-6), 75.57 (C-4), 39.65 (C-2), 27.15 (C-3).

4-*O*-Benzoylhex-5-ene-1,4(*S*)-diol (7a): oil; $[\alpha]^{20}_D$ +30.3° (*c* 4.7); IR 3150–3600 (bs), 1735 (s) cm^{-1}; ^1H NMR δ 7.09–8.25 (m, 5 H, aromatic H), 5.81 (ddd, 1 H, H-5, *J*(4,5) = 6.7, *J*(5,6a) = 17.0, *J*(5,6b) = 10.3), 5.71 (dt, 1 H, H-4, *J*(3,4) = 6), 5.29 (d, 1 H, H-6a), 5.06 (d, 1 H, H-6b), 3.44 (t, 2 H, H-1, *J*(1,2) = 6.4), 2.31 (bs, 1

Table II. Analytical and Characteristic NMR Data of Ω-Deoxy Halo Sugars Employed in Dealkoxyhalogenation Reactions

educt	mp, °C	$[\alpha]^{20}_D$ (c, CH_2Cl_2)	δ H-1	J(1,2), Hz	δ C-1	δ CH_2-X	other important chemical shifts (δ)
1a[12]	142–143[a]	+109.5 (1.0)	4.97	3.6	97.72	5.04	
1b	103–106	+45.7 (1.3)	5.33	3.7	97.31	3.97	
1c	oil	+27.9 (1.3)	4.93	3.6	97.90	4.52	
1d	oil	+60.0 (2.5)[b]	4.94	3.6	97.61	32.00	
1e	oil	+67.4 (6.0)	4.80	3.5	97.66	4.34	154.63 (OCOO)
1f	oil	+43.8 (4.2)	4.78	3.5	97.31	5.98	
3	oil	+47.1 (6.1)	4.56	1.4	100.87	5.27	6.72 (NHAc), 50.70 (C-2)
5a	oil	+67.2 (8.3)	4.95	3.6	98.04	6.42	29.17, 24.24 (C-2, C-3)
5b	oil	+114.2 (6.8)	4.67	3.0	97.87	8.99	29.14, 23.03 (C-2, C-3)
8	78–79	+12.0 (16)	4.90	2.9	94.96	7.65	54.36, 50.51 (C-2, C-3)
9[10]	60–61[d]	+166.1 (10)	4.88	3.0	94.59	32.46	54.60, 51.19 (C-2, C-3)
12	oil	+63.2 (8.3)	4.63	3.5	98.04	5.96	32.71 (C-2)
14	oil	+40.0 (6.5)	4.59	0	96.46	4.83	30.16 (C-3)
15	oil	+60.5 (14.7)	4.52	3.4	98.53	5.28	
18a[16]	oil	−68.5 (5.7)	5.89	3.7	105.92	−1.07	3.82 (H-3), 58.53 (OMe)
18d	oil	−31.9 (5.0)	6.00	3.7	105.67	−0.51	5.07 (H-3)[i]
18e[19]	oil	−91.9 (1.7)	5.95	3.6	105.61	−1.15	4.20 (H-3)[j]
18f	oil	−44.7 (2.7)	5.98	3.7	105.54	−0.01	4.49 (H-3)
18g	oil	−29.7 (0.6)	5.95	3.7	105.55	−1.20	5.21 (H-3), 154.30 (OCOO)
21	oil	+84.9 (4.7)	5.77	3.6	104.07	7.38	4.58 (H-3)
24[20]	oil	+75.4 (9.0)[h]	4.92	0	107.27	−0.60	54.61 (OMe)
27	oil	+29.2 (0.9)	4.68	2.7	99.85	31.32	60.37 (C-2)[j]

[a] Mp 142–143 °C; $[\alpha]^{22}_D$ + 114° (c 1.0, $CHCl_3$), ref 12. [b] $[\alpha]^{20}_D$ +48.2° (c 8.6), ref 10. [c] $[\alpha]^{25}_D$ +119° (c 1.9), ref 10. [d] Mp 60–61 °C; $[\alpha]^{20}_D$ +177° (c 1.03, $CHCl_3$), ref 10. [e] Syrup; ref 16. [f] Mp 74–75 °C; $[\alpha]^{23}_D$ −81.5° (c 0.68, $CHCl_3$), ref 17. [g] $[\alpha]^{23}_D$ −65.5° (c 2, $CHCl_3$), ref 18. [h] $[\alpha]^{24}_D$ +72.6° (c 2.88, MeOH), ref 20. [i] J(H-3,F) = 49.7, J(H-2,F) = 10.3, J(H-4,F) = 27.2, J(C-3,F) = 186, J(C-2,F) = 24.6; J(C-4,F) = 32.6; ^{19}F NMR ($CDCl_3$) δ −211.19. [j] IR 2120 cm^{-1} (s, N_3).

H, OH), 1.49–1.83 (m, 4 H, H-2, H-3); ^{13}C NMR δ 165.60 (COOR), 136.88, 129.81, 128.48, 128.23, 127.92 (aromatic C), 132.76 (C-5), 116.47 (C-6), 75.02 (C-4), 62.07 (C-1), 30.97, 28.51 (C-2, C-3).

4-*O*-Methylhex-5-ene-1,4(*S*)-diol (7b): oil; $[\alpha]^{20}_D$ −15.3° (c 5.7); IR 3650–3200 cm^{-1} (bs), ^1H NMR δ 5.61 (dX part of an ABX, 1 H, H-5, J(4,5) = 6, J(5,6a) = 14, J(5,6b) = 10), 5.16 (X part of the ABX, 2 H, H-6a, H-6b), 3.48–3.59 (m, 3 H, H-1a, H-1b, H-4), 3.25 (s, 3 H, OMe), 2.85 (bs, 1 H, OH), 1.55–1.73 (m, 4 H, H-2, H-3); ^{13} NMR δ 138.62 (C-5), 117.35 (C-6), 83.06 (C-4), 62.65 (C-1), 56.31 (OMe), 32.31, 28.92 (C-2, C-3).

2,3-Anhydro-5,6-dideoxy-4-*O*-methyl-D-*ribo*-hex-5-enitol (10): oil; $[\alpha]^{20}_D$ +34.3° (c 4.5); IR 3650–3200 (bs), 3040 (m) cm^{-1}; ^1H NMR δ 5.83 (d, X part of an ABX, 1 H, H-5, J(4,5) = 7.4, J(5,6a) = 9.9, J(5,6b) = 13.5), 5.37 (AB part of the ABX, 2 H, H-6a, H-6b), 3.83 (vd, 2 H, H-1a, H-1b, J(1,2) = 8), 3.57 (dd, 1 H, H-4, J(3,4) = 7.3), 3.31 (s, 3 H, OMe), 3.26 (dd, 1 H, H-2, J(2,3) = 4.2), 3.02 (dd, 1 H, H-3), 2.85 (bs, 1 H, OH); ^{13}C NMR δ 135.40 (C-5), 119.95 (C-6), 80.28 (C-4), 61.03 (C-1), 57.78, 57.06 (C-2, C-3), 56.39 (OMe).

Methyl 2,3-Anhydro-4-*O*-benzoyl-6-deoxy-α-D-allopyranoside (11): oil; $[\alpha]^{20}_D$ +188.2° (c 1.3); ^1H NMR δ 7.16–8.08 (m, 5 H, aromatic H), 5.06 (dd, 1 H, H-4, J(4,5) = 9.5, J(3,4) = 1.5), 4.91 (d, 1 H, H-1, J(1,2) = 3.0), 4.14 (dq, 1 H, H-5, J(5,6) = 6.3), 3.61 (dd, 1 H, H-3), J(2,3) = 3.1), 3.56 (dd, 1 H, H-2), 3.49 (s, 3 H, OMe), 1.24 (d, 3 H, H-6); ^{13}C NMR δ 166.29 (COOR), 133.58, 130.04, 128.66 (aromatic C), 94.89 (C-1), 73.36 (C-4), 62.60 (C-5), 55.85 (OMe), 55.03, 51.65 (C-2, C-3), 17.59 (C-6).

3(*S*),4(*S*)-Dimethoxy-2(*R*)-vinyloxolane (17): oil; $[\alpha]^{20}_D$ −4.7° (c 8.3); ^1H NMR δ 5.92 (ddd, 1 H, C*H*=CH_2, J(C*H*=, H-2) = 7.0, J(C*H*=, CH=C*H*aHb) = 17.1, J(CH=,CH=CHa*H*b) = 10.4), 5.31 (d, 1 H, CH=C*H*aHb), 5.15 (d, 1 H, CH=CHa*H*b), 4.12 (dd, 1 H, H-2, J(2,3) = 6.8), 3.94 and 3.85 (d, AB system, 2 H, H-5a, H-5b, J(4,5a) = 4.4, J(4,5b) < 1), 3.80 (d, 1 H, H-4), 3.55 (d, 1 H, H-3), 3.38, 3.33 (s, 3 H each, OMe); ^{13}C NMR δ 136.86 (*C*H=CH_2), 116.93 (CH=*C*H_2), 90.10, 84.84, 85.58, 71.49 (C-2, C-3, C-4, C-5), 57.60, 56.99 (OMe).

5-Deoxy-1,2-*O*-isopropylidene-3-*O*-methyl-α-D-xylofuranose (20a): oil; $[\alpha]^{20}_D$ −46.9° (c 4.5); ^1H NMR δ 5.78 (d, 1 H, H-1, J(1,2) = 3.9), 4.50 (d, 1 H, H-2), 4.23 (dq, 1 H, H-4, J(4,5) = 6.4, J(3,4) = 3.0), 3.43 (d, 1 H, H-3), 3.34 (s, 3 H, OMe), 1.41, 1.24 (s, 3 H each, isopropylidene Me, 1.20 (d, 3 H, H-5); ^{13}C NMR δ 111.15 (isopropylidene =C=), 104.80 (C-1), 85.56, 82.26, 76.11 (C-2, C-3, C-4), 57.92 (OMe), 26.76, 26.26 (isopropylidene Me), 13.06 (C-5).

3-*O*-Benzyl-5-deoxy-1,2-*O*-isopropylidene-α-D-xylofuranose (20b): oil; $[\alpha]^{20}_d$ −42.1° (c 3.3); ^1H NMR δ 7.28 (bs, 5 H, aromatic H), 5.85 (d, 1 H, H-1, J(1,2) = 3.8), 4.64 and 4.45 (AB system, 2 H, CH_2Ph, J(AB) = 12), 4.56 (d, 1 H, H-2), 4.27 (dq, 1 H, H-4, J(3,4) = 2.9, J(4,5) = 6.4), 3.67 (d, 1 H, H-3), 1.43, 1.26 (s, 3 H each, isopropylidene Me), 1.27 (d, 3 H, H-5); ^{13}C NMR δ 138.94, 128.62, 128.39, 127.97 (aromatic C), 111.35 (isopropylidene –C–), 105.10 (C-1), 83.22, 83.10, 76.64, 72.01 (C-2, C-3, C-4, CH_2Ph), 26.90, 26.40 (isopropylidene Me), 13.51 (C-5).

5-Deoxy-1,2-*O*-isopropylidene-3-*O*-tosyl-α-D-xylofuranose (20c): oil; $[\alpha]^{20}_D$ −14.3° (c 3.2) ($[\alpha]^{23}_D$ −16.8° (c 1.7, $CHCl_3$) ref 18); ^1H NMR δ 7.80 and 7.35 (AB system, 4 H, aromatic H), 5.87 (d, 1 H, H-1, J(1,2) = 3.6), 4.66 (d, 1 H, H-3, J(3,4) = 3.0), 4.62 (d, 1 H, H-2), 4.44 (dq, 1 H, H-4, J(4,5) = 6.4), 2.44 (s, 3 H, *Me*Ph), 1.46, 1.27 (s, 3 H each, isopropylidene Me), 1.14 (d, 3 H, H-5); ^{13}C NMR δ 145.47, 130.21, 129.23, 128.42 (aromatic C), 112.16 (isopropylidene –C–), 104.68 (C-1), 83.95, 83.94, 75.05, (C-2, C-3, C-4), 26.80, 26.38 (isopropylidene Me), 21.82 (MePh), 13.38 (C-5).

3-Acetamido-3,5-dideoxy-1,2-*O*-isopropylidene-α-D-xylofuranose (20e): mp 127–128 °C dec; $[\alpha]^{20}_D$ −26.5° (c 0.7); IR 3220–3500 (b), 1710, 1620 (s) cm^{-1}; ^1H NMR δ 6.25 (d, 1 H, NHAc, J(NH,H-3) = 9.2), 5.75 (d, 1 H, H-1, J(1,2) = 3.8), 4.44 (d, 1 H, H-2), 4.37 (dq, 1 H, H-4, J(4,5) = 6.1, J(3,4) = 3.4), 4.30 (dd, 1 H, H-3), 1.98 (s, 3 H, MeCO), 1.46, 1.24 (s, 3 H each, isopropylidene Me), 1.18 (d, 3 H, H-5); ^{13}C NMR δ 170.37 (CONH), 111.79 (isopropylidene –C–), 104.25 (C-1), 85.13 (C-2), 74.35 (C-4), 57.34 (C-3), 26.58, 26.24 (isopropylidene Me), 23.16 (MeCON), 13.64 (C-5).

3-*O*-Benzyl-5-deoxy-1,2-*O*-isopropylidene-α-D-ribofuranose (23): oil; $[\alpha]^{20}_D$ +23.1° (c 6.6); ^1H NMR δ 7.30–7.41 (m, 5 H, aromatic H), 5.73 (d, 1 H, H-1, J(1,2) = 3.8), 4.80 and 4.59 (AB system, 2 H, CH_2Ph, J(AB) = 12), 4.56 (dd, 1 H, H-2, J(2,3) = 4.4), 4.17 (dq, 1 H, H-4, J(4,5) = 6.1, J(3,4) = 8.9), 3.33 (dd, 1 H, H-3), 1.63, 1.38 (s, 3 H each, isopropylidene Me), 1.30 (d, 3 H, H-5); ^{13}C NMR δ 137.91, 129.12, 128.54, 128.01 (aromatic C), 112.63 (isopropylidene –C–), 104.02 (C-1), 83.56, 77.41, 74.15, 72.19 (C-2, C-3, C-4, CH_2Ph), 26.73, 26.64 (isopropylidene Me), 17.45 (C-5).

3-Deoxy-3-fluoro-L-*threo*-pent-4-enitol (19d): oil; $[\alpha]^{20}_D$ −1.4° (c 10.5); IR 3600–3100 (bs) cm^{-1}; ^{19}F NMR δ −144.92; ^1H NMR δ 5.95 (m, 1 H, H-4), 5.41 (m, 2 H, H-5a, H-5b), 4.90 (ddd, 1 H, H-3, J(H-3,F) = 48.4, J(3,4) = J(2,3) = 6.1), 3.75 (m, 3 H, H-2, H-1a, H-1b), 2.88 (bs, 1 H, OH), 2.41 (bs, 1 H, OH); ^{13}C NMR δ 132.70 (d, C-4, J(C-4,F) = 18.4), 120.01 (d, C-5, J(C-5,F) = 12.7), 93.96 (d, C-3, J(C-3,F) = 169.9), 73.77 (d, C-2, J(C-2,F) = 21.2), 62.87 (d, C-1, J(C-1,F) 6.5).

4,5-Dideoxy-1,2-*O*-isopropylidene-3-*O*-methyl-L-*threo*-pent-4-enitol (19a): oil; $[\alpha]^{20}_D$ −1.0° (c 9.6); ^1H NMR δ 5.51 (ddd, 1 H, H-4, J(4,5a) = 16.8, J(4,5b) = 14.2, J(3,4) = 7.8), 5.21 (d, 1 H, H-5a), 5.19 (d, 1 H, H-5b), 3.99 (ddd, 1 H, H-2, J(2,3) =

J(1a,2) = J(1b,2) = 7.0), 3.79 (dd, 1 H, H-3), 3.54 (d, 1 H, H-1a), 3.48 (d, 1 H, H-1b), 3.21 (s, 3 H, OMe), 1.30, 1.17 (s, 3 H each, isopropylidene Me); ^{13}C NMR δ 134.16 (C-4), 119.82 (C-5), 109.70 (isopropylidene –C–), 84.24, 77.48, 65.83 (C-1, C-2, C-3), 56.54 (OMe), 26.55, 25.39 (isopropylidene Me).

3-*O*-Benzyl-4,5-dideoxy-1,2-*O*-isopropylidene-D-*erythro*-pent-4-enitol (22): oil; $[\alpha]^{20}_D$ –1.4° (*c* 16); ^{1}H NMR δ 7.36 (bs, 5 H, aromatic H), 5.87 (ddd, 1 H, H-4, J(4,5a) = 18.9, J(4,5b) = 11.1, J(3,4) = 7.9), 5.43 (d, 1 H, H-5b), 5.32 (d, 1 H, H-5a), 4.67 and 4.45 (AB system, 2 H, CH_2Ph, J(AB) = 11.8), 4.16 (ddd, 1 H, H-2, J(1a,2) = J(1b,2) = J(2,3) = 6.0), 4.10 and 3.80 (d, AB system, 2 H, H-1a, H-1b), 3.92 (dd, 1 H, H-3), 1.45, 1.39 (s, 3 H each, isopropylidene Me), ^{13}C NMR δ 135.57 (C-4), 138.50, 129.28, 128.48, 128.08 (aromatic C), 119.74 (C-6), 109.77 (isopropylidene –C–), 81.29, 77.95, 70.88, 67.05 (C-1, C-2, C-3, OCH_2Ph), 26.82, 25.59 (isopropylidene Me).

5,6-Dideoxy-2,3-*O*-isopropylidene-L-*erythro*-pent-5-enitol (26): oil; $[\alpha]^{20}_D$ +23.9° (*c* 2.7); IR 3250–3600 (bs) cm^{-1}; ^{1}H NMR δ 5.87 (d, X part of an ABX, 1 H, H-4, J(3,4) = 7.3, J(4,5a) = 10.1, J(4,5b) = 13), 5.37 (AB part of the ABX, 2 H, H-5a, H-5b), 4.65 (dd, 1 H, H-3, J(3,4) = 7.3, J(2,3) = 7.1), 4.27 (dd, 1 H, H-2, J(1,2) = 7.1), 3.58 (d, 2 H, H-1a, H-1b), 2.12 (bs, 1 H, OH), 1.52, 1.42 (s, 3 H each, isopropylidene Me); ^{13}C NMR δ 133.25 (C-4), 119.13 (C-5), 112.04 (isopropylidene –C–), 78.52 (C-2, C-3), 62.28 (C-1), 28.02, 25.45 (isopropylidene Me).

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Registry No. **1a**, 6304-96-7; **1a** (X = OH), 7432-72-6; **1b**, 34340-06-2; **1b** (X = OH), 34234-44-1; **1c**, 131566-59-1; **1c** (X = OH), 56543-16-9; **1d**, 56543-17-0; **1e**, 131588-21-1; **1e** (X = OH), 29085-83-4; **1f**, 131566-60-4; **1f** (X = OH), 96587-75-6; **2a**, 131566-70-6; **2b**, 131566-71-7; **2c**, 131566-72-8; **2e**, 131566-73-9; **3**, 131566-61-5; **4**, 131566-74-0; **5a**, 21317-48-6; **5b**, 131566-62-6; **6a**, 131566-75-1; **7a**, 131588-23-3; **7b**, 131566-63-7; **8** (X = OH), 92379-66-3; **9**, 18933-59-0; **10**, 131566-77-3; **11**, 18933-60-3; **12**, 131566-64-8; **12** (6-hydroxy analog), 131566-55-7; **13**, 131566-78-4; **14**, 131566-65-9; **14** (6-hydroxy analog), 131566-56-8; **15**, 131588-22-2; **15** (6-hydroxy analog), 131566-57-9; **17**, 131566-79-5; **18a**, 85426-94-4; **18b**, 29580-99-2; **18c**, 29873-56-1; **18d**, 131566-66-0; **18d** (5-hydroxy analog), 18530-84-2; **18e**, 28176-67-2; **18f**, 131566-67-1; **18f** (5-hydroxy analog), 74580-74-8; **18g**, 131566-68-2; **18g** (5-hydroxy analog), 131566-58-0; **19a**, 131566-80-8; **19d**, 131566-81-9; **20a**, 131566-82-0; **20b**, 72933-18-7; **20c**, 16713-89-6; **20e**, 131566-83-1; **21**, 89702-28-3; **21** (5-hydroxy analog), 70798-12-8; **22**, 131615-48-0; **23**, 131566-84-2; **24**, 63087-96-7; **26**, 127758-25-2; **27**, 131566-69-3.

Supplementary Material Available: Elemental analyses data of products and substrates and ^{13}C and ^{1}H NMR spectra of **9**, **18a–e,g**, **21**, and **24** (20 pages). Ordering information is given on any current masthead page.