was treated with 2.07 g (15.2 mmol) of fused $ZnCl_2$ in 20 mL (0.20 mol) of anhydrous benzeldehyde at room temperature for 36 h. After the usual workup procedure, the crude product was benzoylated in pyridine at room temperature. The residuum obtained after the workup was chromatographed, eluting with ethyl acetate–hexane (3:1); decolorization with charcoal (Norit A) was followed by crystallization from hot methanol to give white crystals: mp 189–90 °C (mp **7a**, 196–197 °C; lit.[33] mp 202–203 °C); ^{13}C NMR (CD_3COCD_3) of **7a** δ 166.26 (benzoyl C=O), 101.08 (benzylidene acetal), 98.74 (C1), 75.19 (C4), 69.84, 69.72, 69.55 (C3, C6, C2), 63.33 (C5), 55.66 (OCH_3); ^1H NMR (C_6D_6) δ 6.25 (dd, 1 H, H3, $J_{3,4}$ = 3.0, $J_{3,2}$ = 10.5), 6.15 (dd, 1 H, H2, $J_{2,3}$ = 10.5, $J_{2,1}$ = 3.0), 5.33 (d, 1 H, H1, $J_{1,2} \sim 3$) 5.27 (s, 1 H, benzylidene H), 4.29 (d, 1 H, H4, $H_{4,5} \sim 0$, $J_{4,3} \sim 3$), 4.02 (d, 1 H, $H6_{eq}$, J_{gem} = 12.5), 3.39 (d, 1 H, $H6_{ax}$, J_{gem} = 12.4), 3.15 (s, 1 H, H5, $J_{5,4} \sim 0$), 2.99 (s, 3 H, OCH_3); ^1H NMR of **7b,c** (C_6D_6) δ 4.02 (s, 0.66 H, H6(*S*), 3.41 (s, 0.34 H, H6(*R*)).

Methyl 2,3,4-Tri-*O*-benzoyl-α-D-galactopyranosiduronic Acid Nitrile (8). To a stirred solution of **6a** (0.480 g, 2.28 mmol) in 10 mL of pyridine over 5-Å molecular sieve was added 0.240 g of hydroxylamine hydrochloride (1.5 equiv). The reaction, monitored by TLC ($CHCl_3$–CH_3OH, 3:1), was heated to 65 °C for 24 h. Then 6 mL of pyridine and 1.6 mL of benzoyl chloride (2 equiv) were added, and the reaction mixture was stirred at room temperature for 20 h. The reaction was quenched with water, worked up conventionally, and chromatographed, eluting with ethyl acetate–hexane (1:1). This was followed by preparative TLC (benzene) and crystallization from ether to give white needles: mp 157–158 °C; ^{13}C NMR (CD_3COCD_3) δ 166.00, 165.79, 165.54 (carbonyls on the benzoates), 115.83 (C6), 99.16 (C1), 70.14 (C4), 69.01 (C2), 67.86 (C3), 61.17 (C5), 56.88 (OCH_3); ^1H NMR ($C-D_3OCD_3$) δ 6.23 (m, 1 H, H4, $J_{4,5} \sim 1.0$), 6.02 (dd, 1 H, H3, $J_{3,2}$ = 10.7, $J_{3,4}$ = 3.4), 5.76 (dd, 1 H, H2, $J_{2,1}$ = 3.4, $J_{2,3}$ = 10.7), 5.66 (b s, 1 H, H5), 5.52 (d, 1 H, H1, $J_{1,2}$ = 3.5), 3.63 (s, 3 H, OCH_3). Anal. Calcd for $C_{28}H_{23}NO_8$: C, 67.06; H, 4.62; O, 25.52. Found: C, 66.84; H, 4.64; O, 25.76.

Acknowledgment. Partial support for this work from NIH Grant DE05102 and from the Graduate School of the University of Louisville is gratefully acknowledged. The authors thank John A. Daeuble for some fine experimental help.

(33) Szeja, W. *Synthesis* **1979**, *10*, 821–22.

Highly Selective Metal–Graphite-Induced Reductions of Deoxy Halo Sugars

Alois Fürstner* and Hans Weidmann

Institute of Organic Chemistry, Technical University, A-8010 Graz, Austria

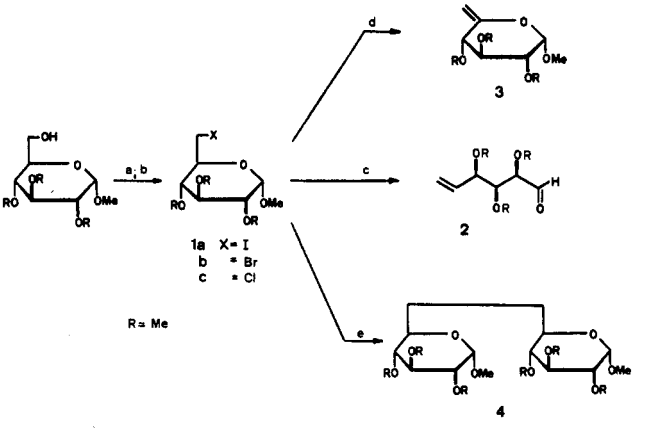
Received August 24, 1988

To explore the applicability of highly active metal–graphite reducing agents to polyfunctional compounds a variety of suitably protected chloro-, bromodeoxy-, and deoxyiodohexopyranosides and hexofuranoses were each treated with potassium–graphite laminate (C_8K) and zinc/silver–graphite, respectively, invariably leading to the efficient formation of olefinic products. However, while C_8K in all cases causes dehydrohalogenation, zinc/silver–graphite reductions proceed by dealkoxyhalogenation, results quite opposite to the formation of glycals by each of the reagents. In contrast, magnesium on graphite readily dimerizes methyl 6-deoxy-6-iodo-α-D-glucopyranoside (**1a**) by a Wurtz reaction.

Introduction

In recent years numerous kinds of metal–graphite combinations[1] containing metals such as zinc,[2] zinc/silver,[3,4] magnesium,[5] titanium,[5,6] tin,[7] iron,[8] nickel,[9] palladium,[10] and platinum,[11] generally prepared by the reduction of metal salts by C_8K,[1,12] proved to be highly effective one- or two-electron donors widely applicable in various kinds of reduction. Among these the highly efficient formation of furanoid and pyranoid glycals by C_8K[13] or zinc/silver–graphite[4] reduction of *O*-alkyl-, *O*-alkylidene-, or *O*-acylglycosyl halides are particularly noteworthy. The new glycal syntheses[4,13] favorably complement each other. They not only allow aprotic Fischer–Zach type reductions

Scheme I[a]



[a] (a) CH_3SO_2Cl, pyridine, CH_2Cl_2, 89%; (b) TBAX, acetonitrile, reflux, 78–84%; (c) zinc/silver–graphite, THF; (d) C_8K, THF; (e) magnesium–graphite, THF.

(1) For review, see: (a) Csuk, R.; Glänzer, B. I.; Fürstner, A. *Adv. Organomet. Chem.* **1988**, *28*, 85. (b) Savoia, D.; Trombini, C.; Umani-Ronchi, A. *Pure Appl. Chem.* **1985**, *57*, 1887.

(2) Boldrini, G. P.; Savoia, D.; Tagliavini, E.; Trombini, C.; Umani-Ronchi, A. *J. Org. Chem.* **1983**, *48*, 4108.

(3) (a) Csuk, R.; Fürstner, A.; Weidmann, H. *J. Chem. Soc., Chem. Commun.* **1986**, 775. (b) Csuk, R.; Fürstner, A.; Sterk, H.; Weidmann, H. *J. Carbohydr. Chem.* **1986**, *5*, 459. (c) Fürstner, A. *J. Organomet. Chem.* **1987**, *336*, C33.

(4) (a) Csuk, R.; Fürstner, A.; Glänzer, B. I.; Weidmann, H. *J. Chem. Soc., Chem. Commun.* **1986**, 1149. (b) Csuk, R.; Glänzer, B. I.; Fürstner, A.; Weidmann, H.; Formacek, V. *Carbohydr. Res.* **1986**, *157*, 235.

(5) (a) Csuk, R.; Fürstner, A.; Weidmann, H. *J. Chem. Soc., Chem. Commun.* **1986**, 1802. (b) Fürstner, A.; Csuk, R.; Rohrer, C.; Weidmann, H. *J. Chem. Soc., Perkin Trans. 1* **1988**, 1729.

(6) Fürstner, A.; Weidmann, H. *Synthesis* **1987**, 1071.

(7) Boldrini, G. P.; Savoia, D.; Tagliavini, E.; Trombini, C.; Umani-Ronchi, A. *J. Organomet. Chem.* **1985**, *280*, 307.

(8) Savoia, D.; Tagliavini, E.; Trombini, C.; Umani-Ronchi, A. *J. Org. Chem.* **1982**, *47*, 876.

(9) Savoia, D.; Tagliavini, E.; Trombini, C.; Umani-Ronchi, A. *J. Org. Chem.* **1981**, *46*, 5340 and 5344.

(10) Savoia, D.; Trombini, C.; Umani-Ronchi, A.; Verardo, G. *J. Chem. Soc., Chem. Commun.* **1981**, 540 and 541.

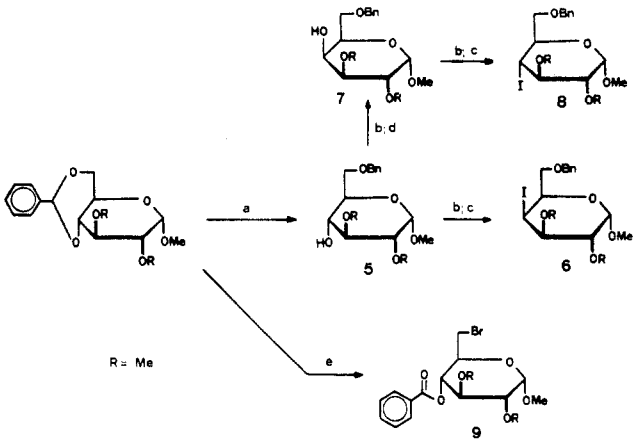
(11) Fürstner, A.; Weidmann, H.; Hofer, F. *J. Catal.*, submitted.

(12) Bergbreiter, D. E.; Killough, J. M. *J. Am. Chem. Soc.* **1978**, *100*, 2126.

(13) Fürstner, A.; Weidmann, H. *J. Carbohydr. Chem.* **1988**, *7*, 773.

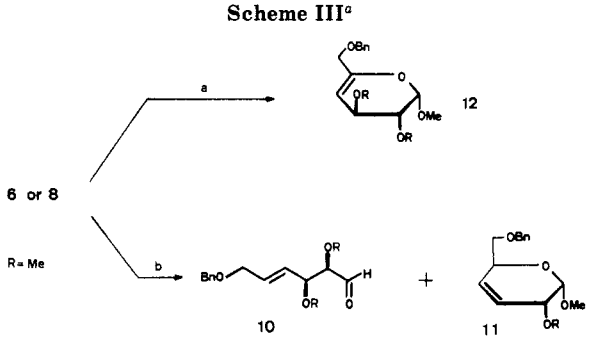
0022-3263/89/1954-2307$01.50/0

Scheme II[a]



[a] (a) $NaBH_3CN$, HCl, ether, 78% (ref 31); (b) $(F_3CSO_2)_2O$; pyridine, CH_2Cl_2; (c) TBAI, acetonitrile, 80–88%; (d) tetra-*n*-butylammonium nitrite, acetonitrile, 60% (ref 32); (e) NBS, $BaCO_3$, CCl_4, 81% (ref 26).

Scheme III[a]



[a] (a) C_8K, THF; (b) zinc/silver–graphite, THF.

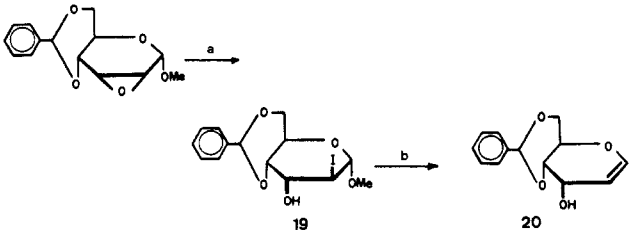
of extended scope, but also disprove the alledgedly restricted applicability of C_8K because of its lack of selectivity.[12]

In view of these encouraging results from reductions of notoriously vulnerable glycosyl halides and the increasing interest in carbohydrate-derived olefinic synthons,[14] a more comprehensive study of deoxy halo sugar reductions by reactive metal–graphite reagents appeared to be indicated.

Results and Discussion

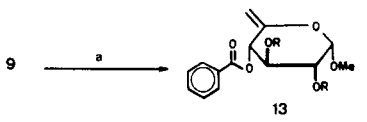
When compounds **1a**, **1b**, and **1c** were treated with zinc/silver–graphite[3,4] in THF, product **2** was invariably obtained (Scheme I). Because of the very high activity of the reagent, which allows adoption of mild reaction conditions, side reactions in zinc-induced reductions of deoxy halo sugars previously observed[15,16] were totally suppressed, and a single, stable product was formed in high yield in each case. The same kind of dealkoxyhalogenation was found in the reduction of **6** and **8**, respectively (Scheme III). Both yielded a similar distribution of products consisting of **11** and a preparatively inseparable mixture of nearly equal amounts of the *Z* and *E* stereoisomers of the ring-opened product **10**, clearly shown by ^{13}C and ^1H NMR spectroscopy (cf. Experimental Section). No conclusive explanation can presently be offered for the complete lack of regio- and stereoselectivity. As a last example in this series of pyranosidic educts, compound **19** on treatment with zinc/silver–graphite resulted in greatly improved formation of the glycal **20**[17] (Scheme IV).

Scheme IV[a]



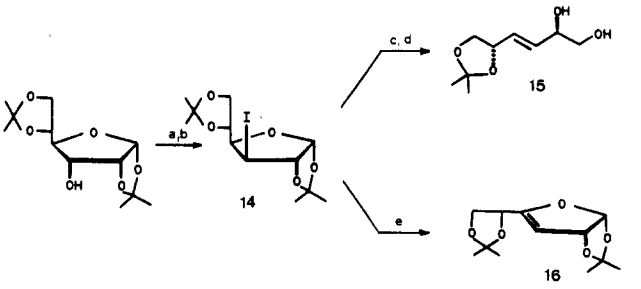
[a] (a) $LiI \cdot 2H_2O$, ether, 20 °C, 45 min, 89% (ref 17); (b) zinc/silver–graphite, THF.

Scheme V[a]



[a] (a) C_8K, THF.

Scheme VI[a]



[a] (a) $(F_3CSO_2)_2O$, pyridine, CH_2Cl_2, (ref 19a); (b) tetra-*n*-butylammonium iodide (TBAI), acetonitrile, reflux, 20 h; 79%; (c) zinc/silver–graphite, THF; (d) $NaBH_4$, ethanol, 2 H; (e) C_8K, THF.

In view of the discrepancy of these results and the complete resistance of a derivative of 2-*O*-benzyl-α-D-glucopyranosyl bromide to zinc/silver–graphite contrary to what was observed with C_8K,[13] a comparative study employing this reagent seemed to be indicated. While zinc/silver–graphite, with the exception of 2-*O*-alkylglycosyl halides, gives rise to dealkoxyhalogenations, C_8K shows a totally opposite behavior. Thus, compounds **1a**, **1b**, **6**, and **8** as well as **9** are invariably subject to dehydrohalogenation by C_8K in THF with exclusive formation of the corresponding enol ethers **3**, **12**, and **13** (Scheme V).

Although these results may be rationalized by the proposed polymeric Lewis base character of C_8K,[12] they are absolutely unexpected considering the facile C_8K-induced dealkoxyhalogenations of glycosyl halides[13] as well as the

(14) For use of structurally related olefinic synthons, see, i.e.: (a) Ferrier, R. J.; Prasit, P. *J. Chem. Soc., Chem. Commun.* **1981**, 983. (b) Ferrier, R. J.; Furneaux, R. H.; Prasit, P.; Tyler, P. C.; Brown, K. L.; Gainsford, G. J.; Diehl, J. W. *J. Chem. Soc., Perkin Trans. 1* **1983**, 1621. (c) Ferrier, R. J.; Prasit, P.; Gainsford, G. J. *J. Chem. Soc., Perkin Trans. 1* **1983**, 1629. (d) Ferrier, R. J.; Prasit, P.; *J. Chem. Soc., Perkin Trans. 1* **1983**, 1645. (e) Ferrier, R. J.; *J. Chem. Soc., Perkin Trans. 1* **1979**, 1455. (f) Ferrier, R. J.; Schmidt, P.; Tyler, P. C. *J. Chem. Soc., Perkin Trans. 1* **1985**, 301. (g) Nakane, M.; Hutchinson, R.; Gollman, H. *Tetrahedron Lett.* **1980**, 1213. (h) Florent, J. C.; Ughetto-Monfrin, J.; Monneret, C.; *J. Org. Chem.* **1987**, *52*, 1051. (i) Hanessian, S.; Ugolini, A.; Therien, M. *J. Org. Chem.* **1983**, *48*, 4430. (j) Beau, J. M.; Aburaki, S.; Pougny, J. R.; Sinay, P. *J. Am. Chem. Soc.* **1983**, *105*, 621. (k) Villalobos, A.; Danishefsky, S. J. *J. Org. Chem.* **1989**, *54*, 15. (l) Bernotas, R. C.; Ganem, B. *Tetrahedron Lett.* **1985**, 1123.

(15) Bernet, B.; Vasella, A. *Helv. Chim. Acta* **1979**, *62*, 1990.

(16) (a) Aspinall, G. O.; Chatterjee, D.; Khondo, L. *Can. J. Chem.* **1984**, *62*, 2728. (b) Aspinall, G. O.; Puvanesarājah, V. *Can. J. Chem.* **1984**, *62*, 2736.

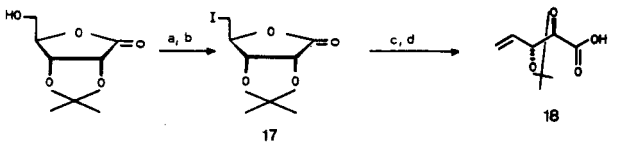
(17) Lemieux, R. U.; Fraga, E.; Watanabe, K. A. *Can. J. Chem.* **1968**, *46*, 61.

Table I. Reduction of Deoxy Halo Sugars

entry	educt	reagent	reaction conditions	product (% yield)[a]	R_f[b]	eluant[c] toluene/EtOAc
1	**1a**	Zn/Ag–graphite	20 °C; 10 min	**2** (93)	0.52	10/1
2	**1b**	Zn/Ag–graphite	20 °C; 45 min	**2** (90)		
3	**1c**	Zn/Ag–graphite	20 °C; 60 min	**2** (88)		
4	**1a**	C_8K	0 °C; 10 min	**3** (94)	0.30[d]	10/1
5	**1b**	C_8K	0 °C; 10 min	**3** (96)		
6	**1a**	Mg–graphite	70 °C; 3 h	**4** (68)[e]	0.25	3/1
7	**6**	Zn/Ag–graphite	20 °C; 10 min	**10** (65)[f]; **11** (30)	0.70 (**10**)	15/1 and 1/1[g]
8	**8**	Zn/Ag–graphite	20 °C; 10 min	**10** (70)[f]; **11** (21)	0.60 (**11**)	15/1 and 1/1[g]
9	**6**	C_8K	0 °C; 15 min	**12** (79)	0.53	10/1
10	**8**	C_8K	0 °C; 15 min	**12** (86)		
11	**9**	C_8K	−10 °C; 15 min	**13** (67)	0.59	10/1
12	**14**	Zn/Ag–graphite	20 °C; 10 min	**15** (83)[h]	0.62[i]	1/3
13	**14**	C_8K	0 °C; 20 min	**16** (83)	0.75	15/1
14	**17**	Zn/Ag–graphite	20 °C; 10 min	**18** (96)	0.53[j]	1/3
15	**19**	Zn/Ag–graphite[k]	20 °C; 40 min	**20** (90)	0.75	15/1
16	**14**	Rieke Zn	20 °C; 10 min	**15** (9)[l]		
17	**14**	Rieke Zn	70 °C; 45 min	**15** (78)		
18	**14**	Zn powder[m]	20 °C; 60 min	**15** (0)[l]		

[a] Isolated yield. [b] Using toluene/EtOAc, 1/1, as solvent unless stated otherwise. [c] For column chromatography. [d] Toluene/EtOAc, 3/1. [e] Beside traces of methyl 6-deoxy-2,3,4-tri-*O*-methyl-α-D-glucopyranoside and **2**. [f] *Z*:*E* = 1.1:1. [g] Solvent change after having eluted compound **10**. [h] After reduction of the resulting aldehyde by $NaBH_4$ in ethanol. [i] Toluene/EtOAc = 0/1. [j] Toluene/EtOAc/glacial acetic acid = 10/10/1. [k] 4-fold excess of Zn/Ag–graphite. [l] Starting material recovered. [m] With ultrasonic irradiation.

Scheme VII



[a] (a) CH_3SO_2Cl, pyridine, CH_2Cl_2, 3 h, 90%; (b) tetra-*n*-butylammonium iodide (TBAI), acetonitrile, reflux, 24 h, 76%; (c) zinc/silver–graphite, THF; (d) acetic acid, H_2O.

reduction of 2-(chloromethyl)oxolane with exclusive formation of the ring-opened product.[12]

Regarding these inconsistent results, the single electron transfer mechanism recently proposed for the zinc-induced formation of analogues of **2**[18] must be met with caution and provides no explanation for dealkoxyhalogenations by C_8K.[13] In order to obtain more information about the different and complementary behavior observed with zinc/silver–graphite and C_8K, respectively, the furanose **14** was treated with both reagents as described above (see Scheme VI). While C_8K again exhibited its distinct Lewis base character in accordance with various other bases by exclusively affording **16**,[19] the reduction with zinc/silver–graphite led to regioselective formation of the thermally unstable 3,4-dideoxy-5,6-*O*-isopropylidene-D-*erythro*-hex-3-enose. In situ $NaBH_4$ reduction of the latter led to the corresponding enitol **15** in very good yield in form of its *E* diastereoisomer only, as shown by the coupling constant $^3J_{3,4}$ of 11.2 Hz. Although the high degree of regio- and stereoselectivity of the latter reaction as compared with that of compounds **6** and **8** is notable, the regioselective dehydrohalogenation of **14** by C_8K with formation of **16** follows from the relative positions of the leaving group in the educt.[19] As can be anticipated from the foregoing zinc/silver–graphite induced reactions, the enoic acid **18**[20] was efficiently formed by this reagent from the iodo lactone **17** (Scheme VII).

The extraordinary high reactivity of zinc/silver–graphite as compared to other activated samples of zinc could be demonstrated by employing **14** as a substrate. While zinc activated by ultrasound[21] in THF completely failed, Rieke zinc[22] reacted much slower and also gave lower yields of **15** (cf. Table I). In addition, when zinc dust in aqueous ethanol, stated to be very well suited for reductive elimination of 6-deoxy-6-iodohexopyranosides,[14-16] was applied to the furanose **14**, consecutive reactions, most likely acid-catalyzed allylic rearrangements followed by hemiacetal formation, were observed, demonstrating the limitation of the aforementioned conditions to pyranoid structures.

Table II. Preparation of Deoxy Halo Sugars

leaving group	solvent	temperature, °C; time, h	product	% yield
CH_3SO_2O	acetonitrile	80; 21	**1a**[a]	84
CH_3SO_2O	acetonitrile	80; 38	**1b**	82
CH_3SO_2O	DMF	150; 48	**1c**[b]	78[c]
CF_3SO_2O	acetonitrile	20; 14	**6**	88
CF_3SO_2O	acetonitrile	80; 8	**8**	80
CF_3SO_2O	acetonitrile	80; 24	**14**[d]	79
CH_3SO_2O	acetonitrile	80; 28	**17**[e]	76

[a] Reference 23. [b] Reference 28. [c] With tetraethyl- instead of tetra-*n*-butylammonium chloride. [d] Reference 19a, 30. [e] Reference 29.

In view of the pronounced single electron transfer ability of magnesium on graphite,[5] it was thought that use of this reagent to ω-deoxy halo sugars might provide information on the mechanism of these active metal-induced reactions. However, in the case of **1a**, instead of the anticipated elimination, reductive coupling with predominant formation of the dimeric product **4** was observed, accompanied by a minor amount of methyl 6-deoxy-2,3,4-tri-*O*-methyl-α-D-glucopyranoside. While this is in agreement with and substantially improves the magnesium-induced Wurtz type coupling of this educt,[23,24] it differs completely from the Rieke magnesium-induced dealkoxyhalogenation

(18) Bernet, B.; Vasella, A. *Helv. Chim. Acta* **1984**, *67*, 1328.
(19) (a) Binkley, R. W.; Ambrose, M. G.; Hehemann, D. G. *J. Org. Chem.* **1980**, *45*, 4387. (b) Tewson, T. J.; Welch, M. J. *J. Org. Chem.* **1978**, *43*, 1090.
(20) Häfele, B.; Schröter, D.; Jäger, V. *Angew. Chem.* **1986**, *98*, 89.
(21) For review, see: Lindley, J.; Mason, T. J. *Chem. Soc. Rev.* **1987**, *16*, 275.
(22) (a) Rieke, R. D.; Hudnall, P. M.; Uhm, S. *J. Chem. Soc., Chem. Commun.* **1973**, 269. (b) Rieke, R. D.; Li, P. T. J.; Burns, B. T.; Uhm, S. *J. Org. Chem.* **1981**, *46*, 4323.
(23) Stout, E. I.; Doane, W. M.; Trinkus, V. C. *Carbohydr. Res.* **1976**, *50*, 282.
(24) For similar Wurtz type couplings of deoxy halo sugars see: Ariatti, M.; Zemlicka, J. *J. Org. Chem.* **1981**, *46*, 5204.

Table III. Physical and Spectral Data of Deoxy Halo Sugars.

compd	mp, °C	$[\alpha]^{20}_D$ (c, solvent)	R_f[a]	selected NMR spectral parameters
1a	39–40	116 (2.5, $CHCl_3$)	0.59	4.81 (H-1, J(1,2) = 3.5); 97.54 (C-1), 7.50 (C-6)
1b	59–60	137 (1.8, $CHCl_3$)	0.58	4.84 (H-1, J(1,2) = 3.5); 97.49 (C-1), 33.46 (C-6)
1c	63–64[b]	147 (1.8, CH_2Cl_2)	0.54	4.84 (H-1, J(1,2) = 3.6); 97.81 (C-1), 44.79 (C-6)
5	syrup[c]	98 (2.8, $CHCl_3$)	0.33	4.85 (H-1, J(1,2) = 3.4); 3.55 (H-4, J(3,4) = 9.4, J(4,5) = 8.9); 97.91 (C-1)
6	syrup	114 (2.5, $CHCl_3$)	0.68	4.82 (H-1, J(1,2) = 3.8), 4.67 (H-4, J(3,4) = 3.9, J (4,5) = 1.4); 98.30 (C-1), 40.38 (C-4)
7	syrup[c]	77 (11, CH_2Cl_2)	0.30	4.90 (H-1, J(1,2) = 3.4), 4.13 (H-4, J(3,4) = 3.0, J(4,5) = 0.8); 98.04 (C-1)
8	syrup	70 (2.0, CH_2Cl_2)	0.55	4.90 (H-1, J(1,2) = 4.2); 97.98 (C-1), 29.70 (C-4)
9	syrup[d]	60 (2.5, $CHCl_3$)	0.54	4.94 (H-1, J(1,2) = 3.6); 97.61 (C-1), 32.00 (C-6)
14	38–41[e]	−15 (3.0, $CHCl_3$)	0.84	5.97 (H-1, J(1,2) = 3.2), 4.46 (H-3, J(3,4) = 2.8); 104.91 (C-1), 34.26 (C-3)
17	90–92[f]	−20 (1.7, CH_2Cl_2)	0.78	5.00 (H-2, J(2,3) = 6.0); 173.11 (C-1), 5.73 (C-5)
19	105–106[c,g]	41 (1.5, $CHCl_3$)	0.75	5.15 (H-1, J(1,2) = 0.4); 102.32 (C-1), 25.02 (C-2)

[a] Using EtOAc/toluene, 1/1, as solvent system. [b] Mp = 62–64 °C; $[\alpha]^{22}_D$ = 162.2° (c 1, $CHCl_3$) (ref 28). [c] IR 3600–3050 cm^{-1} (b s, OH). [d] Syrup; $[\alpha]^{23}_D$ = 72° (c 1.4, $CHCl_3$) (ref 26). [e] Mp = 38–41 °C; $[\alpha]^{21}_D$ = −15.1° (c 3, $CHCl_3$) (ref 30). [f] Mp = 92 °C; $[\alpha]_D$ = −31.8° (c 1.33, acetone) (ref 29). [g] Mp = 105–106 °C; $[\alpha]^{25}_D$ = 39° (c 1.3, ethanol) (ref 17).

claimed to be comparable to that induced by zinc.[25]

Conclusions

In summary various kinds of deoxy halo sugars react with zinc/silver–graphite as well as with C_8K to give olefinic products of distinctly different structure. The zinc/silver–graphite reagent invariably induces dealkoxyhalogenations except in 2-*O*-alkylglycosyl halides. By contrast C_8K induces dehydrohalogenations with the exception of 2-*O*-alkylglycosyl halides, which are dealkoxyhalogenated with formation of glycals.[13]

In view of its extraordinary high reactivity, which permits rapid reactions under mild conditions, as well as the simple workup by filtration of insolubles, which is mainly responsible for the high yields, and its universal applicability, zinc/silver–graphite appears to be superior to other zinc reagents.[14-16,20] Inasmuch as the reaction of magnesium on graphite, recently shown to be an excellent one-electron donor,[5] differs basically from that of zinc, a radical anion mechanism previously proposed for zinc-induced dealkoxyhalogenations[18] does not seem to be very likely.

Experimental Section

General. NMR spectra were recorded with a Bruker MSL 300 instrument at 300 MHz (^1H NMR) or 75 MHz (^{13}C NMR), respectively, with $CDCl_3$ as solvent and tetramethylsilane as internal standard. Chemical shifts are given in ppm, coupling constants (J) in hertz. IR spectroscopy was performed with a Beckman IR 33 (film of the product on a NaCl plate). Optical rotations were measured with a Perkin-Elmer 141 polarimeter. Precoated silica gel sheets (Merck 5554) were used for TLC, and column chromatography was invariably performed on columns of a diameter of 1.5 cm containing 50 g of Merck silica gel (230–240 mesh) with mixtures of ethyl acetate (EtOAc)/toluene in various proportions (cf. Table I) as eluant, thus affording TLC- and NMR-pure products in all cases. All melting points (Tottoli) are uncorrected. Tetrahydrofuran (THF) was distilled over $LiAlH_4$ prior to use. In all experiments graphite samples supplied by Lonza AG, Basle, Switzerland (HSAG 9), were employed, but any other kind of graphite quality turned out to be equally suited.

Educts. With the exception of 9[26] and 19[17] all deoxy halo sugars were synthesized by substitution reactions of the corresponding monosulfonyl derivatives employing tetra-*n*-butylammonium halide.[27] Experimental details and the results obtained are summarized in Table II; selected analytical data of unknown or insufficiently characterized products are contained in Table III.

Preparation of Potassium–Graphite Laminate (C_8K).[1] Graphite (1.5 g, 125 mmol), after being heated for 15 min at 150–160 °C with stirring under argon, and potassium (0.6 g, 15.5 mmol) were kept at 150 °C with stirring until the laminate had formed (10–15 min). The material is highly pyrophoric, necessitating cautious handling in thoroughly dried solvents. The C_8K, the bronze color of which is indicative for its reactivity, is then cooled and ready for use after being suspended in anhydrous THF (25 mL).

Preparation of Zinc/Silver–Graphite. A mixture of anhydrous zinc chloride (1.0 g, 7.35 mmol) and silver(I) acetate (0.1 g, 0.6 mmol) was added in one portion at room temperature to the stirred suspension of C_8K described above under argon. After a first vigorous reaction, the mixture was refluxed for 30 min to complete the reduction and immediately used in the reactions described below.

Preparation of Magnesium–Graphite. This compound was prepared by following the same procedure described for zinc/silver–graphite by employing anhydrous magnesium chloride (0.8 g, 7.65 mmol).

Reductions of Deoxy Halo Sugars by C_8K. General Procedure. A solution of the respective deoxy halo sugar (15 mmol) in THF (20 mL) was added dropwise to a stirred suspension of C_8K (15.5 mmol) in THF (25 mL) at 0 °C under argon, during which the mixture turned black. After filtration and rinsing of the insolubles with THF (50 mL), the filtrate was evaporated under reduced pressure, and the residue was subjected to column chromatography with mixtures of ethyl acetate (EtOAc)/toluene in the respective proportion shown in Table I as eluant.

Methyl 6-Deoxy-2,3,4-tri-*O*-methyl-α-D-*xylo*-hex-5-enopyranoside (3): oil; $[\alpha]^{20}_D$ = 79.2° (c 1.2, $CHCl_3$); IR 1658 cm^{-1} (s); ^1H NMR δ 4.84 (d, 1 H, H-1, J_{12} = 3.3), 4.76 (d, 1 H, H-6, J_{46} = 1.0), 4.70 (d, 1 H, H-6′, $J_{46'}$ = 1.2), 3.62, 3.57, 3.44 (s, 3 H, OMe), 3.42–3.54 (m, 2 H, H-3, H-4), 3.28 (dd, 1 H, H-2, J_{23} = 9.0); ^{13}C NMR δ 153.83 (C-5), 98.61, 96.46 (C-1, C-6), 83.66; 81.80, 81.60 (C-2, C-3, C-4), 61.01, 60.19, 58.40, 55.58 (OMe).

Methyl 6-*O*-benzyl-4-deoxy-2,3-di-*O*-methyl-β-L-*threo*-hex-4-enopyranoside (12): oil; $[\alpha]^{20}_D$ = 160° (c 2.6, CH_2Cl_2); IR 1675 cm^{-1} (s); ^1H NMR δ 7.16–7.34 (m, 5 H, Ph), 5.06 (d, 1 H, H-4, J_{34} = 2.4), 4.98 (d, 1 H, H-1, J_{12} = 3.0), 4.57 (s, 2 H, CH_2Ph), 3.97 (dd, 1 H, H-3, J_{23} = 9.3, J_{34} = 2.4), 3.95 (s, 2 H, H-6_a, H-6_b), 3.51 (dd, 1 H, H-2), 3.55, 3.54, 3.44 (s, 3 H, OMe); ^{13}C NMR δ 149.02 (C-5), 138.50, 128.61, 127.91 (Ph), 99.27, 98.98 (C-1, C-4), 78.46, 74.74, 72.42 (C-2, C-3, CH_2Ph), 69.27 (C-6), 59.01, 56.89, 56.73 (OMe).

Methyl 4-*O*-benzoyl-6-deoxy-2,3-di-*O*-methyl-α-D-*xylo*-hex-5-enopyranoside (13): mp 69–70 °C; $[\alpha]^{20}_D$ = 76° (c 1.5, $CHCl_3$); IR 1745 (s), 1650 cm^{-1} (s); ^1H NMR δ 4.95 (d, 1 H, H-1, J_{12} = 3), 4.8 (b s, 1 H, H-6), 7.1–8.0 (m, 5 H, Ph), 3.6, 3.5, 3.45 (s, 3 H, OMe); ^{13}C NMR δ 151.42 (C-5), 138.09, 133.64, 129.98, 128.68 (Ph), 98.64 (C-1), 96.52 (C-6), 81.49, 80.88 (C-2, C-3), 71.96

(25) See ref 15, footnote 5, p 1993.
(26) (a) Sato, K. I.; Yoshimura, J. *Carbohydr. Res.* **1982**, *103*, 221. (b) Hanessian, S. *Org. Synth.* **1987**, *65*, 243.
(27) For review, see: (a) Binkley, R. W.; Ambrose, M. G. *J. Carbohydr. Chem.* **1984**, *3*, 1. (b) Stang, P. J.; Hanak, M.; Subramanian, R. L. *Synthesis* **1982**, 85.
(28) Klemer, A.; Mersmann, G. *Carbohydr. Res.* **1972**, *22*, 425.
(29) Papageorgiou, C.; Benezra, C. *Tetrahedron Lett.* **1984**, 6041.
(30) Bell, R. H.; Horton, D.; Williams, D. M.; Winter-Mihaly, E. *Carbohydr. Res.* **1977**, *58*, 109.
(31) Garegg, P. J.; Hultberg, H.; Wollin, S. *Carbohydr. Res.* **1982**, *108*, 97.
(32) Albert, R.; Dax, K.; Link, R. W.; Stütz, A. E. *Carbohydr. Res.* **1983**, *118*, C5.

(C-4), 60.98, 59.59, 55.76 (OMe).

3-Deoxy-1,2:5,6-di-*O*-isopropylidene-α-D-*erythro*-hex-3-enofuranose (16): mp 50–51 °C (lit.[19] mp 50–52 °C); $[\alpha]^{20}_D$ = 23° (*c* 1.8, $CHCl_3$) [lit.[19] $[\alpha]_D$ = 21° (*c* 1)]; IR 1662 cm^{-1} (s); ^1H NMR δ 6.06 (d, 1 H, H-1, J_{12} = 5.1), 5.28 (dd, 1 H, H-2, J_{23} = 1.4), 5.23 (dd, 1 H, H-3, J_{35} = 1.2), 4.57 (ddd, 1 H, H-5, J_{56_a} = J_{56_b} = 6.2), 4.13 and 3.95 (d AB system, 2 H, H-6_a, H-6_b, J_{AB} = 6.7), 1.45, 1.43, 1.37 (3 H, s, Me); ^{13}C NMR δ 160.11 (C-4), 112.17, 110.22 (=C= isopropylidene), 108.64 (C-1), 98.99 (C-3), 83.39, 71.34 (C-2, C-5), 67.25 (C-6), 28.22, 27.92, 26.20, 25.51 (Me isopropylidene).

Reductions of Deoxy Halo Sugars by Zinc/Silver–Graphite. General Procedure. The reductions of the corresponding deoxy halo sugars (5.0 mmol) by zinc/silver–graphite (7.35 mmol) and workup of the reaction mixtures followed the same procedure as described for C_8K.

5,6-Dideoxy-2,3,4-tri-*O*-methyl-D-*xylo*-hex-5-enose (2): oil; $[\alpha]^{20}_D$ = 31.4° (*c* 1.7, $CHCl_3$); IR 1730 cm^{-1} (s); ^1H NMR δ 9.73 (s, 1 H, CHO), 5.83 (d X part of an ABX, 1 H, H-5, J_{45} = 7.8, J_{56_a} = 10.5, J_{56_b} = 14.9), 5.34 (AB part of the ABX, 2 H, H-6_a, H-6_b, J_{AB} = 16.0), 3.81 (dd, 1 H, H-3, J_{23} = 4.4, J_{34} = 7.8), 3.74 (d, 1 H, H-2), 3.54 (dd, 1 H, H-4), 3.49, 3.43, 3.24 (s, 3 H, OMe); ^{13}C NMR δ 201.12 (CHO), 134.81 (C-5), 119.07 (C-6), 84.38, 84.29, 81.83 (C-2, C-3, C-4), 60.37, 59.10, 56.54 (OMe).

6-*O*-Benzyl-4,5-dideoxy-2,3-di-*O*-methyl-L-*threo*-hex-4-enose (10): oil; $[\alpha]^{20}_D$ = 75.7° (*c* 4, $CHCl_3$); IR 1735 cm^{-1} (s); ^1H NMR δ 9.74 (d, CHO(*E*), $J_{CHO,2}$ = 1.4), 9.71 (d, CHO(*Z*), $J_{CHO,2}$ = 1.2), 7.25–7.38 (m, 5 H, Ph), 5.86–6.00 (m, 1 H, H-5), 5.75 (dd, H-4(*E*), J_{45} = 15.8, J_{34} = 7.2), 5.63 (dd, H-4(*Z*), J_{45} = 9.8, J_{34} = 9.4), 4.52 (s, 2 H, CH_2Ph), 4.35 (dd, H-3(*Z*), J_{23} = 4.0), 4.05–4.18 (m, 2 H, H-6_a, H-6_b), 4.01 (dd, H-3(*E*), J_{23} = 3.7), 3.61 (dd, H-2(*E*), $J_{2,CHO}$ = 1.4), 3.57 (dd, H-2(*Z*), $J_{2,CHO}$ = 1.2), 3.56, 3.51, 3.27, 3.22 (OMe, (*Z*) and (*E*)), *Z*:*E* = 1.1:1; ^{13}C NMR δ 202.91, 202.78 (CHO), 132.43, 132.39, 128.79, 128.65, 128.60, 128.13, 127.94, 127.88 (C-4, C-5, Ph), 88.07, 87.91 (C-2), 81.95, 77.12 (CH_2Ph), 72.89, 72.50 (C-3), 69.91, 66.09 (C-6), 59.71, 59.61, 57.20, 56.97 (OMe).

Methyl 6-*O*-benzyl-3,4-dideoxy-2-*O*-methyl-α-D-*erythro*-hex-3-enopyranoside (11): oil; $[\alpha]^{20}_D$ = −4.7° (*c* 3.0, $CHCl_3$); ^1H NMR δ 7.25–7.35 (m, 5 H, Ph), 5.82 and 5.76 (d AB system, 2 H, H-3, H-4, J_{AB} = 10.8, J_{45} = 1.2, J_{23} = 0.8), 5.03 (d, 1 H, H-1, J_{12} = 4.1), 4.63 and 4.58 (AB system, 2 H, CH_2Ph), 4.35 (ddd, 1 H, H-5, J_{56_a} = 2.7, J_{56_b} = 3.9), 3.98 (dd, 1 H, H-2), 3.52 (dd, 2 H, H-6_a, H-6_b), 3.52, 3.44 (s, 3 H, OMe); ^{13}C NMR δ 138.27, 128.57, 127.85, 127.58, 124.70 (C-3, C-4, Ph), 97.02 (C-1), 73.64, 73.41, 72.31, (C-2, C-5, CH_2Ph), 68.29 (C-6), 56.84, 56.12 (OMe).

3,4-Dideoxy-5,6-*O*-isopropylidene-D-*erythro*-hex-3-enitol (15): oil $[\alpha]^{20}_D$ = 31.3° (*c* 7.5, CH_2Cl_2); IR 3700–3080 cm^{-1} (b s); ^1H NMR δ 5.85 (dd, 1 H, H-4, J_{34} = 11.2, J_{45} = 6.0), 5.55 (dd, 1 H, H-3, J_{23} = 8.1), 4.47 (ddd, 1 H, H-2, J_{12} = 7.1, $J_{1a,2}$ = 5.8), 4.26 and 4.13 (d AB system, 2 H, H-1, H-1_a, J_{AB} = 13.2), 4.07 and 4.03 (d AB system, 2 H, H-6_a, H-6_b, J_{AB} = 6.3, J_{56_a} = J_{56_b} = 1.3), 3.93 (ddd, 1 H, H-5), 3.02, 2.4 (b s, 1 H each, OH, disappears on addition of D_2O), 1.44, 1.36 (s, 3 H, Me isopropylidene); ^{13}C NMR δ 132.62, 131.02 (C-3, C-4), 109.79 (=C= isopropylidene), 78.14, 68.31, 66.07, 58.57 (C-1, C-2, C-5, C-6), 26.53, 25.22 (Me isopropylidene).

4,5-Dideoxy-2,3-*O*-isopropylidene-D-*erythro*-pent-4-enonic acid (18): oil; $[\alpha]^{20}_D$ = −28° (*c* 10, acetone); IR 3600–2880 (b s), 1715 cm^{-1} (m); ^1H NMR δ 9.8 (b s, 1 H, COOH, disappears on addition of D_2O), 5.80 (X part of an ABX system, 1 H, H-4, J_{34} = 6.8, J_{45_a} = J_{45_b} = 15), 5.42 and 5.38 (AB part of the ABX system, 2 H, H-5_a, H-5_b, J_{AB} = 16), 4.86 (dd, 1 H, H-3, J_{23} = 6.7), 4.71 (d, 1 H, H-2), 1.63, 1.42 (s, 3 H, Me isopropylidene); ^{13}C NMR δ 174.18 (COOH), 136.69 (C-4), 119.74 (C-5), 111.42 (=C= isopropylidene), 78.55, 77.28 (C-2, C-3), 28.21, 25.39 (Me isopropylidene).

1,5-Anhydro-4,6-*O*-benzylidene-1,2-dideoxy-D-*ribo*-hex-1-enitol (20): mp 83–84 °C (lit.[17] mp 83.5 °C); $[\alpha]^{20}_D$ = 219° (*c* 3.2, ethanol) [lit.[17] $[\alpha]^{25}_D$ = 209.5° (*c* 2, ethanol)]; IR 3620–3200 (b s), 1635 cm^{-1} (s); ^1H NMR δ 7.25–7.40 (m, 5 H, Ph), 6.37 (d, 1 H, H-1, J_{12} = 6.0), 5.6 (s, 1 H, H benzylidene), 4.9 (dd, 1 H, H-2, J_{23} = 6), 4.2 (m, 2 H, H-3, H-5), 4.43 and 3.90 (d AB system, 2 H, H-6_a, H-6_b, J_{56_a} = 4.5, J_{56_b} = 9, J_{AB} = 11), 3.73 (dd, 1 H, H-4, J_{34} = 3, J_{45} = 9.5), 2.9 (b s, 1 H, OH, disappears on addition of D_2O); ^{13}C NMR δ 146.19 (C-1), 137.28, 129.42, 128.51, 126.42 (Ph), 101.85, 101.26 (C-2, C benzylidene), 78.25, 68.62, 64.01 (C-3, C-4, C-5), 60.11 (C-6).

Preparation of Bis(methyl 6-deoxy-2,3,4-tri-*O*-methyl-α-D-glucopyranosid-6-yl) (4). A solution of **1a** (1.04 g, 3 mmol) in anhydrous THF (20 mL) was droped into a suspension of magnesium–graphite (7.65 mmol) in THF (25 mL) at ambient temperature under argon, and the mixture was refluxed for 3 h. After cooling, filtration, washing of insolubles with THF (50 mL), and evaporation, column chromatography with toluene/ethyl acetate (3/1) as eluant yields **4** (0.45 g, 68%) and 0.05 g (8%) of methyl 6-deoxy-2,3,4-tri-*O*-methyl-α-D-*gluco*-pyranoside and only traces of **2**. **4**: mp 86–87 °C; $[\alpha]^{20}_D$ = 158° (*c* 1.1, $CHCl_3$); ^1H NMR δ 4.77 (d, 1 H, H-1, J_{12} = 3.6), 3.61, 3.54, 3.51, 3.39 (s, 3 H, OMe), 3.38–3.58 (m, 2 H, H-4, H-5), 3.17 (dd, 1 H, H-2, J_{23} = 9.7), 2.84 (dd, 1 H, H-3, J_{34} = 9.7), 1.89 (m, 1 H, H-6_a), 1.64 (m, 1 H, H-6_b); ^{13}C NMR δ 97.41 (C-1), 84.31, 83.79, 82.33 (C-2, C-3, C-4), 69.70 (C-5), 60.92, 60.73, 59.03, 55.18 (OMe), 27.52 (C-6).

Acknowledgment. Financial support by the Fonds zur Förderung der Wissenschaftlichen Forschung, Vienna (P6286C) is gratefully acknowledged. We also thank C. Illaszewicz, Dr. H. Hönig, and Dr. R. Pucher for recording the NMR spectra.

Synthesis and Reactivity of β-Lactones Derived from L-Threonine and Related Amino Acids

Sunil V. Pansare and John C. Vederas*

Department of Chemistry, University of Alberta, Edmonton, Alberta, Canada T6G 2G2

Received December 8, 1988

The synthesis and nucleophilic ring opening of optically pure N-protected α-amino-β-alkyl β-lactones was investigated. Treatment of *N*-BOC-L-threonine (**8**) and *N*-BOC-L-*allo*-threonine (**9**) under modified Mitsunobu conditions (Ph_3P, dimethyl azodicarboxylate, −78 °C) gives stereospecific (anti) decarboxylative elimination to afford *N*-BOC-aminopropenes **10** and **11**, respectively, in contrast to cyclization of *N*-BOC-L-serine to its β-lactone under these conditions. However, the corresponding *N*-(phenylsulfonyl) derivatives **12**, **13**, and **16** cyclize to chiral β-lactones **14**, **15**, and **17**, respectively, in 40–55% yield by using carboxyl group activation by 4-bromobenzenesulfonyl chloride in pyridine. Nitrogen (pyrazole, benzylamine), oxygen (hydroxide, acetate), and carbon (EtMgCl, $CuBr{\cdot}SMe_2$) nucleophiles prefer to attack at the carbonyl carbon, in contrast to their reactions (except that of hydroxide) with β-butyrolactone and serine β-lactones. However, β-lactones **14**, **15**, and **17** are opened at the β-carbon with inversion of configuration by some sulfur (thiourea) and halogen (magnesium chloride, bromide, iodide) nucleophiles to N-protected optically pure β-substituted amino acids in good yield.

The importance of α-amino acids has prompted the recent development of numerous methods for their stereospecific synthesis.[1] In earlier work we have shown that N-protected derivatives **1** of serine can be cyclized under

0022-3263/89/1954-2311$01.50/0