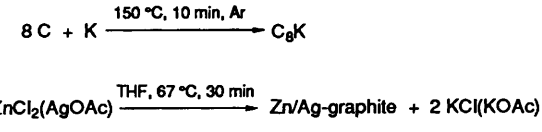
Unprecedented Influence of Azides and the Effect of Bulky Groups on Zinc-induced Reductions of Deoxy Halogeno Sugars

Alois Fürstner,*,† Judith Baumgartner and Denis N. Jumbam
Institute of Organic Chemistry, Technical University, Stremayrgasse 16, A-8010, Graz, Austria

Zinc/silver–graphite induced ring-opening reactions of deoxy halogeno sugars by dealkoxyhalogenation may be suppressed by bulky protecting groups in the substrates, giving rise to simple dehalogenation products. Furanose derivatives are more sensitive to such steric effects than pyranose systems, although an X-ray analysis of 1,2-*O*-isopropylidene-3-*O*-benzyl-5-deoxy-5-iodo-α-D-xylofuranose **3** shows no evidence of steric hindrance by the C-3 substituent. Moreover, dehalogenation instead of reductive ring-opening reactions are observed in all cases in which organic azides are present in the reaction medium. This unprecedented effect of azides on zinc-induced reductions is equally effective both intra- and intermolecularly. This behaviour is best rationalized by assuming radical intermediates for dehalogenations, in contrast to transient organometallic species closely bound to the zinc surface when reductive ring-opening is observed. This mechanistic interpretation is supported by a labelling experiment.

A considerable part of monosaccaride chemistry consists of the use of sugars as highly functionalized and enantiomerically pure starting materials for natural product synthesis.[1,2] A major task in this approach, in general, consists of introducing suitable anchor groups into the sugar precursor to be incorporated into the target molecule.[2] One attractive way to do so is the dealkoxyhalogenation of deoxyhalogeno sugar derivatives resulting in reductive ring-opening of the substrate with simultaneous formation of an alkene and an aldehyde function (Scheme 1).[3] Of the reagents inducing this transformation,

Scheme 1

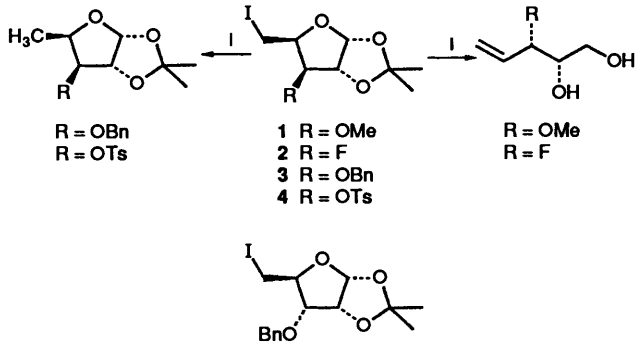


Scheme 2

highly reactive and readily prepared zinc/silver–graphite (Scheme 2) was found to be best suited in terms of yield, reaction rate, functional group compatibility and ease of work-up.[4] Moreover, it is the only reagent which is effective in aprotic media,[4] supresses the undesirable side reactions which interfere under classical conditions (*e.g.* zinc dust in boiling, aqueous alcohols),[3] allows the formation of hydrolytically labile products[4] and is reported to be equally effective in the non-carbohydrate series.[5] However, despite the wealth of variously substituted synthons readily accessible by this procedure,[4] we recently made a number of unexpected observations in exploring this reductive ring-opening reaction in natural product synthesis. Following a systematic investigation, we now report on the general aspects of these exceptions.

Results and Discussion

Steric Effects of Protecting Groups.—The major side reaction that competes with the dealkoxyhalogenation described above consists of simple reductive cleavage of the carbon–halogen bond with formation of a deoxy function in the substrate.[3,4c,4d] Recent examples show that this undesirable process is more likely with bromides than iodides, with furanose rather than pyranose derivatives and is also favoured by lowering of the reaction temperature.[4c,4d] The results obtained from a series of 1,2-*O*-isopropylidene-5-deoxy-5-iodo-α-D-xylofuranoses (Scheme 3) suggest a steric effect exhibited by the substituent at



Scheme 3 *Reagents and conditions:* i, Zn/Ag-graphite, THF, 30–60 °C (ref. 4c)

C-3 on the reaction mechanism.[4c] Thus, while derivatives with rather small groups such as **1** (R = OMe) or **2** (R = F) are reductively ring-opened, those with comparatively bulky ones such as **3** (R = OBn) or **4** (R = OTs) are simply dehalogenated without any formation of acyclic products. This view is further supported by the marked influence of the orientation of the substituent in such substrates. Compounds **3** (D-*xylo*) and **5** (D-*ribo*), both bearing an OBn group at C-3 show the reverse behaviour, with the former being dehalogenated and the latter being predominantly ring-opened.[4c] This calls for a more detailed study of the conformational arrangements in such furanoses and a systematic search for similar effects in pyranose systems known to undergo ring-opening reactions more readily.[4]

An X-ray analysis of 1,2-*O*-isopropylidene-3-*O*-benzyl-5-deoxy-5-iodo-α-D-xylofuranose **3** (Fig. 1),[4c] however, provided no evidence for such hindrance by the benzyloxy group at C-3 for an attack of the zinc/silver–graphite surface reagent[6] on the iodide. In this example, however, the iodine and the ring-oxygen atom are in an antiperiplanar arrangement with a dihedral angle of 177°, a conformation differing from that of all

† *Present Address:* Max-Planck-Institut für Kohlenforschunf, Kaiser Wilhelm Platz 1[1], D-4330 Mülheim a.d. Ruhr, Germany.

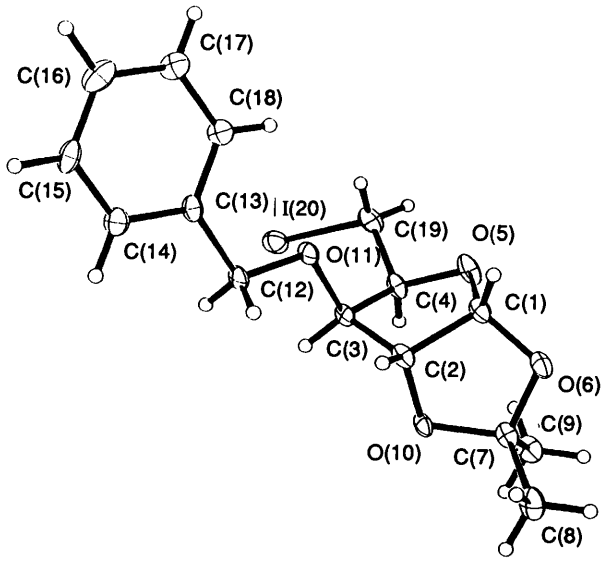
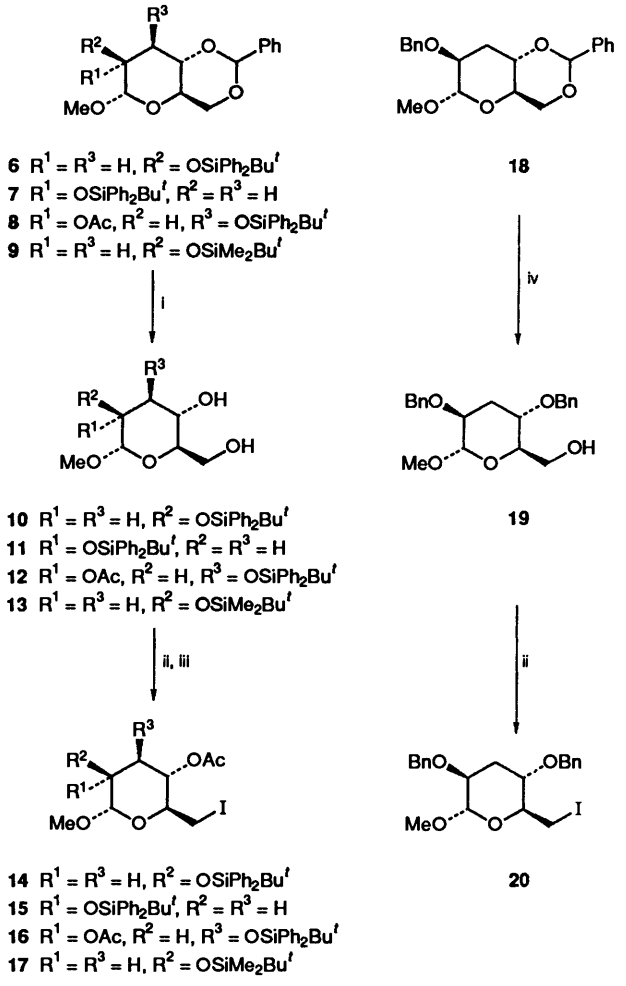


Fig. 1 Projection of the asymmetric unit of the crystal structure of compound **3**. Librational ellipsoids have been drawn at the 50%-level

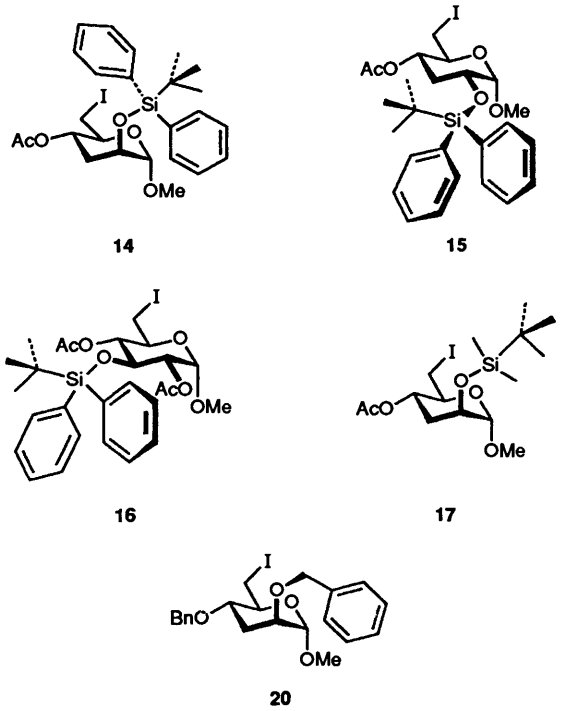
comparable deoxy Iodo sugars reported in the Cambridge Crystallographic Data file invariably exhibiting a synclinal arrangement of these groups.* Since the other derivatives of this furanose series have not been obtained in crystalline form,[4c] direct comparison cannot be used to decide if the specific molecular arrangement of the leaving groups reflects their behaviour when treated with zinc/silver–graphite.

The situation in the pyranose series is less puzzling. In general, with zinc/silver–graphite as the reagent, dehalogenation is either negligible or fails to occur at all as has already been evidenced with a substantial number of examples.[4] To test this aspect further, we prepared 6-deoxy-6-iodohexopyranoside derivatives (Scheme 4) with bulky protecting groups in order to study the steric effects in such systems more closely. Even those substrates with the sterically demanding substituents in the axial position (**14**, **17** and **20**) maintain a $^4C_1$ conformation as evident from ^{1}H NMR data (*cf.* Experimental section). The preparation of the iodide **20** is based on the excellent regioselectivity in favour of the 4-*O*-benzyl ether, obtained in the reductive cleavage of the 4,6-*O*-benzylidene acetal of compound **18** using BH_3-NMe_3/$AlCl_3$ in toluene as the reagent,[7] followed by standard iodination of the resulting primary alcohol **19**.[4c,8]

As summarized in Table 1, all substrates are smoothly ring-opened in excellent yields upon treatment with zinc/silver–graphite in THF, except compound **14**, which undergoes both dealkoxyhalogenation and dehalogenation, with the latter dominating at lower temperature. In order to separate the acyclic product **21** from the 6-deoxypyranoside **22**, the crude mixture was reduced with $NaBH_4$. This, however, gives rise to partial migration of the silyl group in the corresponding enitol. After its desilylation and reacetylation we obtained compound **23** in the yields indicated in Table 1. This unique deviation from the usual behaviour of pyranoses[4] might stem from steric factors, as evident by comparison with the results obtained from substrates **15**, **17** and **20**. Thus, in accordance with our results in the furanose series,[4] upon altering the orientation of the bulky



Scheme 4 *Reagents and conditions:* i, H_2, Pd/C (10%), MeOH, room temp., quant.; ii, PPh_3, I_2, imidazole, toluene, room temp.; iii, Ac_2O, pyridine, DMAP, CH_2Cl_2; iv, BH_3-NMe_3, $AlCl_3$, toluene, room temp., 1 h, 60% (ref. 7)



* Since only 4 examples of ω-deoxy iodo sugars are reported in the Cambridge Crystallographic Data file we extended our comparison to tetrahydrofuran derivatives containing the relevant C–O–C–C–I fragment (9 examples). Again synclinal arrangement is preferred except in cases whose antiperiplanar conformation is stabilized by hydrogen bonding between the iodine and a proximate OH group (2 examples).

Table 1 Zinc/silver-graphite (THF) induced reactions of 6-deoxy-6-iodohexopyranosides bearing bulky protecting groups

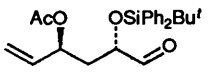
Entry	Substrate	Reaction conditons	Product (% yield)
1	**14**	25 °C, 2h	**23**(20),[b] **22**(60)
2	**14**	87 °C,[a] 1 h	**23**(35),[b] **22**(35)
3	**15**	25 °C, 10 min	**24**(91)
4	**16**	25 °C, 15 min	**26**(85)
5	**17**	25 °C, 10 min	**27**(90)
6	**20**	25 °C, 10 min	**25**(91)

[a] In DME; [b] After $NaBH_4$-reduction of the crude aldehyde, desilylation (TBAF·$3H_2O$, THF) and acetylation (Ac_2O, pyridine, DMAP cat.) of the resulting triol, see Experimental section.

Table 2 Zn/Ag-graphite induced dehalogenation reactions of deoxy halogeno sugars containing azide substituents

Entry	Substrate	Conditions	Product (% yield)
1	**33**	25 °C, 30 min	**43**(81)
2	**36**	25 °C, 30 min	**44**(70)
3	**39**	25 °C, 60 min	**45**(69)
4	**42**	25 °C, 25 min	**46**(98)

$OSiPh_2Bu^t$ group from axial (*cf.* **14**) (D-*arabino*) to equatorial position (*cf.* **15**) (D-*ribo*), it completely loses its deleterious influence on the zinc-induced reaction. Similarly, reducing the size of the substituent in the D-*arabino* configuration ($OSiMe_2Bu^t$ in **17** and OBn in **20**, respectively, instead of the most bulky $OSiPh_2Bu^t$ in **14**) also leads to dealkoxyhalogenation with the hex-5-enals **25** and **27** as the sole products.



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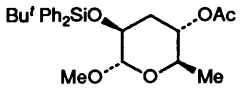

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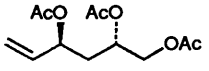

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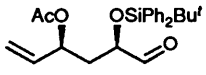

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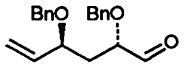

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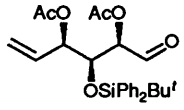

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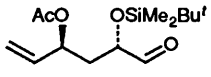

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Dealkoxyhalogenation versus *Dehalogenation: the Azide Switch.*—3-Azido-3,6-dideoxy-1,2-*O*-isopropylidene-α-D-xylofuranose **28** resisted reductive ring-opening but suffered simultaneous reduction of the carbon–iodine as well as the azide function upon treatment with zinc/silver–graphite under comparatively drastic conditions (12 h, 60 °C) to afford **29** after acetylation of the crude reaction mixture (Scheme 5).[4c] Comparable examples of reductions of carbon–halogen bonds accompanied by azide into amine conversion in the sugar series have been achieved under free radical conditions.[9]

Table 3 Effect of an external azide onto Zn/Ag-graphite promoted reactions of deoxy halogeno sugars in THF as solvent

Substrate (equiv.)	Azide (equiv.)	Conditions	Products (% yield)	Recovered azide (%)
47 (1)	—	20 °C, 10 min	**49**(93), **50**(0)[4]	—
47(1)	**48**(1)	20 °C, 60 min	**49**(0), **50**(90)	91
47(1)	**48**(0.1)	20 °C, 60 min	**49**(86), **50**(6)	82
51(1)	—	−20 °C, 10 min	**52**(87), **53**(0)[13]	—
51(1)	**48**(1)	+40 °C, 2 h	**52**(8), **53**(75)	85
51(1)	**48**(1)	+40 °C, 2 h[a]	**52**(4), **54**(77)	85

[a] In [$^2H_8$]-THF.

28 **29**

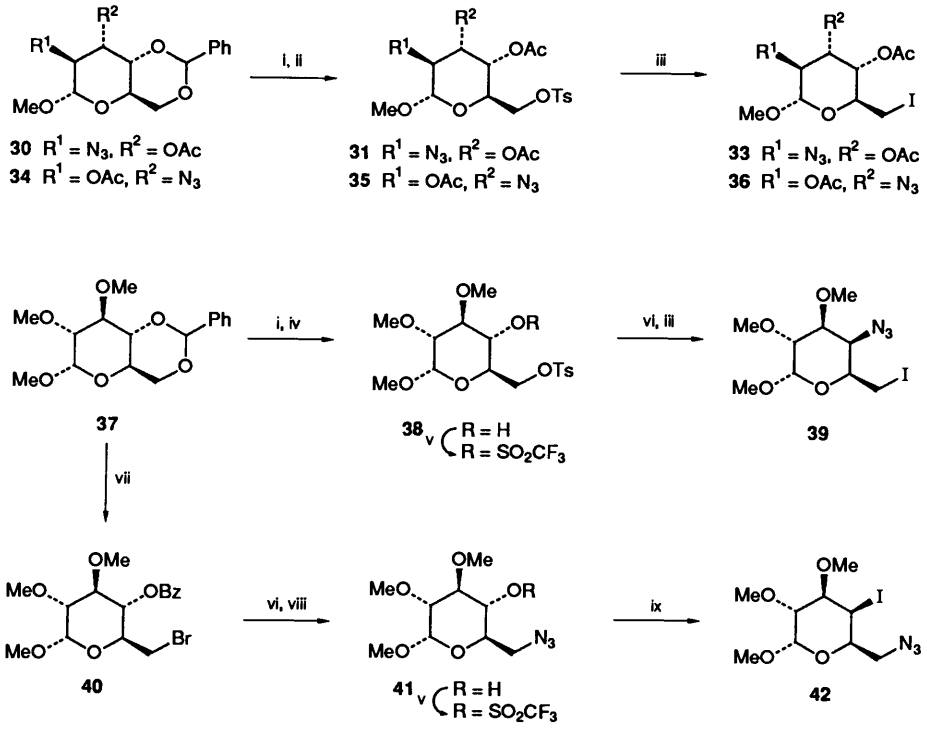
Scheme 5 *Reagents and conditions:* i, Zn/Ag-graphite, THF, 60 °C, 12 h; then Ac_2O–pyridine, 30 min, 68% (ref. 4*c*)

Because of the preparative relevance of azidodeoxy groups this peculiarity needed further investigation.

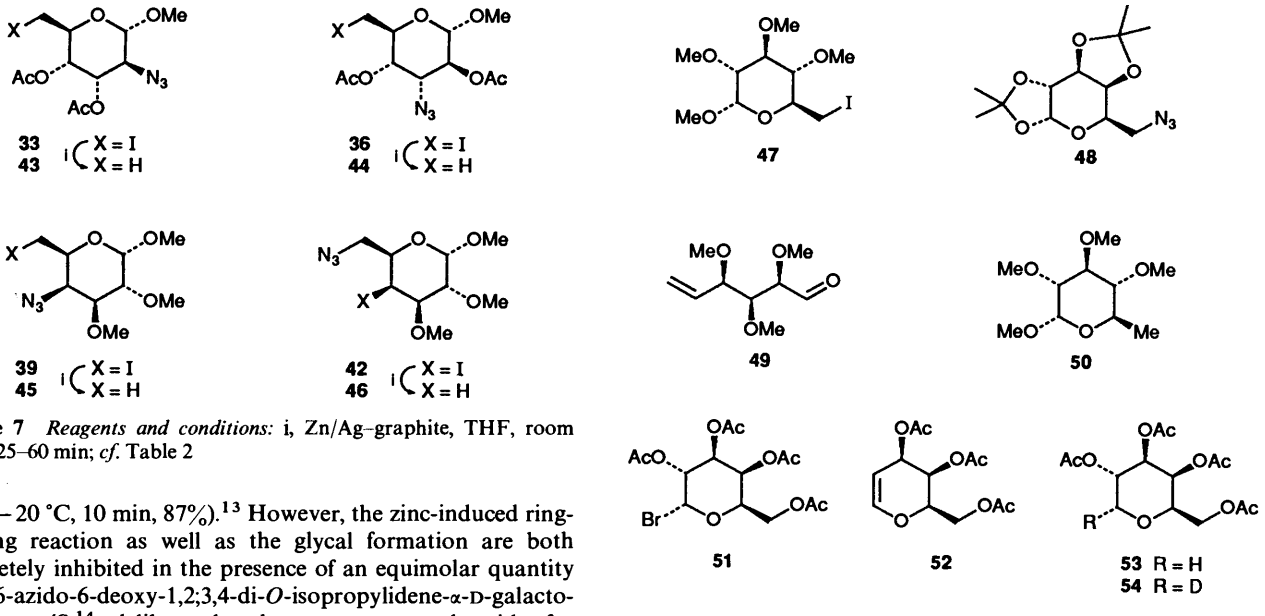
Scheme 6 summarizes the syntheses of suitable deoxy iodo pyranosides each bearing an azidodeoxy function in different ring positions and configurations. Deprotection of the known azides **30** and **34** respectively,[10] selective tosylation of the resulting diols at O-6, acetylation of the remaining alcohol function at C-4 and finally iodine for tosyloxy exchange reactions[4a] give compounds **33** and **36** in high yields. Despite the same functionalities and configuration, only the former adopts the expected $^4C_1$ conformation while the coupling constants (see Table 5) for the latter indicate an equilibrium state between the two possible chair forms. The regioisomeric products **39** and **42** are both prepared from the common precursor **37**[10] by standard protection/nucleophilic substitution steps as outlined in Scheme 6. It is worth mentioning, that in compound **38** (R = SO_2CF_3) the azide perfectly discriminates between the primary tosylate and the triflyloxy group at C-4, the latter being selectively substituted.[11]

All of these substrates invariably suffer dehalogenation when exposed to zinc/silver–graphite in THF at room temperature, irrespective of the relative arrangement of azide and the iodide group (Scheme 7, Table 2), no ring-opened products being detected. In no case does the reagent affect the azide function, probably because of the mild conditions and short reaction times in zinc/silver–graphite induced reduction of pyranosides.[4] In contrast, compounds **33** and **36** decompose when treated under classical conditions (*i.e.* zinc dust in aqueous ethanol),[3] thereby providing further evidence for the superiority of zinc/silver–graphite to other zinc reagents. In the context of this striking incompatibility of azide-containing starting materials for such reductive ring-opening reactions it is interesting to note that, in a total synthesis of the immunoactivator FR900483 published recently[12] the essential azidodeoxy group was also introduced *after* the fragmentation of a 6-deoxy-6-bromopyranoside with zinc in aqueous alcohol.

The importance of these results is further emphasized by the observation that azides exhibit even an *inter*molecular effect onto such zinc-promoted reductions of deoxy halogeno sugars. The results are summarized in Table 3. Methyl 6-deoxy-6-iodo-2,3,4-tri-*O*-methyl-α-D-glucopyranoside **47** on treatment with zinc/silver–graphite (20 °C, 10 min) gives the corresponding hex-5-enal **49** in excellent yield (93%).[4a] Similarly, 2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl bromide **51** is known to afford the corresponding tri-*O*-acetyl-D-galactal **52** with even greater



Scheme 6 *Reagents and conditions:* i, *p*-TsOH·H_2O, MeOH, room temp., quant.; ii, *p*-TsCl, pyridine/CH_2Cl_2, room temp., then Ac_2O; iii, $Bu_4N^+I^-$, MeCN, reflux; iv, *p*-TsCl, pyridine–CH_2Cl_2, room temp., 94%; v, triflic anhydride, pyridine–CH_2Cl_2, 0° ⟶ 25 °C; vi, NaN_3, DMF, room temp., 68–78%; vii, NBS, $BaCO_3$, CCl_4, reflux, 84%;[4a] viii, NaOMe cat., MeOH, room temp.; ix, $Bu_4N^+I^-$, MeCN, room temp.



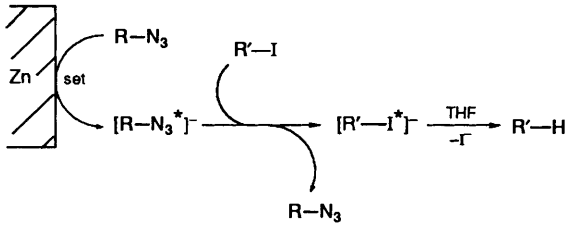
Scheme 7 *Reagents and conditions:* i, Zn/Ag–graphite, THF, room temp., 25–60 min; *cf.* Table 2

ease (−20 °C, 10 min, 87%).[13] However, the zinc-induced ring-opening reaction as well as the glycal formation are both completely inhibited in the presence of an equimolar quantity of 6-azido-6-deoxy-1,2;3,4-di-*O*-isopropylidene-α-D-galacto-pyranose **48**,[14] deliberately chosen as external azide for practical reasons. Interestingly both substrates are simply dehalogenated to products **50** and **53**,[15] respectively, and the azide is recovered unaffected. With <1 equiv. of **48** admixed with the deoxy halogeno sugar the product distribution obtained roughly reflects the ratio of substrate to azide initially chosen (*cf.* Table 3). We are not aware of any precedence for these results.

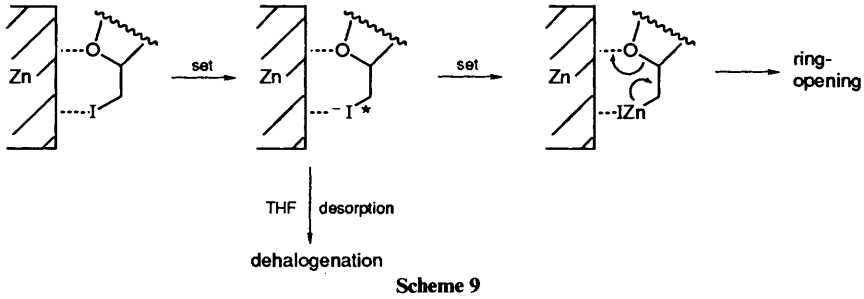
Discussion

The mechanistic interpretation of heterogeneous reactions is known to be troublesome and the above mentioned types of transformation seem to be illustrative examples of a puzzling situation. Since, on principle, dealkoxyhalogenations can be brought about by a great variety of reagent systems under quite different conditions[16] [*e.g.* zinc in boiling aqueous alcohols,[3] butyllithium in THF,[3] SmI_2 in boiling THF/HMPA[17] and highly reactive zinc/silver–graphite in anhydrous ethers (THF, DME) at room temperature[4]] the question arises as to the actual nature of the intermediates and the role played by the metal surface in zinc-induced reactions.[18]

In this context, the pronounced but unprecedented effect of azides on the reaction path deserves detailed consideration.[19] Unfortunately, however, little is known about the interaction of this functional group with metallic zinc except for examples of reductions to the corresponding amines in protic media.[20,21] Under aprotic conditions a single electron-transfer (set) mechanism has been postulated with formation of an



Scheme 8



Scheme 9

intermediate isoelectronic to an allyl radical anion.[20] Since the azide itself is recovered unchanged in our cases, such a transient mesomeric radical must be stabilized by transfer of the unpaired electron, *e.g.* onto the carbon–halogen bond. THF, however, might serve as a hydrogen source for alkyl radicals formed in that way.[22] This assumption of a radical path and a substrate–solvent interaction (Scheme 8) is strongly supported by a control experiment, in which the reduction of the glycosyl halide **51** in the presence of 1 equiv. of the external azide **48** is performed in [$^2H_8$]-THF. In this case, deuterium is selectively incorporated in the axial position of product **54** (R=D). This is in accordance with the anomeric effect known to be operative in glycosyl radicals.[23] Furthermore, it is well established that the reduction of glycosyl halides to the corresponding 1,5-anhydro alditols is best achieved under radical conditions in ethereal solvents.[15]

Hence, if these dehalogenations stem from free radicals in solution formed by azide-mediated single-electron transfer, it is reasonable to assume that radical intermediates are formed in all cases in which dehalogenation dominates. Thus, the effect of bulky substituents might stem from facilitating the desorption of the radical from the zinc surface followed by hydrogen abstraction from the solvent. In contrast, dealkoxyhalogenations should occur with those substrates which, remaining in close contact to the metal surface, allow a second electron-transfer with formation of a transient organozinc species to occur (Scheme 9).* A recent example of a (vinylogeous) fragmentation of an organotin compound upon transmetallation with zinc chloride supports this assumption of organozinc species as intermediates in such fragmentation processes.[24] This mechanistic interpretation would also explain the different bias for reductive ring-opening reaction of bromides and iodides.[4] The lower reactivity of furanose derivatives as compared to pyranose systems might originate from different chelation abilities of the ring oxygen as the second leaving group on the proximate metal centre and has some precedence in recent examples of metallated carbohydrate derivatives.[25] Finally it should be mentioned that Knochel *et al.* have recently mentioned that oxidative insertion of activated zinc into carbon–halogen bonds with formation of organozinc reagents fail in those cases where the substrates bear extra azide functions.[26]

Further investigations on these and other aspects of zinc-promoted processes are in progress.

Experimental

General.—NMR spectra were recorded on a Bruker MSL 300 instrument at 300 MHz (^1H) and 75 MHz (^{13}C) in $CDCl_3$ (Aldrich) as solvent and TMS as internal standard. Chemical shifts (δ) are given in ppm, coupling constants (J) in Hz. Optical rotations ($[\alpha]_D$) were measured on a Jasco DIP300 instrument in CH_2Cl_2 as solvent and are recorded in units of 10^{-1} deg cm^2 g^{-1}. FT-IR spectra were recorded on a Perkin-Elmer 883 spectrometer. The m.p.s (Tottoli) are uncorrected. Column chromatography was invariably performed on Merck silica gel (230–240 mesh) and TLC on precoated sheets (Merck 5554) with mixtures of toluene–ethyl acetate in various proportions as eluents. THF and DME were distilled over potassium/benzophenone, CH_2Cl_2 over P_4O_{10}, toluene over sodium wire, and acetonitrile over molecular sieves 4 Å prior to use. $ZnCl_2$ and AgOAc were purchased from Fluka, Switzerland and potassium from Riedel de Haen, Austria. In all experiments graphite KS 5-44 supplied by Lonza, Switzerland, was employed, although other graphite qualities turned out to be equally suitable for the preparation of metal–graphite reagents.[4,6]

Crystal Data for Compound **3**.—$C_{15}H_{19}IO_4$, M = 390.2. Monoclinic, a = 5.552(10), b = 9.763(8), c = 14.533(11) Å, β = 100.42(8)°, V = 774.8(1.6) Å^3 (by least-squares refinement against setting angles of 13 reflections with 9° ≤ 2θ ≤ 14°, λ = 0.710 69 Å), T/K 85, space group $P2_1$, Z = 2; d_c = 1.67 g/cm^3, colourless crystals grown from diethyl ether;[4c] crystal dimensions 0.5 × 0.3 × 0.2 mm.

Data collection, processing and structure analysis.[27] Modified STOE diffractometer; T/K 85, graphite monochromated Mo-K_α radiation; linear absorption coefficient (μ 20.5 cm^{-1}); intensity data (ω-scan, $\Delta\omega$ = 0.8°) collected for two octants of reciprocal space ($-10 \le h \le 10$, $0 \le k \le 17$, $0 \le l \le 26$; 5.5° ≤ 2θ ≤ 80°), 4507 reflections observed, 3251 significant (F_o) > 4σ(F); *Lp* correction, an empirical absorpton correction and an empirical extinction correction {$F^* = F[1 + 0.002\nu F^2/\sin(2\theta)]^{1/4}$, ν = 0.001 8(3)} were applied to the data. Structure solved with Patterson methods and refined with least-squares including anisotropic atomic displacement parameters (a.d.p's) for all non-hydrogen atoms; H-atoms included at calculated positions, with only one isotropic a.d.p. refined for each of them; R = 0.0381, wR = 0.0502 ($w^{-1} = \sigma^2(F) + 0.0007F^2$) for 201 parameters and 3251 observations. A final difference electron density map showed features up to 1.6(1) e/Å^3 in the vicinity of the iodine atom. The complete set of data has been deposited at the Cambridge Crystallographic Data Centre, Cambridge, U.K.†

* This interpretation corresponds well to Vasella's assumption; *cf.* footnote 2 in ref. 18.

† For details, see 'Instructions for Authors (1992),' *J. Chem. Soc., Perkin Trans. 1*, 1992, issue 1.

Table 4 Preparation of the deoxy iodo pyranosides and selected ^{13}C NMR data

Substrate	Method[a]	Product (yield %)[b]	$[\alpha]_D$ (c, CH_2Cl_2)	C-1	$-CH_n-I$	Other
10	B	**14**(86)[c]	38.6(8.4)	100.61	6.35	32.29(C-3)
11	B	**15**(75)[c]	63.1(3.4)	99.15	5.17	32.85(C-3)
12	B	**16**(78)[c]	44.3(10)	99.40	6.58	21.11(Me_3C)
13	B	**17**(65)[c]	63.8(4.4)	101.08	6.01	32.79(C-3)
19	B	**20**(84)	61.8(3.2)	98.17	7.80	29.29(C-3)
31	A	**33**(78)	42.8(14)	99.37	3.79	60.19(C-2)
35	A	**36**(90)	49.6(0.1)	99.20	4.86	58.44(C-3)
38[d]	A	**39**(58)	94.0(7.2)	98.18	2.99	61.26(C-4)
41	A[e]	**42**(68)	131.7(8)	98.13	39.04	56.86(C-6)

[a] Method A: $Bu_4N^+I^-$, CH_3CN, reflux (see Experimental section[4c]); method B: PPh_3/I_2/imidazole in toluene, room temp. (see Experimental section[4c]). [b] All products were obtained as colourless oils. [c] Overall yield for iodination at 6-O followed by acetylation of the crude 6-deoxy-6-iodo-4-*O*-unprotected intermediate (see Experimental section). [d] After azide for triflyloxy exchange reaction at 4-C (DMF, NaN_3, room temp., 2 h, 78%). [e] $R^1 = SO_2CF_3$; at room temp. in DMF as solvent.

Table 5 Selected ^1H NMR data for the deoxy iodo pyranosides

Compd.	1-H	2-H	3-H	4-H	5-H	$J_{1,2}$	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$
14	4.47	3.85	*a*	5.16	3.67	0	N.r.	10[b]	10
15	4.35	3.86	*c*	4.49	3.71	3.5	10/5	8/5	9
16	4.35	3.82	5.28	3.19–3.28		3.6	9	9	9
17	4.46	3.82	*g*	4.92	3.68	0	<1	10	9
20	4.82	*d*	*e*	3.42	*d*	0	N.r.	10	8
33	4.50	3.69	4.92–4.98		3.95	3.5	6	3.5	6
36	4.62	4.95	*f*	4.97	*f*	0	1	3.8	9.5
39	4.78	3.53–3.67		4.21	3.86	3.6	10	3.5	1.5
42	4.73	2.73	3.40	4.43	3.53	3.8	9.5	2.5	1.2

[a] 1.74 and 2.11 (J_{AB} 13). [b] $J_{3',4}$ 4.5. [c] 2.10 and 2.23 (J_{AB} 12). [d] 3.73–3.76 (4 H, m, 2-H, 5-H, 6-H, 6'-H). [e] 1.90 and 2.36 (J_{AB} 13). [f] 4.03–4.10 (2 H, m, 3-H, 5-H). [g] 2.02 and 1.81 (J_{AB} 13).

Preparation of Deoxyiodo Sugar Derivatives. General Procedures.—(a) *By nucleophilic displacement of sulfonate esters.*[4c] A solution of the sulfonate ester (10 mmol) and tetrabutylammonium iodide (13 mmol) in acetonitrile (100 cm^3) was refluxed until TLC showed complete conversion of the substrate. The solvent was removed under reduced pressure and the residue taken up in ethyl acetate (100 cm^3); the organic layer washed with water (75 cm^3 as several portions), dried (Na_2SO_4) and evaporated. The crude product was then purified by column chromatography. Reaction times, yields and the physical data for the products are summarized in Tables 4 and 5.

(b) *From the parent alcohols.*[4c] To a vigorously stirred solution of the 6-*O*-unprotected pyranoside (10 mmol) in toluene (70 cm^3) were added imidazole (30 mmol), triphenylphosphine (11 mmol) and iodine (12 mmol). After 20–30 min at room temperature, TLC showed complete conversion of the substrate. For work-up, the solution was decanted from the gummy precipitate, decolourized by washing with aqueous $Na_2S_2O_3$ (20 cm^3) and water (10 cm^3), dried over Na_2SO_4 and evaporated under reduced pressure. The residue was purified by flash chromatography. For 4,6-di-*O*-unprotected substrates **10**–**13** the resulting 6-deoxy-6-iodo-4-*O*-unprotected pyranoside was dissolved in CH_2Cl_2 (10 cm^3) and pyridine (950 mg, 12 mmol) and acetic anhydride (1.53 g, 15 mmol) was added. After completion of the acetylation the reaction mixture was further diluted with CH_2Cl_2 (50 cm^3) and quenched with methanol (5 cm^3). The organic layer was then washed with hydrochloric acid (0.1 mol dm^{-3}; 10 cm^3) and water (30 cm^3), dried (Na_2SO_4) and evaporated. Column chromatography of the residue afforded the products in analytically pure form. For yields and physical properties *cf.* Tables 4 and 5.

Preparation of Zinc/Silver–Graphite.—Potassium (0.6 g, 15.5 mmol) was added in pieces with good mechanical stirring to graphite (1.5 g, 125 mmol) at 150–160 °C under argon, previously degassed at this temperature for 10 min. The bronze-coloured C_8K thus obtained within a few minutes was cooled to room temperature and suspended in anhydrous THF (25 cm^3); a mixture of zinc chloride (1.0 g, 7.35 mmol) and silver acetate (0.1 g, 0.6 mmol) was then added in one portion. After the initial vigorous reaction had subsided, the mixture was refluxed for 25 min in order to ensure complete reduction. The zinc/silver–graphite reagent[6] so obtained was immediately used for the reactions described below.

Zinc/Silver–Graphite-induced Reductions of Deoxy Halogeno Sugars: General Procedure.—A solution of the substrate (5 mmol) in THF (3 cm^3) was added with a syringe to a stirred suspension of freshly prepared zinc/silver–graphite in THF under argon (25 cm^3) at the temperature indicated in Tables 1–3. After the reaction was complete the mixture was allowed to cool to room temperature; it was then filtered and the graphite washed with THF (30 cm^3 as several portions). The combined filtrates were evaporated and the residue purified by flash chromatography to afford the product or product mixture as indicated in Tables 1–3.

The triacetate **23** was obtained upon reduction ($NaBH_4$) of the crude reaction mixture obtained from the iodide **14**, followed by desilylation of the resulting enitol with tetrabutylammonium fluoride trihydrate in THF (2 equiv.) for 15 min and finally acetylation (acetic anhydride, pyridine, DMAP cat.) of the resulting triol under standard conditions.

Enals and Enitols.—1,2,4-*Tri*-O-*acetyl*-3,5,6-*trideoxy*-D-threo-*hex*-5-*enitol* **23**. Oil; $[\alpha]_D^{20}$ −10.7 (*c* 0.7); δ_H 5.80 (1 H, ddd, $J_{4,5}$ 6, $J_{5,6}$ 11, $J_{5,6'}$ 17, 5-H), 5.30–5.35 (2 H, m, 2-H, 4-H), 5.23 (1 H, d, 6-H), 5.22 (1 H, d, 6'-H), 4.26 and 4.04 (2 H, dAB, J_{AB} 12, $J_{1,2}$ 3, $J_{1',2}$ 6, 1-H, 1'-H), 2.08, 2.06, 2.04 (3 H each, s, $MeCO_2$),

Table 6 Atomic coordinates ($\times 10^4$) for compound **3**

Atom	*x*	*y*	*z*
C(1)	10 613(7)	373(5)	421(3)
C(2)	8 728(6)	−585(4)	721(3)
C(3)	8 717(6)	−219(4)	1732(3)
C(4)	9 273(7)	1309(5)	1738(3)
O(5)	10 881(6)	1480(3)	1067(3)
O(6)	9 575(5)	763(4)	−492(2)
C(7)	6 978(7)	581(4)	−628(3)
C(8)	6 155(10)	−323(6)	−1478(3)
C(9)	5 695(7)	1938(5)	−707(3)
O(10)	6 489(5)	−108(4)	182(2)
O(11)	10 620(5)	−912(4)	2345(2)
C(12)	9 846(7)	−2243(5)	2568(3)
C(13)	11 802(7)	−2920(4)	3274(3)
C(14)	11 355(8)	−4248(5)	3559(3)
C(15)	13 134(9)	−4942(5)	4171(3)
C(16)	15 383(10)	−4324(6)	4519(3)
C(17)	15 812(8)	−2999(4)	4253(3)
C(18)	14 035(8)	−2294(5)	3625(3)
C(19)	10 576(7)	1873(7)	2658(3)
I(20)	8 227(1)	1734(1)	3681(1)

Table 7 Selected bond lengths (Å) in the crystal structure of compound **3**

C(1)–C(2)	1.524(6)	C(1)–O(5)	1.421(6)
C(1)–O(6)	1.401(6)	C(2)–C(3)	1.514(6)
C(2)–O(10)	1.422(5)	C(3)–C(4)	1.523(7)
C(3)–O(11)	1.424(5)	C(4)–O(5)	1.446(6)
C(4)–C(19)	1.505(7)	C(19)–I(20)	2.153(6)
O(6)–C(7)	1.431(5)	C(7)–C(8)	1.519(7)
C(7)–C(9)	1.499(7)	C(7)–O(10)	1.425(6)
O(11)–C(12)	1.424(6)	C(12)–C(13)	1.505(6)

1.91 and 1.88 (2 H, dAB, J_{AB} 10, 3-H, 3′-H); δ_C 170.79, 170.50, 170.28 (CO_2R), 136.17 (5-C), 117.32 (6-C), 70.55, 67.90, 65.40 (1-C, 2-C, 4-C), 35.63 (3-C), 21.21, 21.11 and 20.92 ($MeCO_2$).

4-O-*Acetyl*-2-O-(tert-*butyldiphenylsilyl*)-3,5,6-*trideoxy*-D-erythro-*hex*-5-*enose* **24**. Oil; $[\alpha]_D^{20}$ −12.6 (*c* 10.4); δ_H 9.59 (1 H, d, $J_{CHO,2}$ 1, CHO), 7.38–7.72 (10 H, m, Ph), 5.73 (1 H, ddd, $J_{4,5}$ 6.5, $J_{5,6}$ 17, $J_{5,6'}$ 10, 5-H), 5.44 (1 H, dt, $J_{3,4} = J_{3',4} = J_{4,5}$ 6.5, 4-H), 5.28 (1 H, d, 6-H), 5.18 (1 H, d, 6′-H), 4.17 (1 H, dt, $J_{2,3} = J_{2,3'}$ 5, 2-H), 2.07 and 1.97 (2 H, ddAB, J_{AB} 11, 3-H, 3′-H), 1.94 (3 H, s, $MeCO_2$) and 1.17 (9 H, s, Me); δ_C 202.70 (CHO), 169.89 (CO_2R), 136.53, 136.15, 133.15, 130.45, 128.19 (Ph, 5-C), 117.87 (6-C), 75.79, 71.29 (2-C, 4-C), 38.10 (3-C), 27.29 (Me), 21.28 ($MeCO_2$) and 19.62 (Me_3CSi).

2,4-*Di*-O-*benzyl*-3,5,6-*trideoxy*-D-threo-*hex*-5-*enose* **25**. Oil; $[\alpha]_D^{20}$ −67.8 (*c* 2.7); δ_H 9.67 (1 H, d, $J_{CHO,2}$ 2.5, CHO), 7.22–7.45 (10 H, m, Ph), 5.81 (1 H, ddd, $J_{4,5}$ 8, $J_{5,6}$ 10, $J_{5,6'}$ 17, 5-H), 5.34 (1 H, d, 6-H), 5.30 (1 H, d, 6′-H), 4.63 and 4.42 (2 H, AB, J_{AB} 11.5, CH_2Ph), 4.60 and 4.29 (2 H, AB, J_{AB} 11, CH_2Ph), 4.15 (1 H, ddd, $J_{2,3}$ 9.5, $J_{2,3'}$ 4, 2-H), 4.07 (1 H, dt, $J_{3,4}$ 8, $J_{3',4}$ 3, 4-H), 2.01 and 1.79 (2 H, ddAB, J_{AB} 10, 3-H, 3′-H); δ_C 202.90 (CHO), 138.57 (5-C), 138.50, 137.70, 135.05, 128.58, 128.44, 128.35, 128.19, 127.93, 127.83, 127.70 (Ph), 117.87 (6-C), 80.91, 76.23, 73.03, 70.54 (2-C, 4-C, -CH_2Ph) and 36.83 (3-C).

2,4-*Di*-O-*acetyl*-5,6-*dideoxy*-3-O-(tert-*butyldiphenylsilyl*)-D-xylo-*hex*-5-*enose* **26**. Oil; $[\alpha]_D^{20}$ −10.2 (*c* 8); δ_H 9.55 (s, CHO), 7.37–7.70 (10 H, m, Ph), 5.79 (1 H, dd, $J_{4,5}$ 6, $J_{3,4}$ 3, 4-H), 5.69 (1 H, ddd, $J_{5,6}$ 16, $J_{5,6'}$ 10, 5-H), 5.25 (2 H, d, 6-H, 6′-H), 5.16 (1 H, dd, $J_{2,3}$ 6, 3-H), 4.26 (1 H, d, 2-H), 2.06 (6 H, s, $MeCO_2$) and 1.15 (9 H, s, Me); δ_C 198.85 (CHO), 169.83, 169.31 (CO_2R), 136.08, 135.95, 132.75, 132.56, 132.13, 129.23, 128.16 (Ph, 5-C), 119.29 (6-C), 75.58, 74.39, 71.35 (2-C, 3-C, 4-C), 27.10 (Me), 20.96, 20.76 ($MeCO_2$) and 19.62 (Me_3CSi-).

4-O-*Acetyl*-2-O-(tert-*butyldimethylsilyl*)-3,5,6-*trideoxy*-D-threo-*hex*-5-*enose* **27**. Oil; $[\alpha]_D^{20}$ −25.1 (*c* 1.25); δ_H 9.62 (1 H, d, $J_{CHO,2}$ 1.4, CHO), 5.80 (1 H, ddd, $J_{4,5}$ 6.6, $J_{5,6}$ 10.2, $J_{5,6'}$ 17.5, 5-H), 5.37 (1 H, ddd, $J_{3,4}$ 4.0, $J_{3',4}$ 3.7, 4-H), 5.22 (1 H, d, 6′-H), 5.20 (1 H, d, 6-H), 4.10 (1 H, ddd, $J_{2,3}$ 5.7, $J_{2,3'}$ 8.8, 2-H), 2.07 (3 H, s, $MeCO_2$), 2.00 and 1.85 (2 H, ddAB, $J_{3,3'}$ 10, 3-H, 3′-H), 0.94 (9 H, s, Me_3C) and 0.08 and 0.07 (3 H each, s, MeSi); δ_C 203.47 (CHO), 170.11 (CO_2R), 136.47 (5-C), 117.45 (6-C), 74.80, 71.05 (4-C, 2-C), 37.64 (3-C), 25.96 (Me_3C), 21.65 ($MeCO_2$), 18.33 (Me_3C) and −4.31 and −4.93 (MeSi).

Deoxysugar Derivatives.—*Methyl* 3,4-*di*-O-*acetyl*-2-*azido*-2,6-*dideoxy*-α-D-*altropyranoside* **43**. Oil; $[\alpha]_D^{20}$ +55.7 (*c* 6.6) ν_{max}/cm^{-1} 2115 (N_3), 1750 and 1745; δ_H 4.95–5.04 (2 H, m, 3-H, 4-H), 4.48 (1 H, d, $J_{1,2}$ 5.3, 1-H), 4.10 (1 H, dq, $J_{4,5}$ 5, $J_{5,6}$ 6.8, 5-H), 3.69 (1 H, dd, $J_{2,3}$ 8.2, 2-H), 3.40 (3 H, s, OMe), 2.02, 2.00 (3 H, s each, CH_3CO_2R) and 1.21 (3 H, d, 6-H); δ_C 169.90 (2 × CO_2R), 99.21 (1-C), 70.31, 68.44, 67.77 (3-C, 4-C, 5-C), 60.93 (2-C), 56.19 (OMe), 20.73, 20.67 (CH_3CO_2) and 16.64 (6-C).

Methyl 2,4-*di*-O-*acetyl*-3-*azido*-3,6-*dideoxy*-α-D-*altropyranoside* **44**. Oil, $[\alpha]_D^{20}$ +83.5 (*c* 0.6); ν_{max}/cm^{-1} 2120 (N_3), 1755 and 1750; δ_H 4.93–5.00 (2 H, m, 2-H, 4-H), 4.55 (1 H, s, 1-H), 4.17 (1 H, dq, $J_{4,5}$ 9, $J_{5,6}$ 5.6, 5-H), 4.02 (1 H, dd, $J_{2,3} = J_{3,4}$ 3.5, 3-H),3.42 (3 H, s, OMe), 2.16 and 2.15 (3 H each, s, CH_3CO_2) and 1.25 (3-H, d, 6-H); δ_C 170.18, 169.63 (CO_2R), 98.74 (1-C), 71.96, 70.60. (2-C, 4-C), 62.74 (5-C), 58.57 (3-C), 55.95 (OMe), 21.11, 20.85 (CH_3CO_2) and 17.42 (6-C).

Methyl 4-*azido*-4,6-*dideoxy*-2,3-*di*-O-*methyl*-α-D-*galactopyranoside* **45**. Colourless crystals, m.p. 78–91 °C; $[\alpha]_D^{20}$ +115.9 (*c* 4.4); ν_{max}/cm^{-1} 2116 (N_3); δ_H 4.74 (1 H, d, $J_{1,2}$ 3.4, 1-H), 3.88 (1 H, dq, $J_{4,5}$ 1, $J_{5,6}$ 6.5, 5-H), 3.79 (1 H, dd, $J_{3,4}$ 3.5, 4-H), 3.65 and 3.50 (2 H, dAB, $J_{2,3}$ 9.7, 2-H, 3-H), 3.47 (6 H, s, 2 × OMe), 3.33 (3 H, s, OMe) and 1.22 (3 H, d, 6-H); δ_C 98.03 (1-C), 80.07, 77.74 (2-C, 3-C), 64.48 (5-C), 63.75 (4-C), 59.17, 58.24, 55.43 (OMe) and 17.43 (6-C).

Methyl 6-*azido*-4,6-*dideoxy*-2,3-*di*-O-*methyl*-α-D-*xylohexopyranoside* **46**. Oil, $[\alpha]_D^{20}$ +129.1 (*c* 6.0); ν_{max}/cm^{-1} 2120 (N_3); δ_H 4.81 (1 H, d, $J_{1,2}$ 3.6, 1-H), 3.85 (1 H, m, 5-H), 3.52 (1 H, ddd, $J_{2,3}$ 9.5, $J_{3,4}$ 12, $J_{3,4'}$ 5, 3-H), 3.43, 3.36, 3.35 (3 H each, s, OMe), 3.22 and 3.15 (2 H, dAB, $J_{5,6}$ 6.9, $J_{5,6'}$ 3.6, 6-H, 6′-H), 3.10 (1 H, dd, 2-H), 1.97 (1 H, ddd, $J_{4,4'}$ 12, $J_{4',5}$ 2.2, 4′-H) and 1.26 (1 H, dt, $J_{4,5}$ 12, 4-H); δ_C 98.22 (1-C), 82.18, 76.27 (2-C, 3-C), 67.01 (5-C), 58.70, 57.53, 55.27 (OMe), 54.56 (6-C) and 33.60 (4-C).

Methyl 6-*deoxy*-2,3,4-*tri*-O-*methyl*-α-D-*glucopyranoside* **50**. Oil,[28] $[\alpha]_D^{20}$ +151.0 (*c* 1.4) (lit.,[28] $[\alpha]_D^{23}$ +151.1 (*c* 1.8, $CHCl_3$)); δ_H 4.73 (1 H, d, $J_{1,2}$ 3.6, 1-H), 3.62, 3.56, 3.51, 3.39 (3 H each, s, OMe), 3.58 (1 H, dq, $J_{4,5}$ 9.5, $J_{5,6}$ 6, 5-H), 3.46 (1 H, t, $J_{2,3} = J_{3,4}$ 9.5, 3-H), 3.18 (1 H, dd, 2-H), 2.74 (1 H, t, 4-H) and 1.26 (3 H, d, 6-H); δ_C 97.53 (1-C), 86.07, 83.51, 82.38 (2-C, 3-C, 4-C), 66.60 (5-C), 60.84, 60.68, 58.96, 55.08 (OMe) and 17.88 (6-C).

2,3,4,6-*Tetra*-O-*acetyl*-1,5-*anhydro*-D-*galactitol* **53** (R = H) was identical with an authentic sample prepared according to ref. 15.

Labelling Experiment: Preparation of 2,3,4,6-*Tetra*-O-*acetyl*-1,5-*anhydro*-1-*deuterio*-α-D-*galactitol* **54**.—To a suspension of C_8K (420 mg, 3.1 mmol)[4] in [$^2H_8$]-THF (3 cm^3) was added a

Table 8 Selected bond angles (°)

C(2)–C(1)–O(5)	105.9(4)	C(2)–C(1)–O(6)	104.5(3)
O(5)–C(1)–O(6)	113.2(4)	C(1)–C(2)–C(3)	104.8(3)
C(1)–C(2)–O(10)	102.7(3)	C(3)–C(2)–O(10)	107.5(3)
C(2)–C(3)–C(4)	101.5(3)	C(3)–C(4)–O(5)	105.0(4)
C(4)–C(3)–O(11)	109.6(3)	O(5)–C(4)–C(19)	107.5(4)
C(3)–C(4)–C(19)	115.3(4)	C(1)–O(5)–C(4)	110.7(3)
C(3)–C(4)–I(20)	93.8(3)	C(2)–O(10)–C(7)	109.3(3)
C(19)–C(4)–I(20)	42.3(2)	O(11)–C(12)–C(13)	110.2(3)
C(1)–O(6)–C(7)	109.2(3)	O(6)–C(7)–O(10)	106.4(3)
C(3)–O(11)–C(12)	110.8(3)	C(4)–C(19)–I(20)	109.7(3)

mixture of $ZnCl_2$ (200 mg, 1.47 mmol) and AgOAc (10 mg, 0.12 mmol under argon. After the suspension has been heated for 20 min at reflux, a solution of compounds **51** (411 mg, 1 mmol) and **48** (285 mg, 1 mmol) in [$^2H_8$]-THF (0.3 cm^3) was added *via* syringe and the mixture was stirred at 40 °C for a further 2 h; after this time TLC showed complete conversion of the glycosyl halide. For work-up the inorganic solids were filtered off and washed with THF (10 cm^3 as three portions) and the combined filtrates were evaporated. The residue was purified by flash chromatography using toluene–ethyl acetate (10:1) as eluent. For the product distribution obtained see Table 3. Analytical data of the title compound **54** (R = D): oil; $[\alpha]_D^{20}$ +43.5 (*c* 0.9); δ_H 5.30 (1 H, d, $J_{3,4}$ 3.3, 4-H), 5.06 and 4.93 (2 H, dAB, $J_{2,3}$ 10.2, $J_{1,2}$ 5.0), 4.02 (1 H, d, 1-H), 3.95 (2 H, d, $J_{5,6} = J_{5,6'}$ 6.5, 6-H, 6'-H), 3.72 (1 H, dd, 5-H), 2.01, 1.91, 1.90, 1.86 (3 H each, s, $MeCO_2$); δ_C 170.14, 169.98, 169.82, 169.68 ($MeCO_2$), 74.71, 71.38, 67.72, 66.29 (2-C, 3-C, 4-C, 5-C), 66.50 ($J_{1\text{-}C,D}$ 21, 1-C), 61.84 (6-C) and 20.52 and 20.42 ($MeCO_2$).

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References

1 (*a*) S. Hanessian, *Total Synthesis of Natural Products: The Chiron Approach*, Pergamon, Oxford, 1983; (*b*) T. D. Inch, *Tetrahedron*, 1984, **40**, 3161; (*c*) A. Vasella, in *Modern Synthetic Methods*, ed. R. Scheffold, Sauerländer-Salle, Frankfurt, 1980, p. 173.
2 For a detailed discussion of this aspect see: F. W. Lichtenthaler, in *New Aspects of Organic Chemistry*, eds. Z. Yoshida, T. Shiba, Y. Ohshiro, Verlag Chemie, Weinheim, 1990, p. 351.
3 Originally described by: (*a*) B. Bernet and A. Vasella, *Helv. Chim. Acta*, 1979, **62**, 1990. For applications and modified procedures see *inter alia*: (*b*) R. J. Ferrier, R. H. Furneaux, P. Prasit, P. C. Tyler, K. L. Brown, G. J. Gainsford and J. W. Diehl, *J. Chem. Soc., Perkin Trans. 1*, 1983, 1621; (*c*) R. J. Ferrier and P. Prasit, *J. Chem. Soc., Perkin Trans. 1*, 1983, 1645; (*d*) R. J. Ferrier, P. Schmidt and P. C. Tyler, *J. Chem. Soc., Perkin Trans. 1*, 1985, 301; (*e*) B. Häfele, D. Schröter and V. Jäger, *Angew. Chem.*, 1986, **98**, 89; (*f*) S. Hanessian, A. Ugolini and M. Therien, *J. Org. Chem.*, 1983, **48**, 4427; (*g*) J. M. Beau, S. Abouraki, J. Pougny and P. Sinay, *J. Am. Chem. Soc.*, 1983, **105**, 621; (*h*) A. Villalobos and S. J. Danishefsky, *J. Org. Chem.*, 1989, **54**, 12; (*i*) R. Bernotas and B. Ganem, *Tetrahedron Lett.*, 1985, 1123; (*j*) J. C. Florent, J. Ughetto-Monfrin and C. Monneret, *J. Org. Chem.*, 1987, **52**, 1051; (*k*) B. Deguin, J. C. Florent and C. Monneret, *J. Org. Chem.*, 1991, **56**, 405; (*l*) L. J. Liotta, J. Lee and B. Ganem, *Tetrahedron*, 1991, **47**, 2433; (*m*) A. F. Sviridov, V. S. Borodkin, M. S. Ermolenko, D. V. Yashunsky and N. K. Kochetkov, *Tetrahedron*, 1991, **47**, 2291; (*n*) S. W. Baldwin and S. C. Gedon, *Synth. Commun.*, 1991, **21**, 587; (*o*) M. Nakata, S. Akazawa, S. Kitamura and K. Tatsuta, *Tetrahedron Lett.*, 1991, 5363; (*p*) N. P. Peet, E. W. Huber and R. A. Farr, *Tetrahedron*, 1991, **47**, 7537; (*q*) J. Pen, I. Hanna, J. Y. Lallamand, *Tetrahedron Lett.*, 1991, 7543; (*r*) J. K. Dickson and B. Fraser-Reid, *J. Chem. Soc., Chem. Commun.*, 1990, 1440; (*s*) M. Nakane, R. C. Hutchinson and H. Gollman, *Tetrahedron Lett.*, 1980, 1213.
4 (*a*) A. Fürstner and H. Weidmann, *J. Org. Chem.*, 1989, **54**, 2307; (*b*) A. Fürstner and H. Weidmann, *J. Org. Chem.*, 1990, **55**, 1363; (*c*) A. Fürstner, D. Jumbam, J. Teslic and H. Weidmann, *J. Org. Chem.*, 1991, **56**, 2213; (*d*) A. Fürstner, U. Koglbauer and H. Weidmann, *J. Carbohydr. Chem.*, 1990, **9**, 561; (*e*) A. Fürstner, *Tetrahedron Lett.*, 1990, 3735.
5 (*a*) R. E. Ireland, P. Wipf, M. Miltz and B. Vanasse, *J. Org. Chem.*, 1990, **55**, 1423; (*b*) R. E. Ireland, T. K. Highsmith, L. D. Gefnes and J. L. Gleason, *J. Org. Chem.*, 1992, **57**, 5071.
6 For the elucidation of the structure of the reagent see: A. Fürstner, H. Weidmann and F. Hofer, *J. Chem. Soc., Dalton Trans.*, 1988, 2023.
7 (*a*) M. Ek, P. J. Garegg, H. Hultberg and S. Oscarson, *J. Carbohydr. Chem.*, 1983, **2**, 305; (*b*) S. Danishefsky, M. P. DeNinno, G. B. Phillips, R. E. Zelle and P. A. Lartey, *Tetrahedron*, 1986, **42**, 2809.
8 P. J. Garegg and B. Samuelsson, *J. Chem. Soc., Perkin Trans. 1*, 1980, 2866.
9 H. Redlich and W. Roy, *Liebigs Ann. Chem.*, 1981, 1215, 1223.
10 (*a*) Compound **30** (R^2 = OH): Y. Ali and A. C. Richardson, *Carbohydr. Res.*, 1967, **5**, 441; (*b*) compound **34** (R^1 = OH): T. Izawa, Y. Nishimura and S. Kondo, *Carbohydr. Res.*, 1991, **211**, 137; (*c*) compound **37**: D. A. N. Griffith and L. Weiler, *Tetrahedron*, 1991, **47**, 2733.
11 For a review on carbohydrate derived triflates see: R. W. Binkley and M. G. Ambrose, *J. Carbohydr. Chem.*, 1984, **3**, 1.
12 S. H. Chen and S. J. Danishefsky, *Tetrahedron Lett.*, 1990, 2229.
13 R. Csuk, A. Fürstner, B. I. Glänzer and H. Weidmann, *J. Chem. Soc., Chem. Commun.*, 1986, 1149.
14 W. A. Szarek and J. K. N. Jones, *Can. J. Chem.*, 1965, **43**, 2345.
15 P. Kocienski and C. Pant, *Carbohydr. Res.*, 1982, **110**, 330.
16 For a review see: P. Kocienski, in *Comprehensive Organic Syntheses*, eds. B. M. Trost, I. Fleming, Pergamon Press, Oxford, 1991, vol. 6, p. 975.
17 L. Crombie and L. J. Rainbow, *Tetrahedron Lett.*, 1988, 6517.
18 For a discussion based on observations with sugar ortholactones see: B. Bernet and A. Vasella, *Helv. Chim. Acta*, 1984, **67**, 1328.
19 For a comprehensive review on the chemistry of azides see: E. F. V. Scriven and K. Turnball, *Chem. Rev.*, 1988, **88**, 351.
20 (*a*) D. N. Kirk and M. A. Wilson, *J. Chem. Soc., Chem. Commun.*, 1970, 64; (*b*) D. N. Kirk and M. A. Wilson, *J. Chem. Soc.*, 1971, 414.
21 H. Ohrui and S. Emoto, *Carbohydr. Res.*, 1969, **10**, 221.
22 For review see: B. Giese, *Radicals in Organic Synthesis: Formation of Carbon–Carbon Bonds*, Pergamon Press, Oxford, 1986 and lit. cited.
23 (*a*) B. Giese and J. Dupuis, *Tetrahedron Lett.*, 1984, 1349; (*b*) J. P. Praly, *Tetrahedron Lett.*, 1983, 3075.
24 S. Jarosz and B. Fraser-Reid, *J. Org. Chem.*, 1989, **54**, 4011.
25 A. G. M. Barrett and L. M. Melcher, *J. Am. Chem. Soc.*, 1991, **113**, 8177.
26 C. E. Tucker, T. N. Majid and P. Knochel, *J. Am. Chem. Soc.*, 1992, **114**, 3983.
27 (*a*) G. M. Sheldrick, SHELX-86, Program for Crystal Structure Solution, University of Göttingen, FRG, 1986; (*b*) G. M. Sheldrick SHELX-76 Program for Crystal Structure Determination, University of Cambridge, 1976; (*c*) DIFABS: N. Walker, D. Stuart, *Acta Cryst., Sect. A*, 1983, **39**, 158; (*d*) SHELXTL PC Version 4.1, Siemens Analytical Instruments Inc., 1990.
28 (*a*) D. Trimmel, W. M. Doane and C. R. Russel, *Carbohydr. Res.*, 1972, **22**, 351; (*b*) J. Haverkamp, M. J. A. DeBie and J. F. G. Vliegenthart, *Carbohydr. Res.*, 1975, **39**, 201.

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