149. Fragmentation of 6-Deoxy-6-halo-hexono-1,5-ortholactones: A Concerted, Nonstereospecific Process

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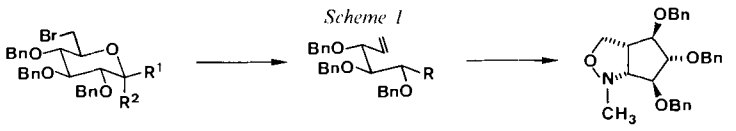
Summary

The synthesis of the D-*arabino*- and D-*ribo*-ortholactones **13a–f** and **15b–f** and their treatment with Zn leading to the unsaturated esters **14a–d** and **16a–d** are described. Possible fragmentation mechanisms are discussed. The results were only compatible with a concerted, nonsynchronous process, where both the axial lone pair of the ring oxygen atom and the lone pair formed during rupture of the C(5),O-bond participate in the elimination of the axial and of the equatorial C(1)-alkoxy groups, respectively.

Introduction. – We have described a synthesis of cyclopentane derivatives from monosaccharides [1–4] (see also [5–11]). The crucial steps in this synthesis are the reductive fragmentation of 6-bromo-6-deoxy-glycosides leading to unsaturated aldehydes and the intramolecular cycloaddition of the corresponding nitrones. This sequence is illustrated in *Scheme 1* by the transformation of the anomeric glucosides **1** and **2** into the cyclopentane **5**.

The reductive fragmentation was effected with activated Zn in boiling aqueous alcohols or by treatment of the halogen compound with BuLi[1]). In parallel experiments, both the α- and β-D-anomers, respectively, of a given pyranoside afforded the same products in essentially the same yields and with the same rates, provided that the reaction mixture was freed from excess Zn and treated with weakly basic ion-exchange resin and charcoal before evaporation of the solvent. Without this treatment, the aldehyde obtained from the α-D-pyranoside, but not the one obtained from the β-D-pyranoside, was contaminated with 20–30% of the corresponding acetal, such as **4**. This indicates that two mechanisms of fragmentation are operating for the two anomers,

Scheme 1



1 $R^1 = OCH_3$, $R^2 = H$

2 $R^1 = H$, $R^2 = OCH_3$

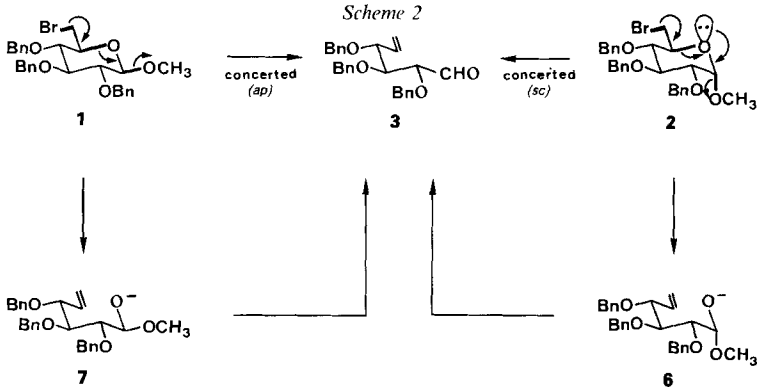
3 R = CHO

4 $R = CH(OR^1)_2$

5

[1]) In addition to the expected aldehyde we always found the secondary alcohols derived from the addition of BuLi to the aldehyde.

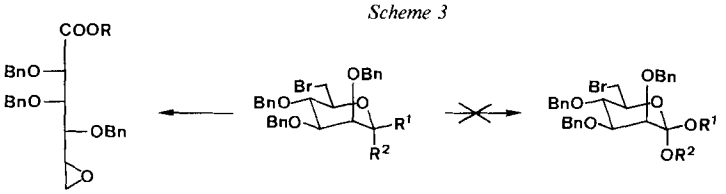
Scheme 2



respectively. This appears to be in keeping with the rules derived by *Grob* for the concerted fragmentation of compounds Ā-B-C-D-E, where B, C, and D are C-atoms, E denotes a leaving group, and Ā a group possessing a lone pair of electrons [12] [13]. According to these rules, only the β-D-anomers *(Scheme 2)* should fragment in a concerted way since all the bonds to be broken are antiperiplanar to each other ('concerted *ap*-fragmentation')[2]. The α-D-anomers where the C(5),O- and the axial C(1),O-bond are in a synclinal arrangement lead to the unsaturated aldehydes *via* the corresponding hemiacetals. However, on one hand it is conceivable that both anomers react *via* the formation of a hemiacetal intermediate, such as **6** and **7**. On the other hand, also the α-D-anomer may *a priori* fragment in a concerted way, if the axial lone pair of the ring O-atom participates in the elimination of the axial C(1)-alkoxy group before the C(5),O-bond is broken ('concerted *sc*-fragmentation').

We wished to examine the possibility of such a participation of a lone pair orthogonal to the bonds broken in a 'concerted *ap*-fragmentation'. For this purpose, we examined the fragmentation of mixed ortholactones, yielding unsaturated esters in different proportions according to the mechanism of fragmentation.

Scheme 3



12a R = CH_3
12b R = CH_2CH_3

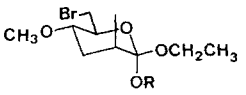
8 $R^1 = OCH_3$, $R^2 = H$
9 $R^1 = H$, $R^2 = OH$
10 $R^1, R^2 = O$

11a $R^1 = CH_3$, $R^2 = CH_2CH_3$
11b $R^1 = CH_2CH_3$, $R^2 = CH_3$
11c $R^1, R^2 = CH_3$
11d $R^1, R^2 = CH_2CH_3$

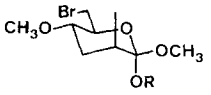
[2]) We assume that the reaction is initiated by a single electron transfer, followed by the expulsion of bromide ion from the intermediate radical anion, a second single electron transfer, and a heterolytic fragmentation. These processes occur most certainly on the surface of the bulk metal, involving (one or more) zinc-organic species, by an analogy with the formation of *Grignard* reagents [14a]. Our interpretation is based on the assumption, that the neutral radicals do not fragment. This is evidenced by the failure of allyl ethers to form allylbenzene upon reaction with phenyl radicals, in contrast to the reaction of allyl thioethers [14b].

Preliminary experiments were accomplished in the mannose series. Hydrolysis of **8** afforded the hemiacetal **9** which was oxidized to the lactone **10**. All experiments for the preparation of the ortholactones **11** by reaction of **10** with Me_3OBF_4 or Et_3OBF_4 and subsequent treatment of the reaction mixture with the appropriate alcohol [15] failed. At temperatures above 40°C, **10** decomposed in the presence of the *Meerwein* salt. At room temperature, the only products were the epoxides **12** obtained by base-catalyzed alcoholysis of **10** [16]. The large number of σ-acceptor substituents in **10** may cause the weak nucleophilicity of the carbonyl group. In fact, under analogous conditions, 6-(1-bromomethyl)tetrahydro-2*H*-pyran-2-one gave the expected ethyl methyl ortholactone [17].

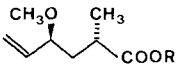
A substituent at C(2) of the ortholactone is important in the analysis of a two-step fragmentation (see below). An equatorial RO-group at C(4) stabilizes the $^4C_1$-conformation of the ortholactone. In addition, it may be advantageous as a potential ligand in a presumed zinc-organic intermediate. Therefore, we chose the D-*arabino*- and D-*ribo*-ortholactones[3]) **13** and **15** as suitable models for the study of the fragmentation leading to the products **14** and **16**, respectively.



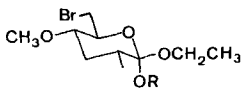
13a R = CH_2CH_3
13b R = CH_3
13c R = CH_2CD_3



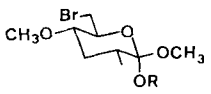
13d R = CH_2CH_3
13e R = CH_3
13f R = CD_3



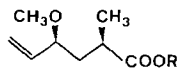
14a R = CH_2CH_3
14b R = CH_3
14c R = CH_2CD_3
14d R = CD_3
14e R = H



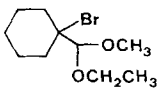
15a R = CH_2CH_3
15b R = CH_3
15c R = CH_2CD_3



15d R = CH_2CH_3
15e R = CH_3
15f R = CD_3



16a R = CH_2CH_3
16b R = CH_3
16c R = CH_2CD_3
16d R = CD_3



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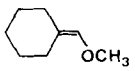

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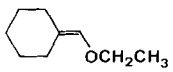

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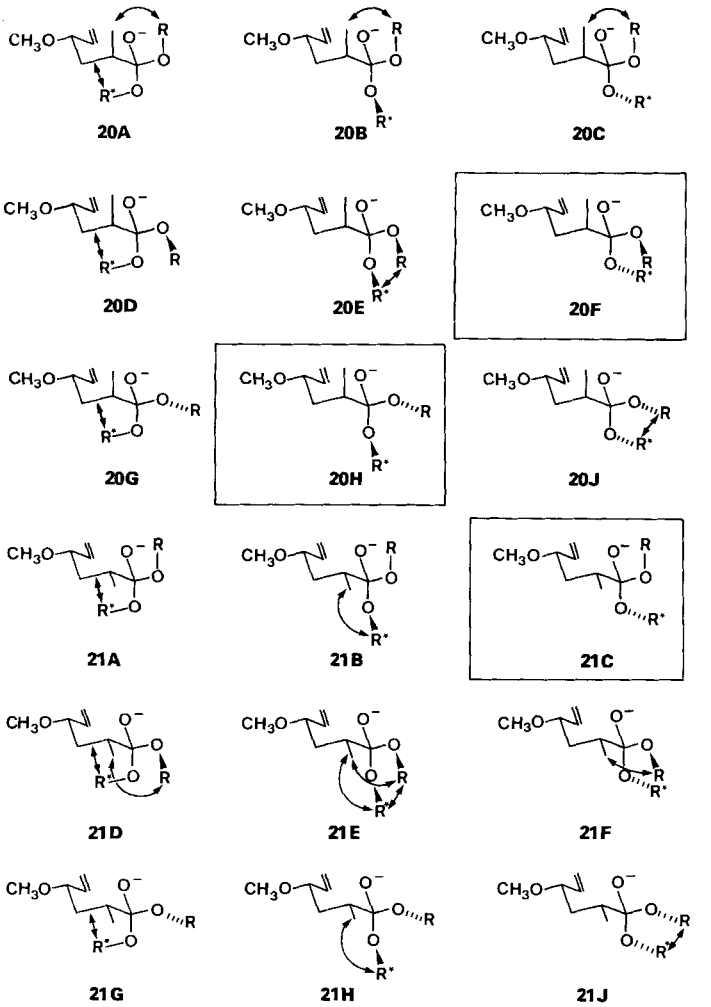
Mechanisms of Fragmentation of 13 and 15 and expected products. – In this section, we deduce the ratio of elimination of the axial *vs.* the equatorial C(1)-alkoxy group according to the different reaction mechanisms operating. The following mechanisms of the fragmentation of **13** and **15** were considered. *A*) Exclusively 'concerted *ap*-fragmentation' (according to *Grob*). *B*) Exclusively 'concerted *sc*-fragmentation' (with a participation of the axial lone pair of the ring O-atom). *C*) Intermediate formation of a conformationally stable hemiorthoester (the expulsion of an alkoxy group being faster

[3]) In this paper, the configurational prefixes are given according to the Anglo-American usage, *i.e.* D-*arabino* and D-*ribo* correspond to D-*erythro*-L-*glycero* and D-*erythro*-D-*glycero*, respectively.

than conformational isomerizations). *D*) Intermediate formation of a conformationally labile hemiorthoester (conformational isomerizations being faster than the expulsion of an alkoxy group). *E*) Pairwise competition of the processes *A*–*D*.

In a fragmentation according to *A* only the equatorial and according to *B* only the axial C(1)-alkoxy group of **13** and **15** is lost[4]). A fragmentation according to *C* or *D* leads to hemiorthoesters which are cleaved to the unsaturated esters according to the rules of *Deslongchamps* [18–20]. The activation energy for the cleavage of hemiorthoester anions but not for neutral hemiorthoesters[5]) may be smaller than the one for conformational isomerizations [21], hence the mechanisms *C* and *D* must be distinguished.

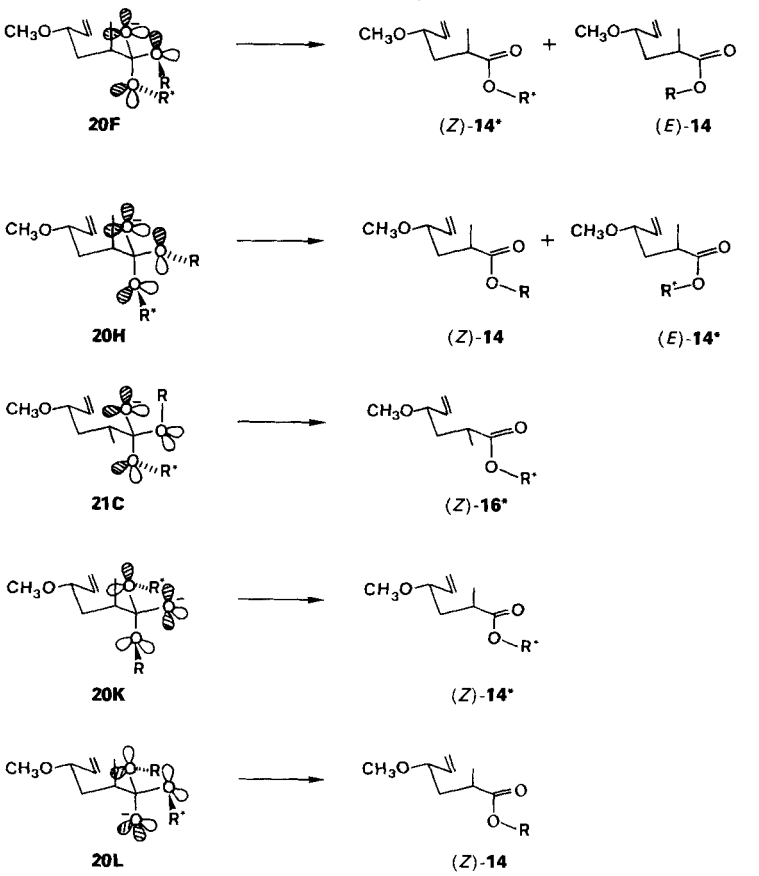


[4]) Assuming that only the $^4C_1$-conformation of the ortholactones participates in the reaction.

[5]) In our case, alkoxyzinc compounds would be likely intermediates.

Of the 9 synclinal conformations of the hemiorthoester **20** which may be formed from the D-*arabino*-ortholactones **13** [20], only the conformers **20F** and **20H** are exempt of a 1,3-diaxial-type interaction of an alkoxy group of the hemiorthoester function with another substituent. Of the 9 synclinal conformations of hemiorthoester **21** which may be formed from the D-*ribo*-ortholactones **15**, only the conformer **21C** is free from such a 1,3-diaxial-type interaction. These 3 conformers are the important ones in the fragmentation of **13** and **15** according to mechanism *C*. Since the steric interaction of the orthoester function with C(3) and the C(2)-methyl group are the same in the starting material **13** and in the intermediate **20**, the conformers **20F** and **20H** should be obtained in equal amounts. *Deslongchamps* has found that the cleavage of hemiorthoesters leading to (*Z*)-esters is favoured over the one leading to (*E*)-esters by secondary electronic effects [20]. If the cleavage affords (*Z*)-esters only[6]), **20F** loses RO^- to yield (*Z*)-**14*** and **20H** loses R^*O^- to yield (*Z*)-**14** *(Scheme 4)*. In this case, a fragmen-

Scheme 4[a])



[a]) The products containing the R*O-group are marked by a star in their numbering.

[6]) Such cleavages are known, see [20].

tation of **13** according to mechanism *C* leads to the esters **14** and **14*** in equal amounts. If (*E*)-esters are also formed, the difference of the leaving group properties of RO^- and R^*O^- will lead to unequal proportions of (*Z*)-**14***/(*E*)-**14** (from **20F**) and of (*Z*)-**14**/(*E*)-**14*** (from **20H**). This effect on the proportions of **14** (*E* and *Z*) to **14*** (*E* and *Z*)[7]) remains weak as long as the (*Z*)-esters are formed in large excess, or as long as RO^- and R^*O^- do not differ strongly.

The D-*ribo*-conformer **21C** loses RO^- to afford (*Z*)-**16***, *i.e.* in a fragmentation of **15** according to mechanism *C*, only the equatorial alkoxy group is lost.

In a fragmentation according to mechanism *D*, all 27 synclinal conformers of the hemiorthoesters **20** or **21** arising from the rotation around the C(1),C(2)- and C(1),O-bonds must be considered. In addition to **20F** and **20H**, there are the 2 conformers **20K** and **20L**, without a 1,3-diaxial-type interaction, obtained by the rotation around the

Table 1. *Expected Loss of the Equatorial Alkoxy Group Assuming a Single Fragmentation Mechanism, Resp. Pairs Thereof*

Mechanism	Ortholactone	Expected loss of the equatorial alkoxy group [%]
A	**13a–f, 15a–f**	100
B	**13a–f, 15a–f**	0
C	**13a–f**	50
	15a–f	100
D[a])	**13a, 13c, 13e, 13f**	50
	15a, 15c, 15e, 15f	50
	13b, 15b	20
	13d, 15d	80
A and *B*	**13a–f, 15a–f**	100– 0
A and *C*	**13a–f**	100– 50
	15a–f	100
A and *D*[a])	**13a, 13c, 13e, 13f**	100– 50
	15a, 15c, 15e, 15f	100– 50
	13b, 15b	100– 20
	13d, 15d	100– 80
B and *C*	**13a–f**	0– 50
	15a–f	0–100
B and *D*[a])	**13a, 13c, 13e, 13f**	0– 50
	15a, 15c, 15e, 15f	0– 50
	13b, 15b	0– 20
	13d, 15d	0– 80
C and *D*[a])	**13a, 13c, 13e, 13f**	50
	15a, 15c, 15e, 15f	100– 50
	13b	50– 20
	13d	50– 80
	15b	100– 20
	15d	100– 80

[a]) Assuming the same leaving-group properties for CH_3O^- and CD_3O^- and for $CH_3CH_2O^-$ and $CD_3CH_2O^-$, respectively, and considering that CH_3O^- is a better leaving group than $CH_3CH_2O^-$ by a factor of 4.

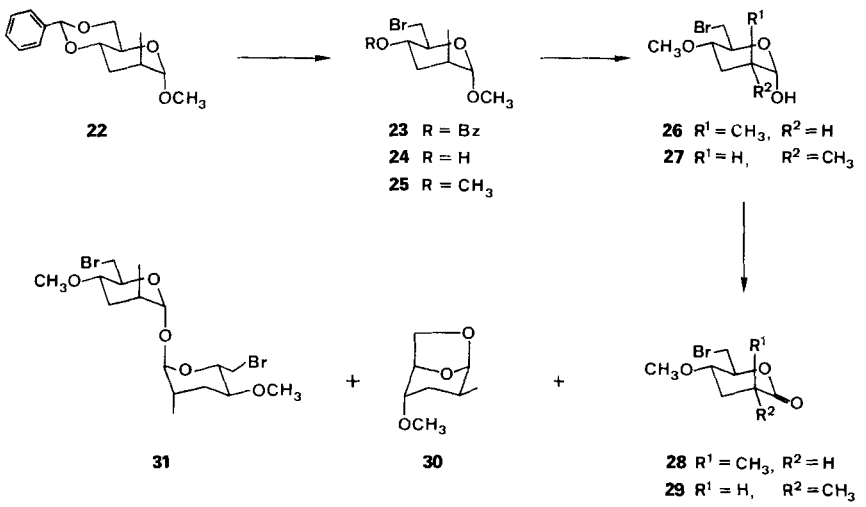
[7]) These proportions only can be experimentally determined.

C(1),C(2)-bond. These two conformers can only lose one alkoxy group: **20K** loses RO^- yielding (*Z*)-**14***, and **20L** loses R^*O^- yielding (*Z*)-**14**. A similar set of 4 favoured conformers with an analogous reaction pattern is deduced from the hemiorthoester **21**. Since the leaving-group properties of the two C(1)-alkoxy groups in **13c**, **13f**, **15c** and **15f** are very similar to each other (deuteriated *vs.* nondeuteriated substituents), the equatorial and the axial alkoxy groups are lost in equal amounts. The assumption that methoxide is a better leaving group than ethoxide was checked by treating the mixed bromoacetal **17** under the conditions of the reductive fragmentation (NaI/Zn in butanone/THF). The enol ethers **18** [22] [23] and **19** [22] were formed in a ratio of *ca.* 1:4. Similar product ratios are expected in the fragmentation of **13b**, **13d**, **15b** and **15d** according to the mechanism *D*.

The results of these considerations are summarized in *Table 1*, which also indicates the expected loss of the equatorial alkoxy group in the case that two of the above mentioned mechanisms compete in the fragmentation of the ortholactones. The extent of this loss is limited by the exclusive validity of one of the two mechanisms.

Synthesis and Fragmentation of the Ortholactones. – Treatment of the benzaldehyde acetal **22** [24] [25] (*Scheme 5*) with *N*-bromosuccinimide [26] gave the bromoben-

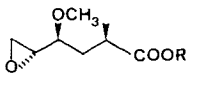
Scheme 5



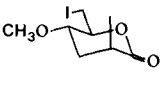
zoate **23** which was debenzoylated (→**24**) and methylated to **25**. The crude product of hydrolysis (aq. CF_3COOH) of **25** was oxidized with pyridinium chlorochromate in the presence of 3 Å molecular sieves [27]. Chromatography of the products afforded the glycosan **30** (8%), the dimeric anhydride **31** (3%), and a mixture of the D-*arabino*- and D-*ribo*-lactones **28** and **29** which upon crystallization gave pure **28** (62%). The mother liquor, a 6:4 mixture of **29** and **28**, could not be separated.

For the preparation of the D-*arabino*-ortholactones **13a–c**, the lactone **28** was first allowed to react with a large excess of recrystallized Et_3OBF_4 in CH_2Cl_2. The mixture was then poured into a cold solution of the desired sodium alkoxide in the correspond-

ing alcohol containing CH_2Cl_2[8]). The incomplete reaction of **28** with a smaller excess of suspended Me_3OBF_4[9]) in CH_2Cl_2 caused partial epimerization at C(2). After treatment of the reaction mixture with sodium alkoxide (as above), the corresponding D-*arabino*- and D-*ribo*-ortholactones **13d–f** and **15d–f** and the corresponding D-*ribo*-epoxide **32a–c**[10]) were separated by column chromatography. Ortholactones **15b** and **15c** were prepared from the 4:6 mixture of **28** and **29** and separated by column chromatography. (For experimental details and the yields of ortholactones see *Exper. Part, Table 3.*)



32a R = CH_2CH_3
32b R = CH_3
32c R = CD_3



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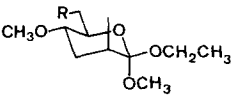
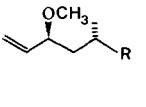


34 R = $(CH_2)_3CH_3$
35 R = I
36 R = OCH_3



37 R = CHO
38 R = $CHOH(CH_2)_3CH_3$

The mixed ortholactones **13a–f** and **15b–f** were pure according to TLC, ^{1}H- and ^{13}C-NMR spectroscopy. According to the prominent *retro-Diels-Alder* fragments $CH_3CH{=}C(OR^1)(OR^2)$ in the MS of the ortholactones[11]), all mixed ortholactones contain at most 3–5% of the corresponding 'symmetrical' dialkoxy ortholactones. The preferred axial attack of the alkoxy group during the preparation of the ortholactones determines the configuration of the anomeric centre. The configurations were confirmed by ^{1}H- and ^{13}C-NMR spectroscopy. On account of the anomeric effect, the signals of an axial alkoxy group are shifted upfield compared with the signals of the same group in the equatorial position (see *Exper. Part*).

BuLi or activated Zn in aqueous alcohols have been used in the fragmentation of the bromopyranosides [1–4]. BuLi was not suitable for the fragmentation of bromo-ortholactones[12]). Since the activated Zn powder [1] [4] always contains traces of acid, it is not appropriate for the examination of the fragmentation of ortholactones. Acid-free, active Zn powder was obtained by the method of *Rieke et al.* [29]. Treatment of the pyranoside **25** with this active Zn in dry THF gave the unsaturated aldehyde **37** in a good yield. The bromo-ortholactone **13b** did not react under these conditions. However, treatment of the iodo-ortholactone **35**[13]) with active Zn in THF/butanone gave a mixture **14a**/**14b**. Generally, the formed iodo-ortholactones were not isolated, but directly treated with the black powdered Zn. The results of these fragmentations are listed in *Table 4, Exper. Part.*

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[8]) In the absence of CH_2Cl_2 the mixed ortholactones were solvolyzed to the 'symmetrical' dialkoxy ortholactones (see also [15]).

[9]) The reagent *(Fluka, purum)* was used without any purification.

[10]) The configuration of **32a–c** at C(2) was not conclusively determined. The comparison of the ^{1}H-NMR spectra of **32a** and **32b** with those of **14a**, **14b**, and **16b** points towards the D-*ribo*-configuration for **32**.

[11]) M^+ is not visible.

[12]) Upon treatment with excess BuLi **25** gave the unsaturated alcohols **38**, whilst **13b** gave the coupling product **34** in good yields. Similar results were obtained by *Molleyres* [28].

[13]) The ortholactonization (Et_3OBF_4/$NaOCH_3$) of **33** afforded the dimethoxyortholactone **36**. Therefore, **35** was prepared from **13b** (NaI in butanone).

The following observations are relevant for the interpretation of the results. *a*) At 80°C, the bromo-ortholactones react with black powdered Zn in butanone/THF at about the same rate as the corresponding iodides. At 50°C, they react much slower than the iodides. The proportions of the unsaturated esters remained the same (see *Table 4, Run 3c*).

b) The variation of the ratio of K and $ZnBr_2$ (usual conditions: 1.8–1.9 mol of K to 1 mol of $ZnBr_2$) for the preparation of black powdered Zn had no significant influence on the proportions of the esters. In incomplete reactions, the ortholactones could be re-isolated. When an excess of K was used for the preparation of black powdered Zn (2.45 mol of K to 1 mol of $ZnBr_2$), the yield of the esters declined, but their proportion remained constant (*Runs 2a* and *2b*). Fragmentations in the presence of pyridine did not change the proportion of the products (*Runs 1b* and *2b*). Thus, the acid-catalyzed formation of dioxolenium ions is excluded.

c) Under the usual reaction conditions, the products suffered less than 1% of transesterification. Epimerization at C(2) was found to an extent of about 1% (*Runs 6b* and *6d*).

d) About 5% of the crude product is lost during evaporation of the etheral solution, but the residue and the distillate contained the esters in the same ratio (*Runs 6c*).

Reference products were prepared in the following way: the fragmentation of the bromolactone **28** gave a high yield of the unsaturated acid **14e** which was alkylated with EtBr to give **14a** and with CH_2N_2 to give **14b**. Pure **16b** was obtained by the fragmentation of the dimethyl ortholactone **15e**.

The ratios of products derived from the fragmentation of the mixed ortholactones were determined in the following manner: **14a/b** and **16a/b** (ethyl *vs.* methyl ester) by GC, **14d/b** and **16d/b** (deuteriated *vs.* nondeuteriated methyl esters) by ^{1}H-NMR spectroscopy[14]) and **14c/a** and **16c/a** (deuteriated *vs.* nondeuteriated ethyl esters) by GC/MS coupling[15])[16]). The results of the fragmentations are summarized in *Table 2*, whilst all experiments are listed in *Table 4 (Exper. Part)*.

Table 2. *Loss of the Equatorial Alkoxy Group in the Fragmentation of the Ortholactones* **13** *and* **15**

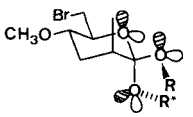
Starting material	Loss of the equatorial alkoxy group[a]) [%][b])		
	at 80°C	at 50°C	at r.t.
13b	49	35	33
13c	67	73	78
13f	65	63	64
13d	66	67	64
15b	55	55	48
15c	78	76	77
15f	69	65	63
15d	70	70	69

[a]) As inferred from the percentage of the unsaturated esters from the indicated starting material.
[b]) Average of the values of *Table 4* (average deviation *ca.* 5%).

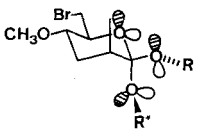
[14]) By integration of the singulets of the MeO-groups.
[15]) In the ^{1}H-NMR spectrum an unequivocal integration of the triplet of the EtO-group was not possible.
[16]) Peaks corresponding to M^+ were not visible. The ratios were determined by integrating the peaks at *m/z* 102 and 105 of ethyl and of 2,2,2-trideuterioethyl propionate, the products of a *McLafferty* rearrangement.

Discussion. – Our observations exclude a transesterification of the fragmentation products **14a–d** and **16a–d**. Since the ratios of these esters depend only slightly upon the reaction temperature, the discussion will be confined to the results obtained at a temperature of 50°C.

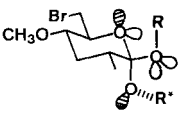
The fragmentation of 6 out of 8 ortholactones leads to a similar result in that 63 to 76% of the respective equatorial alkoxy group is lost. ^{1}H-NMR evidence indicates the $^4C_1$-conformation of the ortholactones, and there is no reason to assume that the transition state conformation should be basically different from it. Accepting this, no one of the mechanisms *A* to *D* taken by itself can rationalize the experimental results. Also the competition of the mechanisms *A* and *C* ('concerted *ap*-fragmentation' and fragmentation *via* conformationally stable hemiorthoesters) is excluded since both mechanisms predict that the D-*ribo*-ortholactones **15** shoulde lose their equatorial alkoxy groups exclusively. A competition of the mechanisms *B* and *C*, *B* and *D*, and *C* and *D*, respectively, is also incompatible with the experimental results. The only remaining combinations of two mechanisms are those of *A* with either *B* or *D*.



13F



13H



15C

Considering a combination of the mechanisms *A* and *D*, the loss of about 70% of the equatorial alkoxy groups of the ortholactones **13c** and **f** and **15c** and **f** possessing deuteriated *vs.* undeuteriated axial and equatorial alkoxy groups, respectively[17]), could be explained by a 2:3 combination of these mechanisms. This combination of the mechanisms *A* and *D*, however, does not explain the results of the fragmentation of **13b** and **15b** having a loss of 35 and 55%, respectively, of the equatorial alkoxy group. Considering that the MeO-group is a better leaving group than the EtO-group by a factor of 4, the above mentioned combination of the mechanisms *A* and *D* predicts that **13b** and **15b** (possessing an equatorial EtO- and an axial MeO-group) would lose 52% of the equatorial alkoxy group and that **13d** and **15d** (possessing an equatorial MeO- and an axial EtO-group) would lose 88% of the equatorial alkoxy group. If the ratio of the leaving group ability of the MeO- and EtO-groups should be less than 4:1, then the relative losses of the equatorial alkoxy groups of **13** and **15** would converge to a value of 70%. Only a competition (or combination) of the two concerted mechanisms, the '*ap*-fragmentation' *A* and the '*sc*-fragmentation' *B*, is in agreement with the experimental results.

A *concerted* and *synchronous* fragmentation of a C(6)-carbanion-equivalent implies a synchronous weakening of the C(5),O- and the equatorial C(1),O-bonds. In a qualitative MO picture, this is due to an interaction of the formal lone pair at C(6) with the two antiperiplanar C(5),O- and the equatorial C(1), O-σ*-orbitals. In a *concerted,* but *nonsynchronous* process [30] a more advanced weakening of the C(5),O-bond leads to

[17]) The secondary isotope effects are neglected.

an increase of the electron density at the ring O-atom and to a nonspecific distribution of the electron density into the σ^*-orbitals of both the axial and the equatorial C(1),O-bonds. This corresponds to a strengthening of the preexisting interaction of the axial lone pair of the ring O-atom with the axial C(1),O-bond. The conformation of the equatorial alkoxy group may permit a second interaction of the axial C(1),O-bond with an antiperiplanar lone pair. In this case, the nonsynchronicity of the fragmentation will cause a more pronounced weakening of the axial C(1),O-bond than of the equatorial C(1),O-bond. This is in keeping with the rules of *Deslongchamps*, according to which the ejection of an alkoxy group is favoured by two antiperiplanar lone pairs. Such an interaction is possible in the two most stable conformers **13F** and **13H**[18]) of the D-*arabino*-ortholactones, but not in the most stable conformer **15C**[18]) of the D-*ribo*-ortholactones. The extent in which this difference is preserved in the transition state and relevant to it should be reflected in a more pronounced loss of the axial alkoxy group from the D-*arabino*-ortholactones. This is the case as can be gathered from *Table 2*. The effect is weak, with the exception of the ortholactones possessing an equatorial EtO- and an axial MeO-group, where the difference of the leaving-group quality of the alkoxy groups appears to amplify the effect. This difference in the leaving-group qualities is paralleled by the higher anomeric effect observed for 2-methoxytetrahydropyran as compared with 2-ethoxytetrahydropyran [31].

To the best of our knowledge, there are three other cases where such an influence of a lone pair on the stereochemical course of a fragmentation could be possible: the base-catalyzed hydrolysis of *S*-adenosyl-L-methionine [32], the synthesis of macrolides by *Eschenmoser et al.* [33] [34] and the hydrolysis of bisacetals by *Kirby & Martin* [35] [36]. *Eschenmoser et al.* postulate a nonconcerted process and *Kirby & Martin* postulate a semiconcerted reaction. We interpret the partial loss of the axial alkoxy group observed in the fragmentation of ortholactones as a consequence of the asynchronicity of a concerted fragmentation and as an indirect measure for the asynchronicity.

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Experimental Part

General. See [37]. Anh. solvents were obtained by the distillation over the following reagents: NaH (CH_2Cl_2, Et_2O, NEt_3, toluene), CaH_2 (DMF, DMSO, HMPA), Na (THF), and 4 Å molecular sieves (CCl_4). Reactions under anh. conditions were carried out in a dry N_2- or Ar-atmosphere. Compounds on TLC were detected by spraying with a 0.02M I_2 in 10% aq. H_2SO_4 or with 10% phosphomolybdic acid in EtOH followed by heating at about 200°. ^{1}H-NMR spectra were recorded on a *Varian EM 390* (90 MHz), *Varian HA 100* (100 MHz) or *Varian XL 200* (200 MHz). GC analysis (0.5% solutions in hexane) was performed on a *Hewlett Packard 5880A* with flame ionization detector using a capillary column (*SE-52*, 15 m/0.3 mm).

2,3,4-Tri-O-benzyl-6-bromo-6-deoxy-α-D-mannopyranose (**9**). A solution of 1.07 g (2.03 mmol) of **8** [2] [4] in 24 ml of AcOH/1M H_2SO_4 2:1 was kept for 90 min at 90°. The mixture was poured into 200 ml of cold H_2O.

[18]) Based upon the same criteria as those used in the discussion of the relative stability of the conformers of the hemiorthoesters **20** and **21**.

After neutralization by addition of $NaHCO_3$ and extraction with 3 × 200 ml portions of CH_2Cl_2, the org. layer was dried ($MgSO_4$) and concentrated *i.v.* Crystallization from Et_2O/hexane gave 586 mg of **9**. Chromatography of the mother liquor on 40 g of silica gel (benzene/AcOEt 4:1) and subsequent crystallization afforded further 216 mg of **9**. Total yield: 802 mg (77%). M.p. 134°, R_f (benzene/AcOEt 4:1) 0.40, $[\alpha]_D = +28.0°$ ($c = 0.9$, $CHCl_3$). IR ($CHCl_3$): 3580*w*, 3330*w* (br.), 3060*w*, 3000*w*, 2920*w*, 2870*w*, 1600*w*, 1490*w*, 1450*m*, 1360*m*, 1095*s*, 1020*s*, 910*w*. IR (KBr): 3475*s*, 3090*w*, 3070*w*, 3040*m*, 2950*w*, 2940*m*, 2920*w*, 2880*w*, 2860*w*, 1495*m*, 1470*w*, 1455*m*, 1415*w*, 1405*w*, 1375*w*, 1368*m*, 1360*m*, 1310*w*, 1295*w*, 1258*m*, 1225*w*, 1215*w*, 1200*w*, 1175*w*, 1155*w*, 1135*s*, 1108*s*, 1090*s*, 1070*s*, 1040*s*, 1030*s*, 1020*s*, 1000*s*, 940*w*, 925*w*, 910*m*, 885*w*, 840*w*, 830*w*, 790*w*, 755*m*, 745*s*, 695*s*, 672*m*, 660*m*. ^{1}H-NMR (100 MHz, $CDCl_3$): 2.80 (*d*, $J = 3.5$, exchangeable with D_2O, HO–C(1)); 3.5–4.1 (*m*, 6H); 4.62 (*s*, PhCH_2); 4.66 and 4.98 (*AB*, $J = 11$, PhCH_2); 4.71 (*s*, PhCH_2); 5.25 (*dd*, $J = 3.5,2$; with D_2O: *d*, $J = 2$, H–C(1)); 7.1–7.5 (*m*, 15H). ^{13}C-NMR ($CDCl_3$): 138.07 (3*s*); 128.20–127.46 (several *d*); 92.63 (*d*); 79.35 (*d*); 76.79 (*d*); 75.16 (*t*); 74.89 (*d*); 72.63 (*t*); 72.08 (*t*); 71.39 (*d*); 33.63 (*t*). MS: 513 (0.1), 511 (0.1), 496 (0.2), 494 (0.2), 423 (0.5), 421 (0.5), 297 (0.5), 295 (0.5), 253 (10), 181 (3), 172 (3), 170 (3), 108 (33), 107 (26), 92 (20), 91 (100), 90 (6), 89 (7), 79 (47), 77 (22), 65 (17), 63 (7), 51 (10), 50 (6), 39 (9). Anal. calc. for $C_{27}H_{29}BrO_5$ (513.43): C 63.16, H 5.69, Br 15.57; found: C 63.15, H 5.79, Br 15.51.

*2,3,4-Tri-*O*-benzyl-6-bromo-6-deoxy-*D*-mannono-1,5-lactone* (**10**). A solution of 500 mg (0.98 mmol) of **9** in 4 ml of DMSO/Ac_2O 4:3 was stirred for 18 h at r.t. After addition of 20 ml of 2M $NaHCO_3$, stirring was continued for 30 min. The mixture was diluted with 200 ml of Et_2O, washed with H_2O (3 × 200 ml), dried ($MgSO_4$) and concentrated *i.v.* The crude product was dried *i.v.* until only a faint odour of Me_2S persisted. Several crystallizations from Et_2O/hexane afforded 482 mg (97%) of **10**. M.p. 90°, R_f (benzene/AcOEt 4:1) 0.34, $[\alpha]_D = -13.3°$ ($c = 0.9$, $CHCl_3$). IR ($CHCl_3$): 3050*w*, 2990*w*, 2860*w*, 1770*s*, 1480*w*, 1445*w*, 1150*m* (sh), 1120*s*, 1070*s*, 1020*m*. IR (KBr): 3095*w*, 3070*w*, 3035*w*, 3010*w*, 2970*w*, 2925*w*, 2875*w*, 1770*s*, 1605*w*, 1585*w*, 1495*m*, 1470*w*, 1455*s*, 1415*m*, 1405*m*, 1370*w*, 1355*w*, 1345*m*, 1325*w*, 1285*w*, 1275*w*, 1240*w*, 1225*w*, 1210*m*, 1185*s*, 1145*s*, 1105*s*, 1090*s*, 1070*s*, 1050*m*, 1035*s*, 1025*s*, 1000*m*, 985*m*, 960*m*, 910*w*, 880*w*, 845*w*, 815*w*, 740*s*, 695*s*, 670*w*, 618*w*, 612*w*. ^{1}H-NMR (100 MHz, $CDCl_3$): 3.44 (*dd*, $J = 11$, 5.7; irrad. at 4.32: *d*, $J = 11$, H–C(6)); 3,59 (*dd*, $J = 11$, 5.3; irrad. at 4.32: *d*, $J = 11$, H′–C(6)); 3.84 (*dd*, $J = 6$, 2, H–C(4)); 4.06 (*dd*, $J = 3$, 2, H–C(3)); 4.32 (br. *q*, $J = 5.5$; irrad. at 3.52: *d*, $J = 6$, H–C(5)); 4.36 (*d*, $J = 3$, H–C(2)); 4.38 (*s*, PhCH_2); 4.58 and 5.07 (*AB*, $J = 12$, PhCH_2); 4.62 and 4.86 (*AB*, $J = 12$, PhCH_2); 7.0–7.5 (*m*, 15H). ^{13}C-NMR ($CDCl_3$): 168.23 (*s*); 137.27 (*s*); 136.99 (*s*); 136.38 (*s*); 128.28–127.61 (several *d*); 77.90 (*d*); 77.30 (*d*); 76.39 (*d*); 75.08 (*d*); 72.93 (*t*); 72.80 (*t*); 71.69 (*t*); 31.53 (*t*). MS: 512 (0.4), 510 (0.4), 465 (0.1), 463 (0.1), 421 (7), 419 (7), 197 (6), 181 (3), 147 (12), 108 (5), 107 (7), 92 (15), 91 (100), 79 (8), 77 (5), 65 (10), 51 (4), 39 (4). Anal. calc. for $C_{27}H_{27}BrO_5$ (511.41): C 63.41, H 5.32, Br 15.63; found: C 63.25, H 5.24, Br 15.53.

*Methyl 5,6-Anhydro-2,3-4-tri-*O*-benzyl-*D*-mannonate* (**12a**). To a solution of 115 mg (0.22 mmol) of **10** in 1 ml of dry CH_2Cl_2 was added 1 ml of NaOMe in MeOH (1.4 mmol). The resulting mixture was stirred for 10 min at r.t. and then hydrolyzed with 1M $NaHCO_3$ (5 ml). Extraction with AcOEt (3 × 80 ml), drying ($MgSO_4$) and concentration of the org. layer *i.v.* afforded the crude product, which was purified by prep. TLC (benzene/AcOEt 4:1): 63 mg (61%) of **12a** as an oil were obtained. For analysis, a sample was distilled at 140°/0.001 Torr. R_f (benzene/AcOEt 4:1) 0.52, $[\alpha]_D = -5.2°$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3080*w* (sh), 3060*w*, 3030*w*, 2995*w*, 2950*w*, 2920*w*, 2860*w*, 1740*s*, 1490*w*, 1450*m*, 1435*w*, 1390*w*, 1105*s* (sh), 1085*s*, 1075*s*, 1025*m*. ^{1}H-NMR (100 MHz, $CDCl_3$): 2.6–2.8 (*m*, 2H); 3.05–3.25 (*m*, 1H); 3.59 (*dd*, $J = 3.5$, 2, H–C(3)); 3.62 (*s*, CH_3O–C(1)); 3.98 (*dd*, $J = 7.5$, 3.5, H–C(4)); 4.31 and 4.65 (*AB*, $J = 9$, PhCH_2); 4.33 and 4.61 (*AB*, $J = 10$, PhCH_2); 4,49 (*s*, PhCH_2); 4.62 (*d*, $J = 2$, H–C(2)); 7.1–7.4 (*m*, 15H). ^{1}H-NMR (100 MHz, C_6D_6): 2.37 (*dd*, $J = 5.5$, 3.5; irrad. at 3.1: *d*, $J = 5.5$; H–C(6)); 2.50 (*dd*, $J = 5.5$, 2.5; irrad. at 3.1: *d*, $J = 5.5$; H′–C(6)); 3.0–3.2 (*m*, irrad. at 2.45: *d*, $J = 5$; H–C(5)); 3.30 (*s*, CH_3O–C(1)); 3.67 (*dd*, $J = 5$, 4; irrad. at 3.1: *d*, $J = 4$; H–C(4)); 4.1–4.8 (*m*, 8H); 6.9–7.4 (*m*, 15H). ^{13}C-NMR ($CDCl_3$): 171.40 (*s*); 138.02 (*s*); 137.57 (*s*); 136.84 (*s*); 128.09–127.50 (several *d*); 80.32 (*d*); 77.50 (*d*); 77.13 (*d*); 74.54 (*t*); 73.21 (*t*); 72.46 (*t*); 51.69 (*q*); 50.90 (*d*); 46.28 (*t*). MS: 372 (2), 371 (6), 279 (2), 270 (2), 266 (2), 265 (11), 253 (2), 193 (3), 182 (5), 181 (12), 175 (3), 164 (5), 107 (3), 92 (15), 91 (100), 65 (6), 57 (3), 43 (4), 41 (3). Anal. calc. for $C_{28}H_{30}O_6$ (462.54): C 72.71, H 6.54; found: C 72.45, H 6.69.

*Methyl 4-*O*-Benzoyl-6-bromo-2,3,6-trideoxy-2-*C*-methyl-α-*D*-arabino-hexopyranoside* (**23**)[3]. A mixture of 12.6 g (47.7 mmol) of **22** [25][19], 10.54 g (59.2 mmol) of NBS (*Fluka, purum*; recrystallized from H_2O), 9.8 g (49.7 mmol) of $BaCO_3$ and 105 mg (0.6 mmol) of azobisisobutyronitrile (*Fluka, purum*) in 340 ml of dry CCl_4 was heated under reflux for 30 min. After 5 min, the mixture became orange and after 20 min again colourless. The mixture was diluted with CH_2Cl_2, washed with water (3×), dried ($MgSO_4$) and concentrated *i.v.* Chromatography of the residue on 220 g of silica gel (hexane/AcOEt 4:1) gave 15.59 g (95.5%) of slightly impure **23** as

[19]) Acetal **22** was obtained as a solid, m.p. 73°.

a yellowish oil. For analysis, a sample was purified by column chromatography and subsequent distillation at 150°/0.005 Torr. R_f (hexane/AcOEt 2:1) 0.51, $[\alpha]_D = +97.7°$ ($c = 1$, $CHCl_3$). IR ($CHCl_3$): 3040*w*, 3020*w*, 2980*m*, 2950*m*, 2920*m*, 2890*w*, 2850*w*, 1735*s*, 1610*w*, 1590*w*, 1500*w*, 1475*w*, 1460*m*, 1425*w*, 1395*m*, 1375*w*, 1340*m*, 1320*m*, 1300*m*, 1275*s*, 1180*m*, 1155*m*, 1135*m*, 1105*s*, 1080*m*, 1050*s*, 1035*m*, 1005*m*, 965*s*, 940*w*, 910*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.18 (*d*, $J = 7.5$, CH_3–C(2)); 1.8–2.25 (*m*, 3H); 3.3–3.7 (*m*, 2H–C(6)); 3.47 (*m*, CH_3O–C(1)); 4.07 (*ddd*, $J = 9.6$, 6.9, 3.3, H–C(5)); 4.47 (*s*, H–C(1)); 5.15 (*td*, $J = 9,6$, 6.0, H–C(4)); 7.2–7.7 (*m*, 3H); 7.9–8.1 (*m*, 2H). MS: 313 (1), 311 (1), 222 (3), 220 (3), 203 (4), 191 (1), 189 (1), 165 (2), 161 (3), 141 (3), 109 (3), 106 (7), 105 (100), 83 (6), 81 (7), 77 (26), 73 (6), 72 (63), 55 (7), 51 (7), 41 (6). Anal. calc. for $C_{15}H_{19}BrO_4$ (343.22): C 52.49, H 5.58; found: C 52.31, H 5.54.

*Methyl 6-Bromo-2,3,6-trideoxy-2-*C*-methyl-*α*-*D*-*arabino*-hexopyranoside* (**24**). A solution of 5.44 g (15.9 mmol) of slightly impure **23** in 90 ml of dry MeOH containing 256 mg (10.8 mmol) Na was stirred for 150 min at r.t. After addition of 5 ml of 1M $NaHCO_3$, the solution was concentrated *i.v.* The residue was dissolved in 100 ml of CH_2Cl_2, dried ($MgSO_4$) and concentrated *i.v.* Chromatography of the crude product on 120 g of silica gel (hexane/AcOEt 9:1 to 4:1) gave 3.634 g (96%) of **24** as a colourless oil. For analysis, a sample was distilled at 120°/0.005 Torr. R_f (hexane/AcOEt 2:1) 0.27, $[\alpha]_D = +102.4°$ ($c = 0.8$, $CHCl_3$). IR ($CHCl_3$): 3620*w*, 3470*w* (br.), 3010*m*, 2980*m*, 2940*m*, 2840*w*, 1470*m*, 1450*w*, 1420*w*, 1390*m*, 1375*m*, 1340*w*, 1320*w*, 1305*w*, 1265*m*, 1195*m*, 1175*m*, 1150*s*, 1100*s*, 1075*s*, 1040*s*, 995*m*, 960*s*, 900*w*, 870*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.08 (*d*, $J = 7.5$, CH_3–C(2)); 1.45–2.2 (*m*, 4H, 1H exchangeable with D_2O); 3.40 (*s*, CH_3O–C(1)); 3.45–3.9 (*m*, 4H); 4.39 (*s*, H–C(1)). ^{13}C-NMR ($CDCl_3$): 102.04 (*d*); 72.67 (*d*); 64.78 (*d*); 54.74 (*q*); 34.18 (*t*); 33.98 (*t*); 33.39 (*d*); 17.02 (*q*). MS: 209 (3), 207 (3), 127 (3), 117 (9), 115 (12), 109 (3), 83 (10), 81 (8), 73 (7), 72 (100), 71 (23), 61 (17), 57 (78), 55 (21), 53 (5), 45 (8), 43 (16), 42 (10), 41 (25), 39 (15). Anal. calc. for $C_8H_{15}BrO_3$ (239.11): C 40.02, H 6.32; found: C 39.88, H 6.20.

*Methyl 6-Bromo-2,3,4-trideoxy-2-*C*,4-*O*-dimethyl-*α*-*D*-*arabino*-hexopyranoside* (**25**). A solution of 9.45 g (39.7 mmol) of **24** in 40 ml of dry CH_2Cl_2 was dropped during 10 min to a chilled mixture (ice bath) of 1.95 g (79.6 mmol) of NaH (*Fluka*, 90% in oil; washed with dry Et_2O) and 11 ml (0.22 mol) of MeI in 200 ml of dry DMF. After stirring at 0° for 30 min, the excess of NaH was destroyed by careful addition of MeOH. After dilution with 400 ml of Et_2O, the org. layer was washed with 1M $NaHCO_3$ (3 × 300 ml), dried ($MgSO_4$) and concentrated *i.v.* Bulb-to-bulb distillation at 140°/0.04 Torr gave 9.522 g of **25** as a colourless oil. Chromatography of the residue of distillation on 30 g of silica gel (hexane/AcOEt 9:1) afforded further 220 mg of **25**. Total yield: 9.742 g (97.5%). For analysis, a sample was distilled at 90°/0.005 Torr. R_f (hexane/AcOEt 4:1) 0.41, $[\alpha]_D = +127.4°$ ($c = 0.9$, $CHCl_3$). IR ($CHCl_3$): 3000*m*, 2970*m*, 2940*s*, 2910*m*, 2830*m*, 1465*m*, 1445*w*, 1420*w*, 1385*m*, 1375*m*, 1340*w*, 1310*w*, 1295*w*, 1275*w*, 1250*w*, 1195*w*, 1175*m*, 1150*s*, 1130*s*, 1100*s*, 1065*w*, 1045*w*, 1010*m*, 995*m*, 960*m*, 930*w*, 895*w*, 865*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.21 (*d*, $J = 7.5$, CH_3–C(2)); 1.6–2.15 (*m*, 3H); 3.3–3.85 (*m*, 4H); 3.34 (*s*, CH_3O–C(4)); 3.40 (*s*, CH_3O–C(1)); 4.40 (*s*, H–C(1)). ^{13}C-NMR ($CDCl_3$): 102.24 (*d*); 73.27 (*d*); 70.89 (*d*); 56.16 (*q*); 54.67 (*q*); 34.48 (*t*); 32.85 (*d*); 29.46 (*t*); 17.11 (*q*). MS: 223 (3), 221 (3), 211 (3), 209 (3), 191 (3), 189 (3), 155 (5), 141 (16), 129 (11), 109 (11), 97 (10), 85 (9), 81 (24), 73 (7), 72 (100), 71 (62), 67 (9), 59 (6), 57 (12), 55 (16), 53 (7), 45 (16), 44 (7), 43 (18), 42 (8), 41 (33), 39 (14). Anal. calc. for $C_9H_{17}BrO_3$ (253.14): C 42.70, H 6.77; found: C 42.51, H 6.80.

Oxidation of the Crude Product of Hydrolysis of **25**. To a solution of 3.745 g (14.9 mmol) **25** in 75 ml of dioxane/H_2O 1:1, 45 ml of anh. CF_3COOH were added. The mixture was stirred for 150 min at 50° and then poured into 300 ml of cold H_2O. The acid was neutralized by careful addition of $NaHCO_3$. After extraction with AcOEt (4 × 500 ml), the org. layer was dried ($MgSO_4$) and concentrated *i.v.* The crude product (4.38 g) was dissolved in 150 ml of dry CH_2Cl_2. After addition of 6.5 g (30 mmol) of pyridinium chlorochromate and 20 g of ground 3 Å molecular sieves [27], the mixture was stirred for 80 min at r.t. After addition of 300 ml of Et_2O, the mixture was filtrated (Et_2O) through 80 g of silica gel to give 3.57 g of a yellowish, solid product. Repeated crystallizations from Et_2O/hexane afforded 1.731 g of **28**. Chromatography of the combined mother liquors on 90 g of silica gel (hexane/AcOEt 4:1) gave 278 mg (7.4%) of **25**, 132 mg (3%) of slightly impure **31**, 815 mg of a mixture **28**/**29**, and 196 mg (8.3%) of slightly impure **30**. Crystallization from Et_2O/hexane afforded further 475 mg of **28**. Total yield of **28**: 2.188 g (62.4%). GC analysis revealed that the oily mother liquor (286 mg, 8%) was a 3:2 mixture **29**/**28**. *6-Bromo-2,3,6-trideoxy-2-*C*,4-*O*-dimethyl-*D*-arabino-hexono-1,5-lactone* (**28**). For analysis, a sample was sublimated at 72°/0.003 Torr. M.p. 75°, R_f (hexane/AcOEt 2:1) 0.25, $[\alpha]_D = +107.2°$ ($c = 0.8$, $CHCl_3$). IR ($CHCl_3$): 3040*w*, 3010*m*, 2990*m*, 2950*m*, 2910*w*, 2850*w*, 1760*s*, 1465*m*, 1425*w*, 1390*m*, 1370*m*, 1345*w*, 1325*w*, 1280*w*, 1170*s*, 1145*m*, 1110*s*, 1030*m*, 990*w*, 965*w*, 930*w*, 870*w*, 850*w*. ^{1}H-NMR (200 MHz, $CDCl_3$): 1.25 (*d*, $J = 6.8$, CH_3–C(2)); 1.78 (*ddd*, $J = 14.5$, 12.2, 6.5, H–C(3); irrad. at 3.69: *dd*, $J = 14.5$, 12.2); 2.10 (*ddd*, $J = 14.5$, 6.5, 3.5, H'–C(3); irrad. at 3.65: *dd*, $J = 14.5$, 6.5); 2.77 (*dd*, $J = 12.2$, 6.8, 6.5, H–C(2); irrad. at 1.25: *dd*, $J = 12.2$, 6.5); 3.40 (*s*, CH_3O–C(4)); 3.61 (*dd*, $J = 10.7$, 4.5, H–C(6); irrad. at 4.35: *d*,

J = 10.7); 3.68 (*dd*, J = 10.7, 4.2, H'–C(6); irrad. at 4.35: *d*, J = 10.7); 3.69 (*ddd*, J = 7, 6.5, 3.5, H–C(4); irrad. at 4.35: signal changed); 4.35 (*ddd*, J = 7, 4.5, 4.2, H–C(5); irrad. at 3.65: *s*). ^{13}C-NMR ($CDCl_3$)[20]: 174.00 (*s*); 78.29 (*d*); 74.45 (*d*); 56.76 (*q*); 32.13 (*t*); 31.57 (*t*); 31.09 (*d*); 15.61 (*q*). 195 (1), 193 (1), 157 (6), 143 (1), 125 (1), 114 (5), 97 (5), 86 (30), 85 (12), 71 (36), 59 (100), 58 (30), 56 (16), 55 (9), 45 (7), 43 (9), 41 (22), 39 (8). Anal. calc. for $C_8H_{13}BrO_3$ (237.09): C 40.53, H 5.53; found: C 40.49, H 5.55.

*1,6-Anhydro-2,3-dideoxy-2-*C*,4-*O*-dimethyl-β-*D*-*arabino*-hexopyranose* (**30**). Bulb-to-Bulb distillation of slightly impure **30** at 90°/0.005 Torr gave pure **30** as a colourless oil. R_f (hexane/AcOEt 2:1) 0.15, $[\alpha]_D = -141.6°$ (c = 0.5, $CHCl_3$). IR ($CHCl_3$): 3040*w* (sh), 3020*m*, 2980*s*, 2950*s*, 2910*m*, 2890*m*, 2840*w*, 1490*w*, 1465*m*, 1445*w*, 1385*w*, 1370*m*, 1340*w*, 1315*w*, 1295*w*, 1160*s*, 1130*s*, 1115*s*, 1095*s*, 1055*s*, 1025*w*, 995*s*, 980*s*, 955*w*, 940*m*, 905*s*, 895*s*, 850*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 0.85 (*d*, J = 6, CH_3–C(2)); 1.15–1.6 (*m*, 1H); 1.6–2.2 (*m*, 2H); 3.05–3.25 (*m*, H–C(4)); 3.43 (*s*, CH_3O–C(4)); 3.55–3.9 (*m*, 2H–C(6)); 4.58 (*m*, H–C(5)); 5.21 (br. *s*, H–C(1)). ^{13}C-NMR ($CDCl_3$): 105.01 (*d*); 75.89 (*d*); 73.64 (*d*); 66.22 (*t*); 56.34 (*q*); 32.35 (*d*); 28.82 (*t*); 16.59 (*q*). MS: 158 (1, M^+), 116 (12), 115 (27), 112 (7), 100 (10), 97 (8), 87 (8), 85 (9), 82 (11), 80 (6), 79 (11), 73 (7), 72 (9), 71 (100), 70 (22), 69 (6), 67 (5), 58 (11), 57 (6), 56 (5), 55 (8), 45 (11), 43 (10), 42 (12), 41 (24), 39 (8).

*(6-Bromo-2,3,6-trideoxy-2-*C*,4-*O*-dimethyl-α-*D*-arabino-hexopyranosyl) 6-Bromo-2,3,6-trideoxy-2-*C*,4-*O*-dimethyl-α-*D*-arabino-hexopyranoside* (**31**). Impure **31** (132 mg) was heated at 120°/12 Torr for 2 h. After treatment with charcoal, chromatographically pure **31** (103 mg) was obtained as a solid. M.p. 74°, R_f (hexane/AcOEt 4:1) 0.34, $[\alpha]_D = +166°$ (c = 0.9, $CHCl_3$). IR ($CHCl_3$): 2970*m*, 2930*s*, 2880*m*, 2830*m*, 1465*m*, 1455*m* (sh), 1415*w*, 1385*m*, 1365*w*, 1340*w*, 1310*w*, 1290*w*, 1265*w*, 1170*m*, 1145*s*, 1130*s*, 1095*s*, 1015*s*, 980*m*, 960*s*, 930*m*, 890*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.25 (*d*, J = 7, CH_3–C(2)); 1.7–2.25 (*m*, 3H); 3.2–3.9 (*m*, 4H); 3.35 (*s*, CH_3O–C(4)); 4.93 (*d*, J = 1.5, H–C(1)). ^{13}C-NMR ($CDCl_3$): 96.25 (*d*); 73.79 (*d*); 71.76 (*d*); 56.24 (*q*); 34.15 (*t*); 32.52 (*d*); 29.34 (*t*); 17.22 (*q*). MS: 381 (2), 379 (2), 349 (4), 347 (4), 224 (9), 223 (99), 222 (26), 221 (100), 220 (17), 192 (6), 191 (83), 190 (7), 189 (84), 165 (14), 163 (15), 141 (8), 115 (49), 110 (6), 109 (50), 85 (23), 83 (8), 82 (8), 81 (52), 71 (33), 67 (7), 59 (8), 57 (9), 55 (32), 53 (7), 45 (40), 43 (34), 41 (40), 39 (11).

*6-Bromo-2,3,6-trideoxy-2-*C*,4-*O*-dimethyl-α-*D*-arabino-* and *-α-*D*-ribo-hexopyranose* (**26** *and* **27**). A sample of the crude hydrolysis product of **25** was chromatographically (hexane/AcOEt 4:1) purified. ^{13}C-NMR revealed that the obtained oil was a 4:1 mixture **26**/**27**. R_f (hexane/AcOEt 2:1) 0.22. IR ($CHCl_3$): 3610*m*, 3440*w* (br.), 3020*m*, 2990*m*, 2950*s*, 2890*m*, 2840*w*, 1735*w*, 1470*m*, 1465*m*, 1425*w*, 1385*w*, 1375*w*, 1335*w*, 1315*w*, 1255*m*, 1180*m*, 1130*s*, 1105*s*, 1065*m*, 1055*m*, 1030*s*, 980*s*, 965*m*, 935*w*, 915*w*, 895*w*, 865*w*, 840*w*. ^{1}H-NMR (90 MHz, $CDCl_3$)[21]): 1.03 (*d*, J = 7.0) and *1.08* (*d*, J = *7.5*, CH_3–C(2)); 2.7–3.3 (*m*, 3H); 3.12 (br. *d*, J = 3; exchangeable with D_2O, HO–C(1)); 3.2–3.8 (*m*, 3H); 3.37 (*s*, CH_3O–C(4)); 3.94 (*dt*, J = 6 and 3, H–C(5)); 4.93 (br. *s*; with D_2O: *4.93* (*d*, J = 2) and 4.95 (*d*, J = 2), H–C(1)). ^{13}C-NMR ($CDCl_3$): **26**: 95.77 (*d*); 73.30 (*d*); 70.87 (*d*); 56.28 (*q*); 34.63 (*t*); 32.91 (*d*); 28.82 (*t*); 17.07 (*q*); **27**: 96.53 (*d*); 76.92 (*d*); 72.87 (*d*); 56.60 (*q*); 33.90 (*t*); 32.34 (*d*); 31.79 (*t*); 12.01 (*q*).

(1-Bromocyclohexane)carboxaldehyde Ethyl Methyl Acetal (**17**). To a cooled solution (–30°, CO_2/CCl_4) of 357 mg (2.8 mmol) of **19** in 10 ml of dry Et_2O were added dropwise 150 µl (2.9 mmol) of Br_2 [38]. The resulting orange solution was stirred for 20 min at –30°. After addition of 5 ml of NaOEt/EtOH (67 mg Na), the yellow mixture was warmed up to 0° (ice bath) and stirred at 0° for 40 min. After addition of 20 ml of 1M $NaHCO_3$ and extraction with 3 portions of Et_2O, the org. layer was dried (Na_2SO_4) and concentrated *i.v.* Bulb-to-bulb distillation of the residue at 130–140°/12 Torr afforded 557 mg of **17** as a colourless oil. R_f (hexane/AcOEt 9:1) 0.47. IR ($CHCl_3$): 2980*m*, 2940*s*, 2860*m*, 1450*m*, 1370*w*, 1345*w*, 1280*w*, 1245*w*, 1185*w*, 1145*m*, 1120*s*, 1110*m*, 1095*s*, 1065*s*, 1015*w*, 985*w*, 895*w*, 865*m*. ^{1}H-NMR (90 MHz, CCl_4): 1.20 (*t*, J = 6.5, CH_3); 1.4–2.1 (*m*, 10H); 3.48 (*s*, OCH_3); 3.5–3.95 (*m*, OCH_2); 4.28 (*s*, O_2CH). ^{13}C-NMR ($CDCl_3$): 109.98 (*d*); 76.35 (*s*); 66.83 (*t*); 57.98 (*q*); 34.50 (*t*); 34.36 (*t*); 25.41 (*t*); 22.09 (2*t*); 15.26 (*q*). MS: 221 (0.5), 219 (0.5), 207 (0.7), 205 (0.7), 171 (1), 163 (1), 161 (1), 143 (3), 125 (4), 111 (6), 93 (8), 90 (5), 89 (100), 83 (5), 81 (30), 79 (6), 67 (12), 61 (70), 55 (14), 53 (9), 45 (8), 43 (5), 41 (21), 39 (15).

Synthesis of **18** *and* **19**. The vinyl ethers **18** [22] [23] (GC: R_t 6.29 min) and **19** [22] (GC: R_t 7.50 min) were obtained by treatment of the corresponding dimethyl and diethyl acetal, respectively, with pyridine and phosphoric acid [39].

General Method for the Preparation of the Ortholactones **13a–f** *and* **15b–f** (exper. details, see *Table 3*). A solution of the lactone and an excess of Et_3OBF_4 (*Fluka purum*, recrystallized from CH_2Cl_2/Et_2O) in 8–10 ml of dry CH_2Cl_2 or the mixture of the lactone and an excess of Me_3OBF_4 (*Fluka purum*) in 15 ml of dry CH_2Cl_2 was

[20]) In addition to the signals of **28**, the ^{13}C-NMR of the mother liquor (3:2 mixture **29**/**28**) shows the following signals of **29**: 172.06 (*s*); 80.33 (*d*); 74.15 (*d*); 56.99 (*q*); 33.76 (*d*); 33.60 (*t*); 31.79 (*t*); 17.14 (*q*).

[21]) The signals attributed to **27** are indicated in italics.

Table 3. *Synthesis of the Ortholactones* **13a–f** *and* **15b–f**: *Starting Materials and Products*

Run	**28** [mg (mmol)]	*Meerwein* salt[a]) [mg (mmol)]	Alcohol	Na [mg (mmol)]	Products [mg (%)]
1	210 (0.89)	Et: 2050 (10.8)	EtOH	408 (17.7)	**13a:** 214 (78)
2	265 (1.12)	Et: 2735 (14.4)	MeOH	450 (19.2)	**13b:** 310 (93)
3	154 (0.65)[b])	Et: 2625 (13.8)	MeOH	550 (23.4)	**13b:** 46 (24)
					15b: 101 (52)
4	122 (0.52)[b])	Et: 2620 (13.8)	CD_3CH_2OH[c])	371 (16)	**13c:** 31 (20)
					15c: 25 (16)
5	248 (1.05)	Me: 913 (6.2)	EtOH	300 (12.7)	**13d:** 115 (37)
					15d: 32 (10)
					32a: 83 (39)
6	215 (0.91)	Me: 880 (6.0)	MeOH	336 (14.3)	**13e:** 87 (34)
					15e: 32 (13)
					32b: 77 (45)
7	241 (1.02)	Me: 1005 (6.8)	CD_3OD[d])	244 (10.4)	**13f:** 94 (32)
					15f: 40 (14)
					32c: 99 (51)

[a]) Et: Et_3OBF_4, Me: Me_3OBF_4. [b]) 2:3 mixtures of **28** and **29**. [c]) *Stohler* (98% D). [d]) *Fluka, puriss.* (> 99.8% D).

stirred for 16–20 h at r.t. The resulting mixture was transferred with a syringe into 48–60 ml of a cold 4:1 mixture (−70°) of CH_2Cl_2 and the appropriate alcohol containing an excess of Na (including rinsing twice with 1 ml of dry CH_2Cl_2). After stirring for 20 min at −70° and warming up to r.t., the mixture was diluted with AcOEt, washed with 2N $NaHCO_3$ (3×), dried (K_2CO_3) and concentrated *i.v.* Flash chromatography [40] on 25 g of silica gel (the column was prepared with hexane/NEt_3 99:1 and eluted with hexane/AcOEt 19:1) gave the pure ortholactones as liquids, whose solutions in CH_2Cl_2 over K_2CO_3 were stable for several weeks on storage in a refrigerator. For analysis, samples were distilled at 90°/0.005 Torr.

*1,5-Anhydro-6-bromo-2,3,6-trideoxy-1,1-di-*C*-ethoxy-2-*C*,4-*O*-dimethyl-*D*-arabino-hexitol* (**13a**). R_f (hexane/AcOEt 4:1) 0.45, $[\alpha]_D = +70.3°$ ($c = 1.6$, CCl_4). IR (CCl_4): 2980*s*, 2930*s*, 2900*m*, 2825*w*, 1465*w*, 1450*w*, 1440*w*, 1410*w*, 1380*w*, 1365*w*, 1350*w*, 1335*w*, 1315*w*, 1295*w*, 1270*w*, 1250*w*, 1235*m*, 1180*m*, 1110*s*, 1080*s*, 1055*s*, 1045*s*, 1020*m*, 990*m*, 970*m*, 960*w*. ^{1}H-NMR (90 MHz, CCl_4): 1.00 (*d*, $J = 7$, CH_3–C(2)); 1.15 (*t*, $J = 7$, CH_2 of ax. OEt); 1.17 (*t*, $J = 7$, CH_2 of eq. OEt); 1.66 (*ddd*, $J = 12$, 10, 4.5, H_{ax}–C(3)); 1.88 (*ddd*, $J = 12$, 5.5, 3.7, H_{eq}–C(3)); 2–2.4 (*m*, H–C(2)); 3.2–3.8 (*m*, 8H); 3.31 (*s*, CH_3O–C(4)). ^{13}C-NMR ($CDCl_3$): 113.45 (*s*); 75.18 (*d*); 72.90 (*d*); 57.37 (*t*); 56.55 (*q*); 55.50 (*t*); 33.74 (*t*); 32.83 (*d*); 31.72 (*t*); 15.04 (*q*); 14.83 (*q*); 14.66 (*q*). MS: 267 (8), 265 (8), 221 (2), 219 (2), 207 (2), 205 (2), 193 (2), 191 (2), 179 (2), 177 (2), 165 (6), 163 (5), 152 (2), 150 (2), 148 (7), 134 (30), 133 (16), 131 (7), 130 (40), 128 (18), 125 (8), 120 (15), 119 (100), 117 (17), 116 (16), 115 (11), 113 (9), 105 (33), 103 (10), 102 (8), 99 (15), 97 (9), 91 (22), 87 (9), 85 (16), 81 (7), 79 (8), 77 (10), 74 (9), 71 (85), 59 (9), 57 (17), 55 (12), 51 (7), 45 (10), 44 (10), 43 (14), 41 (31), 40 (7), 39 (14).

*(S)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-*C*-ethoxy-1-*C*-methoxy-2-*C*,4-*O*-dimethyl-*D*-arabino-hexitol* (**13b**). R_f (hexane/AcOEt 4:1) 0.37, $[\alpha]_D = +69.7°$ ($c = 1.5$, CCl_4). IR (CCl_4): 2980*s*, 2940*s*, 2830*w*, 1465*m*, 1450*w*, 1440*w*, 1420*w*, 1415*w*, 1385*w*, 1375*w*, 1365*m*, 1350*w*, 1340*w*, 1315*w*, 1295*w*, 1275*w*, 1255*w*, 1235*m*, 1220*m*, 1180*s*, 1115*s*, 1080*s*, 1060*s*, 1045*s*, 1015*m*, 985*s*, 970*m*, 960*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 1.07 (*d*, $J = 7.3$, CH_3–C(2)); 1.25 (*t*, $J = 7.1$, CH_3CH_2O); 1.80 (*ddd*, $J = 12.3$, 10.5, 4.5, H_{ax}–C(3); irrad. at 3.4: *dd*, $J = 12.3$, 4.5); 1.99 (*ddd*, $J = 12.3$, 5, 3, H_{eq}–C(3); irrad. at 3.4: *dd*, $J = 12.3$, 3); 2.2–2.37 (*m*, H–C(2); irrad. at 1.07: *dd*, $J = 4.5$, 3); 3.26 (*s*, CH_3O–C(1)); 3.36 (*s*, CH_3O–C(4)); 3.40 (*td*, $J = 10.5$, 5, H–C(4)); 3.5–3.8 (*m*, 3H); 3.53 (*q*, $J = 7.1$, CH_3CH_2O). ^{1}H-NMR (90 MHz, CCl_4): 1.00 (*d*, $J = 7$, CH_3–C(2)); 1.17 (*t*, $J = 7$, CH_3CH_2O); 1.66 (*ddd*, $J = 12$, 10, 4.5, H_{ax}–C(3)); 1.96 (*ddd*, $J = 12$, 6.5, 3, H_{eq}–C(3)); 2.05–2.4 (*m*, H–C(2)); 3.20 (*s*, CH_3O–C(1)); 3.25–3.8 (*m*, 6H); 3.31 (*s*, CH_3O–C(4)). ^{13}C-NMR ($CDCl_3$): 113.57 (*s*); 75.17 (*d*); 72.83 (*d*); 57.36 (*t*); 56.49 (*q*); 47.66 (*q*); 33.65 (*t*); 32.56 (*d*); 31.67 (*t*); 15.02 (*q*); 14.65 (*q*). MS: 267 (3), 265 (3), 253 (2), 251 (2), 221 (3), 219 (3), 207 (1), 205 (1), 193 (2), 191 (2), 179 (2), 178 (14), 177 (2), 165 (4), 163 (38), 153 (12), 152 (3), 150 (3), 116 (43), 107 (7), 89 (8), 88 (13), 85 (12), 81 (7), 79 (7), 72 (8), 71 (100), 69 (8), 59 (9), 57 (14), 55 (8), 51 (6), 45 (8), 44 (7), 43 (15), 41 (31), 39 (10). Anal. calc. for $C_{11}H_{21}BrO_4$ (297.19): C 44.46, H 7.12; found: C 44.17, H 7.33.

(R)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-C-[(2,2,2-$^2H_3$)ethoxy]-1-C-ethoxy-2-C,4-O-dimethyl-D-arabino-*hexitol* (**13c**). R_f (hexane/AcOEt 4:1) 0.45. IR (CCl_4): 2980*m*, 2930*m*, 2890*w*, 2820*w*, 2230*w*, 1465*w*, 1450*w*, 1415*w*, 1380*w*, 1365*w*, 1235*m*, 1180*m*, 1140*m*, 1115*s*, 1080*m*, 1065*m*, 1040*m*, 1020*m*, 990*m*, 920*w*, 910*w*. ^{1}H-NMR (90 MHz, CCl_4): 1.00 (*d*, J = 7, CH_3–C(2)); 1.17 (*t*, J = 7, CH_3 of eq. OEt); 1.66 (*ddd*, J = 12, 10, 4.5, H_{ax}–C(3)); 1.88 (*ddd*, J = 12, 5.5, 3.7, H_{eq}–C(3)); 2–2.4 (*m*, H–C(2)); 3.2–3.8 (*m*, 8H); 3.31 (*s*, CH_3O–C(4)). MS: 270 (5), 268 (5), 267 (8), 265 (8), 221 (2), 219 (2), 207 (2), 205 (2), 193 (2), 191 (2), 179 (2), 177 (2), 165 (6), 163 (6), 159 (8), 152 (3), 150 (3), 136 (3), 133 (38), 125 (9), 99 (12), 97 (7), 85 (14), 81 (7), 75 (8), 72 (6), 71 (100), 69 (6), 59 (9), 58 (6), 57 (17), 55 (8), 45 (11), 43 (12), 41 (30), 39 (10).

(R)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-C-ethoxy-1-C-methoxy-2-C,4-O-dimethyl-D-arabino-*hexitol* (**13d**). R_f (hexane/AcOEt 4:1) 0.37, $[\alpha]_D$ = +65.1° (c = 1.9, CCl_4). IR (CCl_4): 2980*s*, 2940*s*, 2900*m* (sh), 2880*m*, 2835*w*, 2825*w*, 1465*m*, 1450*m*, 1440*w*, 1410*w*, 1380*m*, 1365*m*, 1355*m*, 1315*w*, 1295*w*, 1270*w*, 1235*m*, 1220*m*, 1190*m*, 1180*m*, 1130*s* (sh), 1110*s*, 1080*s*, 1055*s*, 1020*s*, 990*s*, 960*m*, 920*w*. ^{1}H-NMR (90 MHz, CCl_4): 0.99 (*d*, J = 7, CH_3–C(2)); 1.16 (*t*, J = 7, CH_3CH_2O); 1.67 (*ddd*, J = 12.3, 9.3, 4.5, H_{ax}–C(3)); 1.93 (*dt*, J = 12.3, 3.5, H_{eq}–C(3)); 2–2.4 (*m*, H–C(2)); 3.23 (*s*, CH_3O–C(1)); 3.3–3.8 (*m*, 4H); 3.32 (*s*, CH_3O–C(4)); 3.38 (*q*, J = 7, CH_3CH_2O). ^{13}C-NMR ($CDCl_3$): 113.69 (*s*); 75.03 (*d*); 72.78 (*d*); 56.54 (*q*); 55.63 (*t*); 49.40 (*q*); 33.72 (*t*); 32.30 (*d*); 31.64 (*t*); 14.83 (*q*); 14.50 (*q*). MS: 267 (3), 265 (3), 253 (9), 251 (9), 221 (3), 219 (3), 193 (2), 191 (2), 179 (2), 177 (2), 175 (3), 171 (4), 165 (9), 163 (9), 152 (6), 150 (6), 139 (4), 137 (4), 125 (4), 117 (6), 116 (83), 111 (7), 99 (7), 89 (10), 88 (20), 85 (18), 81 (7), 72 (8), 71 (100), 59 (6), 57 (11), 45 (6), 41 (13). Anal. calc. for $C_{11}H_{21}BrO_4$ (297.19): C 44.46, H 7.12; found: C 44.63, H 7.02.

1,5-Anhydro-6-bromo-2,3,6-trideoxy-1,1-di-C-methoxy-2-C,4-O-dimethyl-D-arabino-*hexitol* (**13e**). R_f (hexane/AcOEt 4:1) 0.30, $[\alpha]_D$ = +75.3° (c = 1.5, CCl_4). IR (CCl_4): 2980*m*, 2940*s*, 2880*m*, 2835*m*, 1465*m*, 1455*m* (sh), 1440*w*, 1410*w*, 1380*w*, 1370*w*, 1355*w*, 1335*w*, 1320*w*, 1295*w*, 1270*w*, 1240*m*, 1220*m*, 1180*m*, 1165*m*, 1115*m*, 1105*s*, 1080*s*, 1060*s*, 1045*s*, 1010*m*, 985*s*, 960*m*, 900*w*. ^{1}H-NMR (90 MHz, CCl_4): 1.00 (*d*, J = 7, CH_3–C(2)); 1.65 (*ddd*, J = 12.5, 10, 4.5, H_{ax}–C(3)); 1.88 (*ddd*, J = 12.5, 5, 3.5, H_{eq}–C(3)); 2–2.4 (*m*, H–C(2)); 3.20 (*s*, ax. CH_3O–C(1)); 3.23 (*s*, eq. CH_3O–C(1)); 3.31 (*s*, CH_3O–C(4)); 3.35–3.8 (*m*, 4H). ^{13}C-NMR ($CDCl_3$): 113.73 (*s*); 74.97 (*d*); 72.65 (*d*); 56.46 (*q*); 49.28 (*q*); 47.62 (*q*); 33.58 (*t*); 31.94 (*d*); 31.52 (*t*); 14.42 (*q*). MS: 253 (6), 251 (6), 221 (2), 219 (2), 193 (2), 191 (2), 171 (4), 165 (5), 163 (5), 152 (4), 150 (4), 139 (2), 137 (2), 111 (12), 102 (52), 85 (16), 81 (8), 79 (8), 72 (12), 71 (100), 69 (8), 59 (10), 57 (19), 55 (11), 53 (9), 45 (11), 43 (14), 41 (55), 39 (21). Anal. calc. for $C_{10}H_{19}BrO_4$ (283.16): C 42.42, H 6.76; found: C 42.65, H 6.64.

(R)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-C-(2H3)methoxy-1-C-methoxy-2-C,4-O-dimethyl-D-arabino-*hexitol* (**13f**). R_f (hexane/AcOEt 4:1) 0.30. IR (CCl_4): 2980*m*, 2940*m*, 2910*m*, 2880*w*, 2840*w*, 2825*w*, 2250*w* (sh), 2225*w*, 2130*w*, 2075*w*, 1465*m*, 1455*w*, 1440*w*, 1415*w*, 1385*w*, 1370*w*, 1365*w*, 1340*w*, 1320*w*, 1300*w*, 1275*w*, 1240*m*, 1225*m*, 1190*m*, 1180*m*, 1130*s*, 1105*s*, 1090*s*, 1050*s*, 1010*m*, 980*m*, 960*m*, 895*w*, 870*w*. ^{1}H-NMR (90 MHz, CCl_4): 1.00 (*d*, J = 7, CH_3–C(2)); 1.65 (*ddd*, J = 12.5, 10, 4.5, H_{ax}–C(3)); 1.88 (*ddd*, J = 12.5, 5, 3.5, H_{eq}–C(3)); 2.0–2.45 (*m*, H–C(2)); 3.2 (*s*, CH_3O–C(1)); 3.3–3.8 (*m*, 4H); 3.31 (*s*, CH_3O–C(4)). ^{13}C-NMR: 113.77 (*s*); 75.03 (*d*); 72.73 (*d*); 56.52 (*q*); 49.34 (*sept.* of low intensity); 33.64 (*t*); 32.01 (*d*); 31.60 (*t*); 14.48 (*q*). MS: 256 (3), 254 (3), 253 (4), 251 (4), 221 (2), 219 (2), 193 (2), 191 (2), 165 (6), 163 (6), 152 (7), 150 (7), 139 (3), 137 (3), 111 (7), 108 (4), 105 (90), 102 (< 1), 85 (12), 81 (6), 71 (100), 59 (8), 58 (10), 57 (9), 55 (8), 45 (6), 43 (8), 41 (23), 39 (7).

(S)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-C-ethoxy-1-C-methoxy-2-C,4-O-dimethyl-D-ribo-*hexitol* (**15b**). R_f (hexane/AcOEt 4:1) 0.50, $[\alpha]_D$ = +103.2° (c = 1.1, CCl_4). IR (CCl_4): 2980*s*, 2940*s*, 2910*m*, 2870*m*, 2840*w*, 2830*m*, 1465*m*, 1450*m*, 1440*m*, 1415*w*, 1375*m*, 1365*m*, 1315*w*, 1270*w*, 1250*m*, 1230*s*, 1200*m*, 1190*m*, 1175*m*, 1135*s*, 1110*s*, 1100*s*, 1085*s*, 1055*s*, 1025*s*, 1010*s*, 970*m*, 915*w*, 875*w*, 845*w*. ^{1}H-NMR (90 MHz, CCl_4): 0.89 (*d*, J = 6.5, CH_3–C(2)); 1.18 (*t*, CH_3CH_2O); 1.40 (*td*, J = 13.5, 11, H_{ax}–C(3)); 1.6–2.15 (*m*, 2H); 2.95–3.85 (*m*, 6H); 3.23 (*s*, CH_3O–C(1)); 3.33 (*s*, CH_3O–C(4)). ^{13}C-NMR ($CDCl_3$): 112.90 (*s*); 76.31 (*d*); 74.42 (*d*); 58.72 (*t*); 56.41 (*q*); 47.11 (*q*); 34.12 (*t*); 33.69 (*d*); 32.89 (*t*); 15.58 (*q*); 14.96 (*q*). MS: 267 (4), 265 (4), 253 (3), 251 (3), 221 (2), 219 (2), 193 (1), 191 (1), 179 (1), 177 (1), 165 (6), 163 (6), 152 (4), 150 (4), 139 (2), 137 (2), 125 (4), 117 (7), 116 (100), 102 (8), 89 (10), 88 (21), 85 (11), 72 (9), 71 (89), 59 (12), 57 (26), 56 (8), 55 (12), 53 (6), 45 (11), 43 (12), 41 (31), 39 (7). Anal. calc. for $C_{11}H_{21}BrO_4$ (297.19): C 44.46, H 7.12; found: C 44.20, H 6.89.

(R)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-C-[(2,2,2-$^2H_3$)ethoxy]-1-C-ethoxy-2-C,4-O-dimethyl-D-ribo-*hexitol* (**15c**). R_f (hexane/AcOEt 4:1) 0.55. IR (CCl_4): 2980*m*, 2935*m*, 2900*m*, 2870*w*, 2820*w*, 2230*w*, 1465*w*, 1450*w*, 1415*w*, 1375*w*, 1360*w*, 1270*w*, 1250*w*, 1225*m*, 1185*m*, 1145*s*, 1135*s*, 1110*s*, 1100*s*, 1080*s*, 1070*s*, 1040*s*, 1030*s*, 1010*s*, 965*w*. ^{1}H-NMR (90 MHz, CCl_4): 0.90 (*d*, J = 6.5, CH_3–C(2)); 1.17 (*t*, J = 7, CH_3 of eq. OEt); 1.43 (*td*, J = 13.5, 11, H_{ax}–C(3)); 1.6–2.1 (*m*, 2H); 2.9–3.8 (*m*, 8H); 3.32 (*s*, CH_3O–C(4)). MS: 270 (4), 268 (4), 267 (8), 265 (8), 221 (2), 219 (2), 207 (2), 205 (2), 193 (2), 191 (2), 179 (2), 177 (2), 165 (7), 163 (7), 152 (3), 150 (3), 134 (7), 133 (73), 125 (8), 122 (6), 113 (7), 111 (10), 105 (7), 101 (9), 99 (7), 97 (12), 95 (6), 91 (6), 88 (15), 85

(15), 83 (7), 81 (15), 79 (8), 75 (15), 74 (8), 72 (6), 71 (100), 69 (13), 67 (11), 59 (10), 58 (9), 57 (29), 56 (8), 55 (27), 53 (8), 45 (13), 43 (28), 42 (9), 41 (57), 39 (18).

(R)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-C-ethoxy-1-C-methoxy-2-C,4-O-dimethyl-D-ribo-*hexitol* (**15d**). R_f (hexane/AcOEt 4:1) 0.49, $[\alpha]_D = +106.4°$ ($c = 2.3$, CCl_4). IR (CCl_4): 2980*s*, 2940*s*, 2900*m*, 2870*m*, 2835*m*, 2825*m*, 1460*w*, 1450*m*, 1440*w*, 1410*w*, 1375*m*, 1365*m*, 1315*w*, 1270*m*, 1235*s*, 1225*m*, 1190*s*, 1135*s*, 1110*s*, 1100*s*, 1085*s*, 1070*s*, 1055*s*, 1025*s*, 1010*s*, 1000*m*, 980*m*, 960*m*, 890*w*, 870*w*, 845*w*. ^{1}H-NMR (90 MHz, CCl_4): 0.88 (*d*, $J = 6.5$, CH_3–C(2)); 1.13 (*t*, $J = 7$, CH_3CH_2O); 1.43 (*td*, $J = 13.5$, 11, H_{ax}–C(3)); 1.7–2.2 (*m*, 2H); 3.0–3.85 (*m*, 6H); 3.31 (*s*, CH_3O–C(1)); 3.33 (*s*, CH_3O–C(4)). ^{13}C-NMR ($CHCl_3$): 113.14 (*s*); 76.42 (*d*); 74.49 (*d*); 56.56 (*q*); 55.20 (*t*); 51.00 (*q*); 34.29 (*t*); 32.82 (*d* and *t*); 15.5 (*q*); 14.90 (*q*). MS: 267 (2), 265 (2), 253 (8), 251 (8), 221 (5), 219 (5), 193 (3), 191 (3), 165 (9), 163 (9), 152 (5), 150 (5), 139 (3), 137 (4), 130 (5), 117 (7), 116 (97), 111 (7), 89 (15), 88 (23), 87 (9), 85 (14), 81 (8), 79 (6), 72 (10), 71 (100), 69 (10), 59 (10), 57 (21), 56 (7), 55 (9), 45 (10), 44 (8), 43 (11), 41 (33), 39 (11), 35.5 (6).

1,5-Anhydro-6-bromo-2,3,6-trideoxy-1,1-di-C-methoxy-2-C,4-O-dimethyl-D-ribo-*hexitol* (**15e**). R_f (hexane/AcOEt 4:1) 0.45, $[\alpha]_D = +112.7°$ ($c = 1.6$, CCl_4). IR (CCl_4): 2970*m*, 2940*s*, 2910*m*, 2870*m*, 2840*m*, 1460*m*, 1440*w*, 1415*w*, 1385*m*, 1360*m*, 1315*w*, 1270*w*, 1240*m*, 1225*m*, 1190*m*, 1135*s*, 1110*s*, 1100*s*, 1085*s*, 1070*s*, 1055*s*, 1025*s*, 1010*s*, 965*m*, 915*w*, 875*w*, 845*w*. ^{1}H-NMR (90 MHz, CCl_4): 0.88 (*d*, $J = 6.5$, CH_3–C(2)); 1.41 (*td*, $J = 13.5$, 11, H_{ax}–C(3)); 1.7–2.25 (*m*, 2H); 2.95–3.65 (*m*, 4H); 3.23 (*s*, ax. CH_3O–C(1)); 3.33 (*s*, eq. CH_3O–C(1) and CH_3O–C(4)). ^{13}C-NMR ($CDCl_3$): 113.08 (*s*); 76.32 (*d*); 74.53 (*d*); 56.55 (*q*); 51.04 (*q*); 47.35 (*q*); 34.17 (*t*); 32.86 (*t*); 32.81 (*d*); 14.89 (*q*). MS: 253 (6), 251 (6), 221 (2), 219 (2), 207 (1), 205 (1), 193 (2), 191 (2), 179 (1), 177 (1), 171 (4), 165 (6), 163 (6), 152 (3), 150 (3), 139 (3), 137 (3), 111 (9), 103 (6), 102 (100), 85 (18), 81 (8), 79 (7), 72 (15), 71 (94), 69 (7), 59 (11), 57 (24), 55 (10), 53 (7), 45 (11), 43 (12), 41 (43), 39 (18).

(R)-1,5-Anhydro-6-bromo-2,3,6-trideoxy-1-C-($^2H_3$*)methoxy-1-C-methoxy-2-C,4-O-dimethyl*-D-ribo-*hexitol* (**15f**). R_f (hexane/AcOEt 4:1) 0.45. IR (CCl_4): 2970*m*, 2940*m*, 2910*m*, 2870*m*, 2840*w*, 2825*w*, 2250*w*, 2240*w*, 2200*w*, 2130*w*, 2080*w*, 1465*m*, 1455*m*, 1445*w*, 1415*w*, 1380*m*, 1365*m*, 1320*w*, 1275*m*, 1245*m*, 1225*m*, 1190*s*, 1135*s*, 1115*s*, 1095*s*, 1065*s*, 1055*s*, 1025*s*, 985*w*, 965*m*, 935*w*, 915*w*, 900*w*, 880*w*, 850*w*. ^{1}H-NMR (90 MHz, CCl_4): 0.88 (*s*, CH_3–C(2)); 1.41 (*td*, $J = 13.5$, 11, H_{ax}–C(3)); 1.7–2.25 (*m*, 2H); 2.95–3.7 (*m*, 4H); 3.32 (*s*, CH_3O–C(1)); 3.33 (*s*, CH_3O–C(4)). MS: 256 (1), 254 (1), 253 (2), 251 (2), 221 (1), 219 (1), 193 (1), 191 (1), 165 (4), 163 (4), 152 (3), 150 (3), 139 (2), 137 (2), 119 (4), 108 (1), 106 (5), 105 (100), 102 (< 1), 85 (7), 81 (5), 71 (64), 59 (7), 58 (10), 57 (8), 55 (6), 43 (5), 41 (167), 39 (5).

Ethyl 5,6-Anhydro-2,3-dideoxy-2-C,4-O-dimethyl-D-ribo-*hexonate* (**32a**). R_f (hexane/AcOEt 4:1) 0.17. IR ($CHCl_3$): 3010*w*, 2990*s*, 2940*m*, 2910*m*, 2885*m*, 2830*m*, 1730*s*, 1465*m*, 1395*w*, 1380*m*, 1305*m*, 1180*s*, 1165*s*, 1140*s*, 1115*s*, 1095*s*, 1045*m*, 1025*m*, 970*w*, 945*w*, 920*w*, 895*w*, 860*m*, 850*m*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.17 (*d*, $J = 7$, CH_3–C(2)); 1.26 (*t*, $J = 7$, CH_3CH_2O); 1.64 (*ddd*, $J = 14$, 7.5, 4, H–C(3)); 2.03 (*ddd*, $J = 14$, 9, 6.5, H′–C(3)); 2.4–3.25 (*m*, 5H); 3.38 (*s*, CH_3O–C(4)); 4.13 (*q*, $J = 7$, CH_3CH_2O). MS: 202 (0.4, M^+), 171 (0.4), 160 (5), 159 (48), 157 (23), 145 (25), 141 (5), 128 (7), 127 (11), 113 (8), 111 (25), 102 (20), 101 (34), 100 (6), 99 (79), 97 (20), 88 (18), 87 (100), 86 (6), 85 (83), 81 (10), 74 (16), 73 (6), 72 (10), 71 (55), 69 (27), 67 (12), 59 (22), 58 (10), 57 (26), 56 (10), 55 (18), 53 (8), 45 (45), 43 (32), 42 (11), 41 (49), 39 (17).

Methyl 5,6-Anhydro-2,3-dideoxy-2-C,4-O-dimethyl-D-ribo-*hexonate* (**32b**). R_f (hexane/AcOEt 4:1) 0.13. IR ($CHCl_3$): 3010*w*, 2990*m*, 2960*m*, 2940*m*, 2885*w*, 2830*w*, 1730*s*, 1465*m*, 1435*m*, 1380*m*, 1170*m*, 1140*m*, 1115*m*, 1090*m*, 1040*m*, 990*w*, 965*w*, 935*w*, 895*w*, 860*m*, 845*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.20 (*d*, $J = 7$, CH_3–C(2)); 1.65 (*ddd*, $J = 14$, 7, 3.5, H–C(3)); 2.03 (*ddd*, $J = 14$, 9, 7.5, H′–C(3)); 2.4–3.2 (*m*, 5H); 3.40 (*s*, CH_3O–C(4)); 3.71 (*s*, CH_3O–C(1)). MS: 157 (6), 146 (5), 145 (54), 127 (5), 119 (8), 113 (9), 111 (12), 105 (6), 101 (19), 99 (7), 97 (9), 88 (24), 87 (61), 86 (6), 85 (100), 81 (5), 72 (7), 71 (22), 69 (15), 67 (7), 59 (18), 58 (5), 57 (27), 56 (6), 55 (15), 53 (6), 45 (32), 43 (17), 41 (32), 39 (12).

2,3,6-Trideoxy-6-iodo-2-C,4-O-dimethyl-D-arabino-*hexonolactone* (**33**). A solution of 48 mg (0.2 mmol) of **28** and 170 mg (1.13 mmol) of NaI in 3 ml butanone was heated to reflux for 30 min. The mixture was diluted with Et_2O, washed with 3 portions of H_2O, dried ($MgSO_4$) and concentrated *i.v.* Chromatography on 40 g of silica gel (hexane/AcOEt 4:1) and bulb-to-bulb distillation at 140°/0.025 Torr afforded 51 mg (88%) of **33** as a colourless oil. R_f (hexane/AcOEt 2:1) 0.25. IR ($CHCl_3$): 3030*w*, 2990*m*, 2930*s*, 2890*m*, 2830*m*, 1750*s*, 1460*m*, 1410*w*, 1380*m*, 1360*m*, 1335*m*, 1315*m*, 1280*w*, 1235*w*, 1165*s*, 1100*s*, 1015*m*, 980*w*, 960*w*, 915*w*, 840*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.24 (*d*, $J = 6.7$, CH_3–C(2)); 1.77 (*ddd*, $J = 14.2$, 12, 6.7, H–C(3)); 2.10 (*ddd*, $J = 14.2$, 6.7, 3.7, H′–C(3)); 2.82 (*sext.*, $J = 6.7$, H–C(2)); 3.41 (*s*, CH_3O–C(4)); 3.46 (*d*, $J = 4.5$, 2H–C(6)); 3.54 (*ddd*, $J = 12$, 6.7, 3.7, H–C(4)); 4.08 (*dt*, $J = 6.7$, 4.5, H–C(5)).

(S)-1,5-Anhydro-2,3,6-trideoxy-1-C-ethoxy-6-iodo-1-C-methoxy-2-C,4-O-dimethyl-D-arabino-*hexitol* (**35**). The intermediate iodide **35** obtained from **13b** by the above-mentioned method was purified by flash chromatography (hexane/AcOEt 19:1). R_f (hexane/AcOEt 4:1) 0.39. IR (CCl_4): 2980*s*, 2935*s*, 2900*m*, 2815*m*, 1465*m*,

1455*m*, 1445*m*, 1415*w*, 1410*w*, 1385*m*, 1380*m*, 1370*m*, 1350*w*, 1335*w*, 1315*w*, 1295*w*, 1275*w*, 1240*s*, 1225*m*, 1200*m*, 1175*s*, 1110*s*, 1080*s*, 1045*s*, 1015*m*, 985*s*, 960*m*, 910*w*, 895*w*, 860*w*. ^{1}H-NMR (90 MHz, CCl_4): 1.01 (*d*, J = 7, CH_3–C(2)); 1.18 (*t*, J = 7, CH_3CH_2O); 1.55–2.35 (*m*, 3H); 3.05–3.75 (*m*, 6H); 3.20 (*s*, CH_3O–C(1)); 3.32 (*s*, CH_3O–C(4)). MS: 344 (0.3, M^+), 313 (2), 299 (1), 267 (2), 265 (1), 211 (3), 185 (3), 171 (4), 130 (3), 125 (5), 116 (53), 111 (7), 102 (5), 97 (5), 89 (7), 88 (13), 85 (11), 81 (6), 72 (8), 71 (100), 59 (10), 57 (15), 56 (5), 55 (8), 45 (8), 43 (9), 41 (23), 39 (5).

Table 4. *Product Ratios of the Reactions of* **13**, **15** *and* **17** *with NaI/Zn*

Run[a])	Starting materials	Products[b])	Ratio of products [%]		
			at 80°	at 50°	at r.t.
1a	**13b**	**14b/14a**		32 : 68	
1b[c])				31 : 69	
2a[d])				32 : 68	
2b[c])[d])				28 : 72	
3a			49 : 51	34 : 66	
3b[c])			50 : 50	40 : 60	
3c[e])			48 : 52	only traces (1 : 3)	
4				35 : 65	29 : 71
5	**13d**	**14a/14b**	63 : 37	63 : 37	62 : 38
6a			66 : 33	66 : 34	66 : 34
6b[f])			65 : 35		
6c			68 : 32[g])		
6d[f])	**14b**	**14b/14a/16b**	98.7 : 0.3 : 1		
7	**15b**	**16b/16a**	53 : 47	54 : 46	46 : 54
8	**15d**	**16a/16b**	70 : 30	71 : 29	71 : 29
9a	**13d/15b**	**14a/14b**	69 : 31	72 : 28	66 : 34
		16b/16a	57 : 43	56 : 44	50 : 50
9b	**13b/15d**	**14b/14a**	47 : 53	46 : 54	37 : 63
		16a/16b	71 : 29	69 : 31	68 : 32
10a	**13f**	**14d/14b**[h])	65 : 35	63 : 67	64 : 36
10b	**15f**	**16d/16b**[h])	69 : 31	65 : 35	63 : 37
11a	**13c**	**14c/14a**[i])	67 : 33	73 : 27	78 : 22
11b	**15c**	**16c/16a**[i])	78 : 22	76 : 24	77 : 23
12a	**17**	**18/19**	18 : 82[k])	21 : 79[l])	
12b	**17**	**18/19**	18 : 82[k])	22 : 78[l])	
12c	**17**	**18/19**	18 : 82[k])	22 : 78[l])	

[a]) Identical figure means: the reactions were made with the same solvents and reagents.
[b]) Unless otherwise stated, the ratio of products was determined by GC.
[c]) The reaction with Zn was performed in the presence of 50 µl of pyridine.
[d]) The black powdered Zn was prepared from K and $ZnBr_2$ in a ratio of 2.45 to 1.
[e]) Without NaI.
[f]) The reaction with Zn was performed in the presence of 100 µl of EtOH.
[g]) Starting from 20 mg of **13d**, 17 mg of crude product was obtained. Redistillation of the evaporated Et_2O afforded further 0.5 mg of product (**14a/14b** 68 : 32).
[h]) The ratio of products was determined by integration of the singulets at 3.68 ppm (CH_3O–C(1)) and 3.26 ppm (CH_3O–C(4)) in the ^{1}H-NMR *(Varian FT-80)*.
[i]) The ratio of products was determined by GC/MS: integration of the peaks at *m/z* 102 and 105 (ethyl and trideuteriocthyl propionate).
[k]) At reflux temp.
[l]) At 60°.

General Method for the Reduction of the Ortholactones **13** *and* **15**. A solution of 5–10 mg (0.03 mmol) of ortholactone and a 20-fold excess of NaI (100–200 mg) in 1 ml of butanone was stirred at 80° for 30 min and then allowed to cool down to r.t. After addition of 1 ml of a freshly prepared suspension of black powdered Zn in anh. THF [29], the resulting mixture was stirred at 80° (30 min), 50° (60 min) or r.t. (4–6 h), respectively. After addition of 5 ml of 1M $NaHCO_3$ to the ice-cold mixture, the product was extracted with 3 portions of Et_2O. The org. layer was dried (K_2CO_3) and concentrated at 40°/300 Torr. The residue was dissolved in Et_2O, treated with charcoal, and filtered through *Celite*. After evaporation of the solvent at 40°/300 Torr, the crude product (5–10 mg) was analyzed (GC, ^{1}H-NMR, or GC/MS). The exper. details are listed in *Table 4*.

The Reduction of **17** *with NaI/Zn*. Analogous conditions as for the reduction of the ortholactones were used (reaction time: 2 h at 100 and 4 h at 60°). The results are listed in *Table 4*.

Methyl (2S,4S)-4-Methoxy-2-methylhex-5-enoate (**14b**). A mixture of 173 mg (0.73 mmol) **28** and 585 mg (8.9 mmol) of powdered Zn [1] [4] in 10 ml of PrOH/H_2O 95:5 was heated to reflux for 60 min. The mixture was diluted with AcOEt, washed with 1M H_2SO_4 (1×) and brine (until the washings were neutral), dried ($MgSO_4$), and concentrated *i.v.* to afford 119 mg of **14e**. After esterification with CH_2N_2, chromatography on 40 g of silica gel (hexane/AcOEt 9:1) and subsequent bulb-to-bulb distillation at 90°/12 Torr gave 88 mg (70%) of **14b** as a liquid. R_f (hexane/AcOEt 4:1) 0.37, R_t (GC) 6.58 min, $[\alpha]_D = +0.9°$ ($c = 3.4$, $CHCl_3$). IR ($CHCl_3$): 3080*w*, 3020*w*, 3005*m*, 2980*m*, 2950*m*, 2940*m*, 2880*w*, 2850*w*, 2830*w*, 1730*s*, 1645*w*, 1465*m*, 1435*m*, 1420*w*, 1380*m*, 1370*w*, 1285*m*, 1195*m*, 1170*s*, 1130*m*, 1090*s*, 1040*w*, 995*m*, 965*w*, 930*m*, 855*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.18 (*d*, $J = 7$, CH_3–C(2)); 1.47 (*ddd*, $J = 13.5$, 7, 5, H–C(3)); 2.02 (*dt*, $J = 13.5$, 7.5, H′–C(3)); 2.59 (br. *sext.*, $J = 7$, H–C(2)); 3.26 (*s*, CH_3O–C(4)); 3.56 (*tdd*, $J = 7.5$, 5, 1, H–C(4)); 3.68 (*s*, CH_3O–C(1)); 5.05–5.4 (*m*, 2H–C(6)); 5.68 (*ddd*, $J = 18,9$, 7.5, H–C(5)). ^{13}C-NMR ($CDCl_3$): 176.74 (*s*); 138.11 (*d*); 117.23 (*t*); 80.83 (*d*); 56.10 (*q*); 51.36 (*q*); 39.38 (*t*); 36.26 (*d*); 17.33 (*q*). MS: 157 (0.3), 141 (4), 140 (1), 125 (2), 113 (6), 88 (8), 85 (25), 84 (5), 81 (6), 72 (6), 71 (100), 59 (4), 55 (6), 41 (35), 39 (5). Anal. calc. for $C_9H_{16}O_3$ (172.22): C 62.77, H 9.36; found: C 62.87, H 9.54.

Ethyl (2S,4S)-4-Methoxy-2-methylhex-5-enoate (**14a**). As described above, 195 mg (0.83 mmol) of **28** and 630 mg (9.7 mmol) of powdered Zn in 10 ml of PrOH/H_2O 95:5 afforded 145 mg of **14e** as a yellowish oil. The solution of crude **14e**, 300 µl of Et_3N, and 1 ml of EtBr in 3 ml of HMPA was kept for 30 min at 60°. The mixture was diluted with Et_2O, washed with 1M $NaHCO_3$ (3×), dried ($MgSO_4$), and concentrated at 40°/400 Torr. Chromatography on 20 g of silica gel (hexane/AcOEt 9:1) and subsequent bulb-to-bulb distillation at 100°/12 Torr gave 62 mg (40%) of **14a** as a liquid. R_f (hexane/AcOEt 4:1) 0.41, R_t (GC) 7.71 min, $[\alpha]_D = -1.9°$ ($c = 1.5$, $CHCl_3$). IR ($CHCl_3$): 3080*w*, 3020*w*, 2985*m*, 2940*m*, 2910*m*, 2880*w*, 2830*w*, 1725*s*, 1640*w*, 1460*m*, 1420*w*, 1380*m*, 1180*s*, 1090*s*, 1035*w*, 1025*w*, 980*m*, 965*w*, 930*m*, 865*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.17 (*d*, $J = 7$, CH_3–C(2)); 1.25 (*t*, $J = 7$, CH_3CH_2O); 1.47 (*ddd*, $J = 13.5$, 6.7, 5.5, H–C(3)); 2.04 (*dt*, $J = 13.5$, 7.5, H′–C(3)); 2.58 (br. *sext.*, $J = 7$, H–C(2)); 3.25 (*s*, CH_3O–C(4)); 3.57 (*td*, $J = 7.5$, 5.5, H–C(4)); 4.13 (*q*, $J = 7$, CH_3CH_2O); 5.05–5.35 (*m*, 2H); 5.70 (*ddd*, $J = 18$, 9, 7.5, H–C(5)). ^{13}C-NMR ($CDCl_3$): 176.33 (*s*); 138.17 (*d*); 117.25 (*t*); 80.85 (*d*); 60.05 (*t*); 56.08 (*q*); 39.27 (*t*); 36.31 (*d*); 17.34 (*q*); 14.24 (*q*). MS: 141 (6), 125 (2), 113 (7), 102 (6), 85 (23), 84 (5), 81 (7), 74 (8), 72 (6), 71 (100), 55 (6), 43 (5), 41 (32), 39 (5). Anal. calc. for $C_{10}H_{18}O_3$ (186.25): C 64.49, H 9.74; found: C 64.70, H 10.00.

Methyl (2R,4S)-4-Methoxy-2-methylhex-5-enoate (**16b**). The reaction of 20 mg of **15e** with NaI/black powdered Zn according to the above-mentioned general method gave 13 mg of **16b**, which was purified by TLC (hexane/AcOEt 4:1). R_f (hexane/AcOEt 4:1) 0.39. R_t (GC) 6.15 min. IR ($CHCl_3$): 3070*w*, 3020*w*, 2980*m*, 2950*s*, 2930*s*, 2870*m*, 2850*m*, 2820*w*, 1730*s*, 1460*m*, 1435*m*, 1420*w* (sh), 1380*m*, 1170*m*, 1105*m*, 1080*s*, 1050*m*, 990*m*, 970*w*, 930*m*, 905*w*, 845*w*. ^{1}H-NMR (90 MHz, $CDCl_3$): 1.17 (*d*, $J = 7.5$, CH_3–C(2)); 1.5–2.1 (*m*, 2H); 2.62 (br. *sext.*, $J = 7.5$, H–C(2)); 3.26 (*s*, CH_3O–C(4)); 3.54 (*td*, $J = 7.3$, 5, H–C(4)); 3.68 (*s*, CH_3O–C(1)); 5.05–5.35 (*m*, 2H); 5.69 (*ddd*, $J = 18$, 9, 7.3, H–C(5)). MS: 157 (0.5), 154 (1), 141 (4), 125 (3), 113 (9), 88 (11), 85 (32), 81 (12), 79 (6), 77 (6), 72 (11), 71 (100), 59 (6), 57 (10), 55 (15), 53 (8), 45 (6), 44 (15), 43 (22), 42 (6), 41 (57), 39 (18), 35.5 (12).

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