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KINETIC CYCLOHEXYLIDENATION AND ISOPROPYLIDENATION OF ALDOSE DIETHYL DITHIOACETALS

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ABSTRACT

Aldose diethyl dithioacetals react with 1.2 equivalents of 1-ethoxycyclohexene or 2-methoxypropene in *N,N*-dimethylformamide at 0° with *p*-toluenesulfonic acid as catalyst to give the five-membered ring acetal attached to the two terminal oxygen atoms as the major product in every case. In most instances, a small proportion of the terminal, six-membered ring acetal was also obtained, and in a few cases, terminal seven-membered ring acetals were also isolated. Cyclohexylidenation at room temperature gave the same products, but isopropylidenation at room temperature resulted in certain cases in partial rearrangement. Cyclohexylidenation reactions gave smaller proportions of the minor six- and seven-membered ring products. Structures were established from ^{13}C-n.m.r. and mass spectra. The ^{13}C-n.m.r. spectra of model cyclohexylidene derivatives were found very similar to those of isopropylidene derivatives previously studied. Two new features useful for structure determination were noted when the spectra of the precursor diols were compared with those of both types of derived acetals; the chemical shift of C-2 of a 1,3-propanediol derivative was shifted upfield by 6–9 p.p.m. on acetalation and the shifts of the diol carbon atoms attached to oxygen were affected according to the type of acetal and ring-size formed. Similar observations were made for methylene acetals.

INTRODUCTION

Kinetic acetalation of cyclic carbohydrates gives quite different products than those obtained under thermodynamic control[1]. Acetalations performed under thermodynamic control normally yield the polyacetalated derivative (or derivatives) having the most stable structure[2,3]. In contrast, kinetic acetalation gives products derived from initial formation of a bond to the most reactive hydroxyl group, normally the least hindered one. A significant advantage of the latter method is that the acetalation process can be stopped at the monoacetal stage or carried further as desired[1].

This latter feature of kinetic acetalation led us to study its applicability to aldose diethyl dithioacetals. These compounds could be attractive synthetic inter-

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mediates if more-selective and predictable ways of protecting their hydroxyl groups were available. The present study surveyed isopropylidene[1] and cyclohexylidene acetals[4]. The latter derivatives were examined because they are known[5] to be more stable than isopropylidene acetals to acid conditions, such as might be used in subsequent thermodynamic acetalizations of some of the remaining hydroxyl groups. In addition, we have examined the ^{13}C-n.m.r. parameters of model cyclohexylidene derivatives to determine whether useful structural correlations could be made.

Two previous reports of selective kinetic acetalations of particular aldose diethyl dithioacetals suggested that terminal 1,3-dioxolane acetals would be the major products. Miljkovic and Hagel[6] obtained a 4,5-*O*-isopropylidene derivative of 2-acetamido-2-deoxy-D-xylose diethyl dithioacetal in good yield. Earlier, Wolfrom and Parekh[7] had obtained terminal ethylidene derivatives (one of two possible diastereomers) in poor to fair yields from reactions performed under kinetic conditions.

RESULTS AND DISCUSSION

Model compounds. — Structural determination of carbohydrate acetals has traditionally been performed by chemical methods, supplemented in the case of benzylidene and other acetals derived from aldehydes, by ^{1}H-n.m.r. spectroscopy[8], and later by ^{13}C-n.m.r. spectroscopy. Burden and Stoddart observed only small differences in the ^{13}C-n.m.r. spectra of different types of methylene acetals[9]. However, substituents on the acetal carbon atom and elsewhere cause ^{13}C-n.m.r. parameters in rings having different sizes and conformations to have different values that can be utilized for structural assignment. A number of ^{13}C-n.m.r. parameters were shown to indicate acetal ring-size and configuration for benzylidene acetals[10,11]. Subsequently, it was shown that ^{13}C-n.m.r. parameters of isopropylidene acetals are even more indicative of ring-size[12,13].

The spectra of isopropylidene acetals show two distinctive features[12,13]. The ^{13}C-n.m.r. chemical shifts of the acetal carbon fall in the ranges 108.1–115.7, 97.1–101.1, and 100.8–102.3 p.p.m. for five-, six- and seven-membered rings, respectively[13]. The chemical-shift differences between the signals of the two methyl groups are 9.8–10.9 p.p.m. for those from 2,2-dimethyl-1,3-dioxane rings fixed in single chair conformations but are <5 p.p.m. for those from 1,3-dioxolane or 1,3-dioxepane derivatives[13]. Similar effects might be expected for cyclohexylidene derivatives, and we have prepared model compounds to confirm this expectation.

Table I lists the ^{13}C-n.m.r. chemical shifts for the parent diols, and the methylene, cyclohexylidene, and isopropylidene derivatives of the diols. Some of the data for the acetals have been taken from the literature[12,14,15]. As expected, the shifts observed for the acetal carbons of the various types of cyclohexylidene acetals were very similar to those of the analogous isopropylidene derivatives, and all values fell within the ranges previously established[13]. When the carbohydrate examples were included (see Table II), only the range for seven-membered ring

TABLE I

^{13}C-N.M R CHEMICAL SHIFTS OF MODEL COMPOUNDS

Compound	*Chemical shifts*[a]									
	Alcohol carbon atoms[b]					*Acetal carbon*	*Other cyclohexylidene carbon atoms*			*Isopropylidene carbon atoms*
	C-1	*C-2*	*C-3*	*C-4*	*C-5*		*C-2*	*C-3*	*C-4*	
3a	63.7	63.7								
3b	64.5	64.5				95.0				
3c[c]	64.6	64.6				108.5				25.7, 25.7
3d	64.4	64.4				109.0	35.5	24.2	25.5	
4a	67.8	68.3	18.9							
4b[d]	70.8	72.1	18.1			94.8				
4c[d]	70.8	71.9	18.5			108.6				25.9, 27.1
5a	59.2	34.9	59.2							
5b	67.0	26.8	67.0			94.5				
5c[c]	59.9	25.8	59.9			97.7				24.3, 24.3
5d	59.1	26.0	59.1			97.8	33.2	22.6	26.0	
6a	60.0	40.8	66.3	23.5						
6b[e]	66.6	33.7	72.8	21.7		93.8				
6c[e]	59.9	33.0	65.0	22.3		98.2				30.1, 19.2
7a	24.0	68.4	46.6	68.4	24.0					
7b[e]	21.6	72.6	41.1	72.6	21.6	93.4				
7c[e]	22.2	65.1	40.5	65.1	22.2	98.4				30.4, 19.9
8a	23.5	64.9	46.3	64.9	23.5					
8b[e]	19.2	67.5	37.5	67.5	19.2	86.7				
8c[e]	21.7	62.7	41.5	62.7	21.7	100.0				25.2, 25.2
9a	62.0	29.9	29.9	62.0						
9b	67.5	29.7	29.7	67.5		94.7				
9c[c]	62.1	29.9	29.9	62.1		100.9				25.1, 25.1
9d	61.3	30.1	30.1	61.3		100.9	34.3	23.3	26.0	

[a]In chloroform-*d*; p.p.m. downfield from internal Me_4Si. [b]Carbon atoms in all compounds numbered as in diol. [c]Ref. 12. [d]Ref. 14. [e]Ref. 15.

cyclohexylidene derivatives needed to be altered; it was extended very slightly further downfield, to 102.4 p.p.m.

Two trends in these shifts not previously noted were evident when the data from the diols were compared with those from the derived acetals. The largest effect occurred in 1,3-dioxane derivatives in chair conformations. C-2 of 1,3-propanediol was shielded by 8.1–9.1 p.p.m. on acetal formation. In contrast, the effects of acetal formation on the chemical shifts of all carbons of 1,2-ethanediol and 1,4-butanediol were <2 p.p.m. The effect is attenuated somewhat by substitution, decreasing to 5.5–6.1 p.p.m. when there are equatorial substituents on both C-4 and C-6 of the 1,3-dioxane ring. This large effect on forming 1,3-dioxane rings could be useful for structural studies in a number of situations. For isopropylidene and cyclohexylidene derivatives, the difference between the chemical shifts of the acetal carbons in six- and seven-membered rings is not large. If the six-membered

TABLE II

^{13}C-N.M.R. CHEMICAL SHIFTS[a]

Compound	C-1	C-2	C-3	C-4	C-5	C-6	Acetal C	Other cyclohexylidene carbon atoms					Isopropylidene		SCH_2CH_3	
								C-2	C-6	C-3	C-4	C-5	CH_3	CH_3	CH_2	CH_3
10a[b]	55.1	71.9	70.9	71.6	64.1										24.4	14.5
															24.6	14.5
10b	55 6	71.2	70.4	75.9	66.8		109.9	36.7	34.9	24.1	23.8	25.8			25.2	14.5
															23.8	14.5
10c	54.7	70.0	71.9	63.1	64.1		99.1	37.4	28.3	22.9	22.8	25.6			25.0	14.5
															24.1	14.5
10f	55.8	71.2	70.5	76.3	67.2		109.4						26.9	25.3	25.4	14.6
															23.7	14.5
10g	54.6	70.0	72.8	62.8	64.9		99.1						28.4	19.5	24.7	14.6
															24.1	14.6
11a[b]	54.7	76.9	71.7	73.8	63.3										25.3	14.6
															25.3	14.6
11b	54.7	71.2	71.5	75.1	65.3		109.9	36.2	34.8	24.1	23.9	25.7			25.3	14.7
															25.3	14.6
12a[b]	54.6	74.2	70.6	73.2	63.4										24.9	14.5
															24.6	14.5
12b	55.1	73.4	70.8	77.2	65.7		110 3	36 1	35.1	24.1	23.9	25.5			25.2	14.5
															24.3	14.5
12c	53 4	74.1	70.7	66.0	64.4		99.6	38.2	27.4	[c]	[c]	[c]			[c]	14.5
																14.5
12d	56.1	71.1	76.8	77.5	62.1		110.2	36.9	36.4	[c]	[c]	[c]			[c]	14.5
																14.5
12e	53.2	72.6	70.7	71 2	59.8		102.2	34.6	33.2	23.3	25.0	26.0			25.5	14.4
															25.1	14.3
12f	55.2	73 2	70.9	77.6	66.0		109.6						26.6	25.5	25.5	14.5
															24.3	14.5
12g	55.9	71.2	77.1	78.0	62.3		109.6						27.3	26.9	24.5	14.5
															25.5	14.5
12h	53.6	71.9	74 1	65.2	65.9		99.7						29.7	18.9	25.8	14.8
															25.0	14 7

12i	53.1	80.7	79.9	70.7	65.0		110.1						27.2	27.2	25.1 25.1	14.5 14.5
12j	51.4	76.2	54.4	73.5	62.8		100.4						29.6	19.1	25.5 25.5	14.6 14.6
12k	52.8	71.8	71.4	72.3	60.6		102.0						26.0	22.8	24.7 24.5	14.5 14.4
13a[b]	54.5	75.5	69.3	73.3	71.5	63.7									24.9 24.6	14.5 14.5
13b	55.3	75.2[d]	69.1	74.5[d]	75.0	66.6	109.8	36.7	34.9	24.1	23.8	25.6			25.2 24.1	14.8 14.6
13c	54.7	75.4	69.6	74.1	63.1	63.8	99.1	37.2	28.4	[c]	[c]	[c]			[c]	14.5 14.4
13d	55.0	75.4	68.2	74.5	71.7	60.1	102.4	35.7	33.0	[c]	[c]	[c]			[c]	14.5 14.6
13f	55.3	75.6[d]	69.0	74.4[d]	75.1[d]	66.9	109.2						26.9	25.7	25.4 24.1	14.5 14.5
14a[b]	55.1	71.6	70.2	69.7	70.4	63.7									24.2 24.3	14.4 14.4
14b	55.7	71.9[d]	71.3[d]	70.7[d]	75.9	66.3	109.0	36.1	35.0	24.0	23.8	25.4			25.2 23.8	14.5 14.5
14c	56.0	70.6	68.4	70.3	63.4	65.3	99.2	38.2	27.3	23.0	23.0	25.6			25.3 24.2	14.7 14.5
14d	55.5	71.3	68.9	[c]	[c]	61.7	101.4	36.8	33.1	[c]	[c]	[c]			[c]	[c]
14f	55.8	71.9	71.9	70.6	76.2	66.5	109.2						27.2	26.5	25.4 24.0	14.5 14.5
14g	55.5	72.1	71.2	81.0	78.0	63.3	109.4						27.0	25.4	25.4 23.9	14.5 14.5
14h	55.9	71.6	68.4	70.4	63.2	66.0	99.1						29.5	18.1	25.2 24.3	14.6 14.6

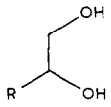
[a]P.p.m. downfield from internal tetramethylsilane in chloroform-*d* solution unless otherwise indicated. [b]In chloroform-*d* containing a few drops of dimethyl sulfoxide-d_6. [c]Could not be assigned to one compound in the mixture. [d]Assignments not certain.

ring derivative existed as a mixture of two chair conformations or if only one compound, a seven-membered ring derivative, were available, the presence or absence of this large effect could confirm a postulated structure. The structures of six-membered methylene derivatives could also be confirmed by observation of this shift.

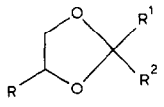
The large upfield shift for 1,3-dioxane derivatives occurs because the carbon atom acquires an additional γ-gauche effect on acetal formation, which is transmitted over two routes of fixed stereochemistry. The carbon analogues of the six-membered ring compounds show similar effects; the shifts for C-3 of pentane, C-4 of heptane and of cyclohexane are 34.5, 29.5, and 27.8 p.p.m., respectively[16]. The absence of any effect for the 1,3-dioxepane derivatives is surprising, particularly since an upfield shift is observed for the analogues alkanes. The shifts for C-3 of hexane, C-4 of octane and cycloheptane are 32.0, 29.7, and 29.4 p.p.m. respectively[16]. A smaller effect for cycloheptane than for cyclohexane would be anticipated because the gauche interaction is transferred over only route in the former compound and because the relationships between the γ-carbon atoms in it deviate considerably from gauche in the several conformations that might be expected to be present[17].

Buchanan *et al.*[13] have observed that chemical shifts of signals of acetal carbon atoms from 2,2-dimethyl-1,3-dioxane derivatives in twist conformations are in the range 100.6–101.1 p.p.m., similar to those from 2,2-dimethyl-1,3-dioxepane derivatives. It should be noted that only one of the likely twist conformations, one with a pseudo-C_2 axis through atoms 2 and 5 (2,5 twist), gives shifts in this range[15]. To test whether the large upfield shift on acetal formation could be used to distinguish between these two possible ring-sizes, the chemical shifts of *cis*- and *trans*-2,2,4,6-tetramethyl-1,3-dioxane were compared with those of their precursor diols (see Table I). The *cis*-derivative exists in a chair conformation. The chemical shift of C-5 of this compound was 6.1 p.p.m. upfield of the signal of the same carbon in *meso*-2,4-pentanediol, a slightly smaller effect than observed above. The magnitude of the upfield effect for C-5 of *trans*-2,2,4,6-tetramethyl-1,3-dioxane, which is known to exist in a 2,5 twist conformation[15], was 4.8 p.p.m. This value is not sufficiently large to indicate whether an acetal ring in an unknown compound is a 1,3-dioxane ring in a twist conformation or a 1,3-dioxepane ring.

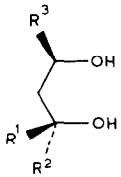
There were also significant but less marked differences between the ^{13}C-n.m.r. chemical shifts of the carbon atoms directly attached to oxygen in the diols as compared to the shifts of the same carbon atoms in the isopropylidene and cyclohexylidene acetals. Formation of five-membered ring acetals result in downfield shifts of ~1 p.p.m. for the primary carbon atoms of model compounds **3b–3d**. When at least one carbon atom was secondary, as in **4b** and **4c** and in all the carbohydrate examples, significant downfield shifts of >2 p.p.m. were always observed for primary carbon atoms and of 3–5 p.p.m. were observed for secondary carbon atoms. In contrast, shifts for the same carbon atoms on formation of six-membered isopropylidene or cyclohexylidene acetals were small. Formation of



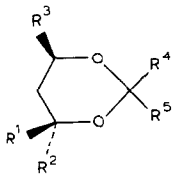
3a R = H
4b R = Me



b $R^1 = R^2 = H$
c $R^1 = R^2 = Me$
d R^1 and $R^2 = -(CH_2)_5-$

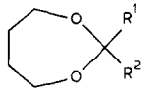


5a $R^1 = R^2 = R^3 = H$
6a $R^1 = Me, R^2 = R^3 = H$
7a $R^1 = R^3 = Me, R^2 = H$
8a $R^1 = H, R^2 = R^3 = Me$

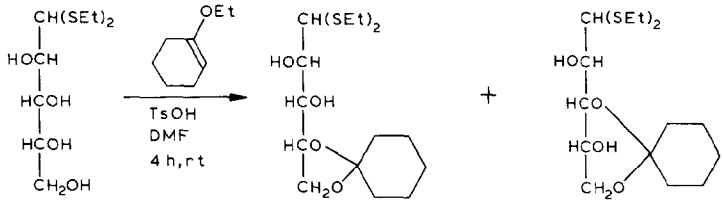


b $R^4 = R^5 = H$
c $R^4 = R^5 = Me$
d R^4 and $R^5 = -(CH_2)_5-$

9a



b $R^1 = R^2 = H$
c $R^1 = R^2 = Me$
d R^1 and $R^2 = -(CH_2)_5-$



10a **10b** 59% **10c** 8%

seven-membered rings caused slight upfield shifts for the cyclohexylidene derivative and had little effect on the shifts of the same carbon atoms of isopropylidene derivatives.

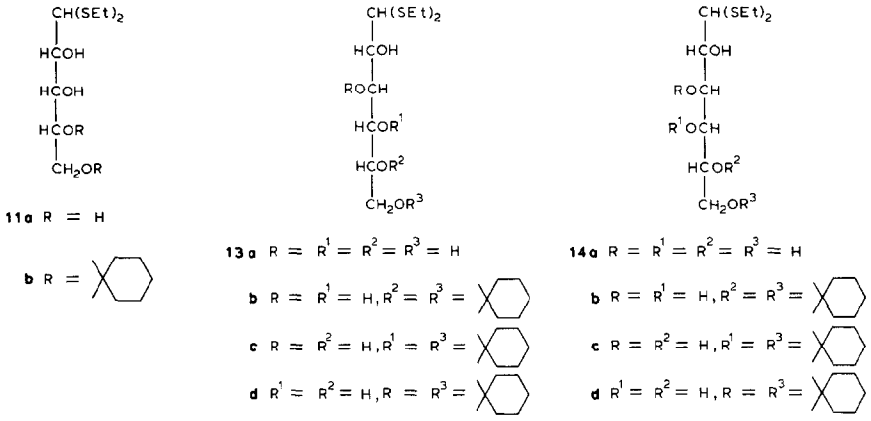
Comparison of the chemical shifts of the same carbon atoms of methylene acetals with those of their precursor diols provides an indication of ring size. The signals of the carbon atoms of ethylene glycol were shifted downfield by 0.8 p.p.m. on formation of a methylene acetal, whereas the terminal carbon signals of 1,3-propanediol and 1,4-butanediol are shifted downfield by 7.7 and 5.5 p.p.m., respectively. The small chemical-shift effect observed on methylene acetal formation from ethylene glycol results from offsetting β- and γ-effects for each carbon. For the

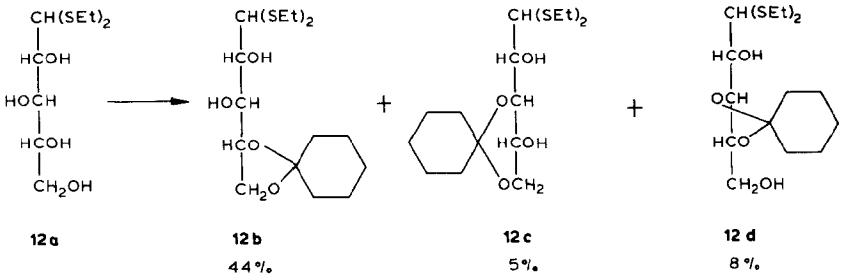
other two diols, acetal formation results in only β-effects being added to the carbon atoms bearing hydroxyl groups. Thus, much larger changes in chemical shift were observed. These varying effects could be used for ring-size assignment for this type of acetal. However, the most useful indicator of methylene ring-size is likely to remain the size of the geminal proton–proton coupling constant in the $-OCH_2-$ group[9].

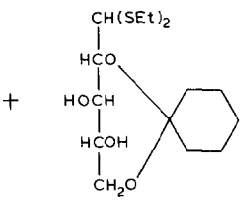
Cyclohexylidene acetals. — Cyclohexylidenation of D-arabinose diethyl dithioacetal (**10a**) with 1.2 equivalents of 1-ethoxycyclohexene in anhydrous *N,N*-dimethylformamide containing 5% of anhydrous *p*-toluenesulfonic acid at room temperature gave 2 products, the 4,5-*O*-cyclohexylidene (**10b**) (59%) and 3,5-*O*-cyclohexylidene (**10c**) (8%) derivatives. Compounds **10b** and **10c** were readily separated by column chromatography. The structures of these compounds were established by a combination of ^{13}C-n.m.r. spectroscopy and mass spectrometry. In the ^{13}C-n.m.r. spectrum of **10b** (see Table II), the chemical shift of the acetal carbon atom was 109.9 p.p.m., indicating the presence of a five-membered ring. The chemical shifts of the carbon atoms in the cyclohexylidene ring α to the acetal carbon (subsequently to be called α-cyclohexyl carbon atoms) were slightly different, appearing at 36.7 and 34.9 p.p.m. Buchanan and co-workers[13] have previously observed that the chemical-shift differences between isopropylidene methyl carbon atoms of 5-membered ring derivatives are on the order of 1–2 p.p.m.

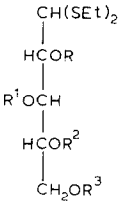
Comparison of the chemical shifts of the chain carbon atoms from the acetals with those from the starting materials allowed assignment of the location of the acetal ring. Schnarr *et al.*[18] have assigned the chemical shifts of the chain carbon atoms of several aldose diethyl dithioacetals for solutions in dimethyl sulfoxide-d_6. The same compounds were examined here in chloroform-*d* containing a few drops of dimethyl sulfoxide-d_6. The differences in shifts between the two sets of measurements for **10a** were small, 0.2 to 0.6 p.p.m. and the values measured here were all larger. The ^{13}C-n.m.r. signals of **10b** were assigned as follows. The signal for C-1 of aldose diethyl dithioacetals has a distinct value[18], and that of the primary carbon can be assigned by its appearance as a triplet in the off-resonance decoupled spectrum. In the spectrum of **10a**, the chemical shifts of C-2, C-3, and C-4 ranged from 70.9 to 71.9 p.p.m. The signals of the corresponding carbon atoms of **10b** had shifts of 70.4, 71.2, and 75.9 p.p.m. The shift of the primary carbon was 66.8 p.p.m. in **10b**, but 64.1 p.p.m. in **10a**. The observation of significant downfield shifts for C-5 and only one other carbon on formation of a five-membered ring acetal proved that the major product was 4,5-*O*-cyclohexylidene-D-arabinose diethyl dithioacetal (**10b**) (see later for supporting mass-spectral evidence). In addition, the ^{13}C-n.m.r. chemical shifts of the same carbon atoms of 4,5-*O*-isopropylidene-D-arabinose diethyl dithioacetal, a known compound, have similar values (see Table II). A similar pattern of ^{13}C-n.m.r. chemical-shift changes on comparison of the signals of the chain carbon atoms of five-membered ring acetals with those of their precursors was observed for the products of the other acetalation reactions to be discussed later (see Table II).

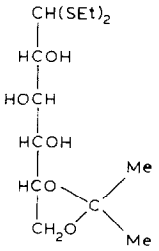
The following ^{13}C-n.m.r. spectral evidence clearly showed that the minor product (**10c**) contained a six-membered ring. The chemical shift of the acetal carbon was 99.1 p.p.m. Comparison of the chemical shifts of **10a** with those of **10c** showed that one secondary carbon signal was shifted markedly upfield (by 8.5 p.p.m.) on acetal formation. The signals for the cyclohexylidene α-carbon atoms appeared at 37.4 and 28.3 p.p.m., a separation of 9.1 p.p.m., similar to the separation observed[13] for the methyl carbon atoms of conformationally fixed, six-membered-ring isopropylidene acetals. Compound **10c** was assigned the 3,5-*O*-cyclohexylidene structure, as the alternative 2,4-*O*-cyclohexylidene arrangement would require large axial substituents at positions 2 and 4 in the chair conformation











12 f $R = R^1 = H, R^2 = R^3 = CMe_2$

g $R = R^3 = H, R^1 = R^2 = CMe_2$

h $R = R^2 = H; R^1 = R^3 = CMe_2$

i $R^2 = R^3 = H, R = R^1 = CMe_2$

j $R^1 = R^3 = H, R = R^2 = CMe_2$

13 f

of a 1,3-dioxane ring. In addition, kinetic acetalation has been shown to give the products of substitution on primary hydroxyl groups initially[1].

Similar cyclohexylidenations at room temperature or 0° of D-ribose diethyl dithioacetal (**11a**), D-xylose diethyl dithioacetal (**12a**), D-glucose diethyl dithioacetal (**13a**), and D-galactose diethyl dithioacetal (**14a**) also yielded the terminal 5-membered ring cyclohexylidene acetals as the major or sole products in 42–70% yields. In most cases, these products were accompanied by minor proportions of the terminal six-membered ring products (0–10%).

In two cases (**12a, 13a**), minor amounts of terminal seven-membered ring products were obtained. These could be unambiguously identified from their ^{13}C-n.m.r. spectra. The presence of a seven-membered ring was apparent from the chemical shift of the acetal carbon, 102.2 p.p.m. for the xylose derivative (**12e**), and 102.4 p.p.m. for the glucose derivative (**13d**). The absence of a marked upfield shift of the signal of a secondary carbon, when the spectrum of either acetal was compared with that of its precursor, confirmed that neither of these compounds contained a six-membered ring. A useful observation was that the signal of the primary carbon of the xylose derivative **12e**, which can only be 2,5-*O*-cyclohexylidene-D-xylose diethyl dithioacetal, was shifted upfield by 4.6 p.p.m. on acetal formation. This effect is in the same direction as that observed for the model compounds but is considerably larger. A similar effect observed for the primary carbon of the glucose derivative (upfield shift 3.6 p.p.m.) confirmed that this compound had a 3,6-*O*-cyclohexylidene ring. The chemical shifts of the second carbon atoms involved in formation of the seven-membered rings, C-2 for **12e** and C-3 for **13d** showed smaller upfield shifts (1.6 and 1.2 p.p.m., respectively) on acetal formation.

The reaction with D-xylose diethyl dithioacetal also yielded a small proportion (7.6%) of a second five-membered ring derivative (**12d**). Although this compound was not obtained pure, it was tentatively assigned the 3,4-*O*-cyclohexylidene

structure on the basis of the close similarity of its ^{13}C-n.m.r. chemical shifts to those of the known 3,4-*O*-isopropylidene derivative (see Table II).

The 70-eV mass spectra of these series of compounds provide support for the structural assignments made here. De Jongh[19] has assigned principal ions in the mass spectra of aldose diethyl dithioacetals and most of these ions are present in the mass spectra of the cyclohexylidene derivatives (see experimental section). Cleavage between each of the chain carbon atoms was a minor fragmentation-route for the parent compounds[19]. However the intensities of peaks corresponding to this route were greater for these derivatives (Table III). The observation of peaks at appropriately different masses for the *O*-isopropylidene derivatives to be discussed later supported the assignments of these peaks in both classes of compounds to the chain-cleavage process. The relative intensities of the peaks for each compound, which arise from this type of fragmentation, provided support for the structural assignments given here.

The presence of a cyclic acetal spanning two oxygen atoms of the chain should make cleavage between the carbon atoms bearing those oxygen atoms less likely. Thus, the ratio of the intensity of the peak at *m/z* 141 to that of the peak at *m/z* 171 should be larger for a terminal five-membered ring cyclohexylidene acetal than for a terminal six-membered ring acetal if both compounds are derived from the same sugar (See Fig. 1). There are two pairs of isomers for which this hypothesis could be tested. The arabinose derivatives **10a** and **10c** gave intensity ratios for *m/z*

TABLE III

INTENSITIES OF MASS-SPECTRAL PEAKS ARISING FROM CHAIN CLEAVAGE

Compound	*Intensities of peaks (as % of base peak)*			
	141[a] or 101[b]	*171[a] or 131[b]*	*201[a] or 161*	*231[a] or 101[b]*
10b	15	6	16	—
10c	9	37	13	3
11b	16	10	15	2
12b	12	14	14	—
12e	10	29	45	4
13b	13	7	3	18
14b	12	9	6	5
14c	8	8	7	5
10f	10	5	7	—
12f	10	14	6	—
12g	6	34	3	—
12h	12	7	6	—
12k	13	37	19	—
13f	14	1	2	12
14f	15	2	2	5
14g	5	5	3	1
14h	9	5	4	6

[a]For cyclohexylidene acetals. [b]For isopropylidene acetals.

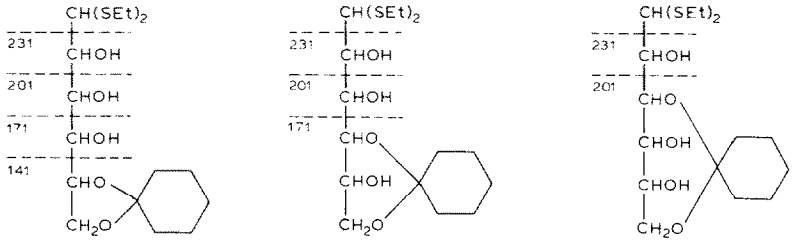


Fig. 1. Favorable chain-cleavage locations in the mass spectra of terminal cyclohexylidene derivatives of aldose diethyl dithioacetals.

141/171 of 2.6 and 0.24, respectively, whereas the galactose derivatives **14b** and **14c** gave ratios of 1.3 and 0.9. Similarly, the intensity ratios for a peak having *m/z* 141 or 171 to that at *m/z* 201 should be smaller for an aldose diethyl dithioacetal having a terminal seven-membered ring acetal than one having a different acetal. For the xylose derivatives **12b** and **12e**, the ratios for *m/z* 141/201 are 0.87 and 0.23 respectively whereas those for *m/z* 171/201 are 1.0 and 0.64 respectively, consistent with the structures assigned.

Isopropylidene acetals. — Isopropylidenation of the diethyl dithioacetals of D-arabinose (**10a**), D-glucose (**13a**), and D-galactose (**14a**) at 0° with 2-methoxypropene under the same conditions as for the cyclohexylidenations again yielded terminal 1,3-dioxolane ring acetals as the major products*. In most cases, the major products were accompanied by small proportions of terminal 1,3-dioxane acetal ring products. Structures were assigned, as for the cyclohexylidene acetals, primarily by ^{13}C-n.m.r. spectroscopy, but with confirmation from the mass spectra.

Most of the major products had been prepared previously in similar or lower yields by cupric sulfate-catalyzed isopropylidenation with acetone[20–22]. In the case of galactose diethyl dithioacetal, this method[20] yielded 4,5-*O*-isopropylidene-D-galactose diethyl dithioacetal (**14f**) rather than the 5,6-*O*-isopropylidene isomer (**14e**) obtained as the major product from the present reaction at 0°. At room temperature, it was observed that **14e** was the major product after 2 h, but **14e** and **14f** were present in about equal amounts after 25 h. These two isomers evidently equilibrate at room temperature in the presence of 5% of *p*-toluenesulfonic acid.

D-Xylose diethyl dithioacetal gave a more complex mixture of products and the reaction was monitored as a function of time at 0°. At each time interval, four *O*-isopropylidene derivatives were obtained; the 4,5- (**12f**), 3,4- (**12g**), 3,5- (**12h**), and 2,5- (**12k**) isomers. The yields isolated after chromatography for reaction times of 0.5, 2, and 24 h were: total, 46, 54, and 83%; **12f**, 17, 20, and 37%; **12g**, 4, 4, and 9%; **12h**, 7, 9, and 13%; and **12k**, 18, 21, and 24%. Compound **12k** was the

*The authors have been informed after submission of this paper that A. Dehbi, E. Fanton, J. Gelas, and D. Horton had independently studied the acetonation of the diethyl dithioacetals of D-glucose, and D-galactose. Their results confirm the present study except that they also isolated an open-chain acetal attached to O-6 from reactions conducted at 0° for a short time.

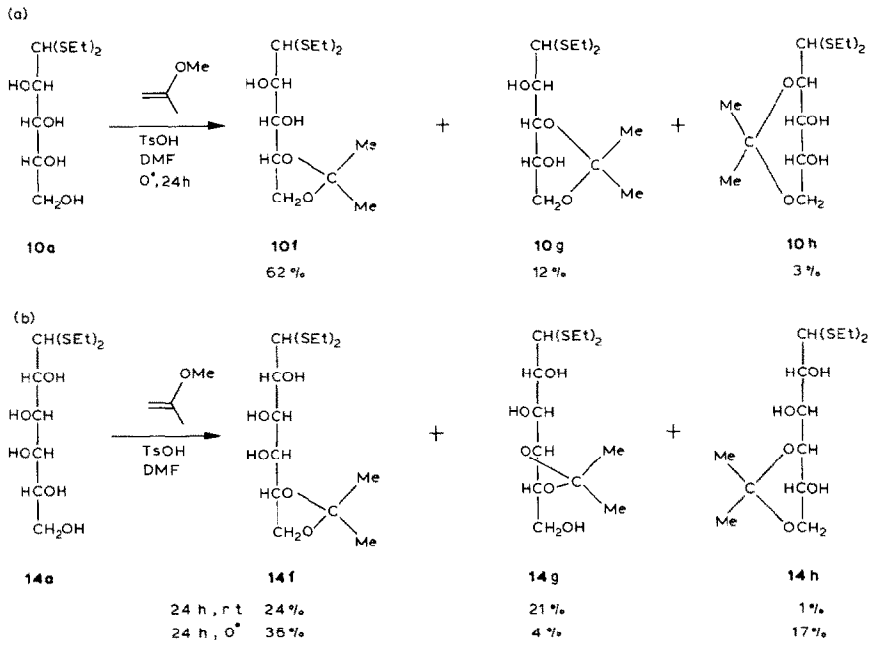


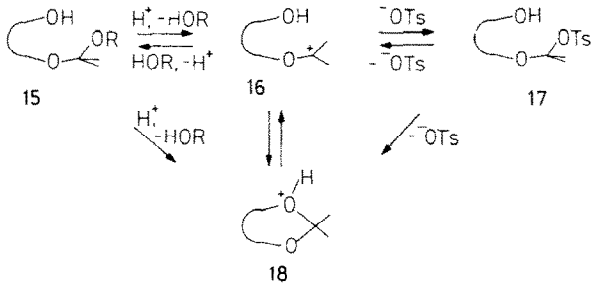
Fig. 2. Isopropylidenation reactions with 2-methoxypropene and *(a)* D-arabinose diethyl dithioacetal (**10a**) *(b)* D-galactose diethyl dithioacetal (**14a**).

major product after both 0.5 and 2 h and was obtained in highest yield after 24 h. However, the increases in yields when the yields from 24 h reaction were compared with those from the 2-h reaction were greatest for **12g** (125%), next for **12f** (85%), and least for **12k** (14%). These figures suggest two trends with increasing time: increasing amount of reaction and increasing amounts of rearrangement, probably from **12k** to **12f** and, more slowly, from **12f** to **12g**. Confirmation of the latter trend was obtained from a reaction at room temperature for 24 h. Compound **12f** was the major product (31% yield), and **12g** (24%) was now the only other important constituent. A small proportion (2%) of 3,5-*O*-isopropylidene-D-xylose diethyl dithioacetal was also isolated. The isopropylidenation of D-xylose diethyl dithioacetal was the only reaction studied here where the terminal five-membered ring acetal was not the major product and also the only reaction where a seven-membered ring formed a significant proportion of the products.

Discussion of the acetalation reaction. — Acetalation reactions with enol ethers are kinetically controlled in DMF in the presence of a trace of *p*-toluenesulfonic acid[1]. Under the conditions used here, cyclohexylidenations at 0° and room temperature and isopropylidenations at 0° give chiefly kinetic products. In most cases, the products obtained are consistent with initial attack at the least hindered hydroxyl group, the primary one. Although OH-2 has been shown to be the most reactive secondary hydroxyl group for acylation of aldose diethyl dithioacetals[23], no derivatives were obtained substituted on O-2 which could not be ascribed to

initial attack elsewhere. The only two aldose diethyl dithioacetals having the *threo* configuration for their two terminal secondary centers, compounds **12a** and **14a**, both gave minor proportions of acetals not attributable to initial reaction at the primary center. As only a single acetal from two secondary hydroxyl groups was obtained in each case, it is likely that initial attack occurred at the penultimate hydroxyl group for these compounds.

Possible routes for the ring-forming part of the mechanism are outlined in Scheme 1. There have been extensive kinetic investigations of the reverse reaction, the hydrolysis of acetals, particularly in water and in aqueous 1,4-dioxane[24,25]. For most simple cyclic acetals, the step **16** + H_2O → **15** + H^+ is probably rate determining[24]. It has been suggested[2] that the reverse step (**15** + H^+ → **16** + H_2O) is rate determining for acetal formation. If this suggestion were true, **15** would accumulate at certain stages of these reactions. As far as we are aware, products like **15** are not predominant in any isopropylidenation or cyclohexylidenation reactions, except very early in the reaction. Probably formation of **15** or earlier steps are rate-determining here.



Scheme 1. Possible pathways for the cyclization step of the mechanism of acetal formation.

Ring formation could take place via two different types of routes. It is well established that acetal hydrolyses in polar protic solvents proceeds via a carbocation. For isopropylidenation and cyclohexylidenation reactions, the center under consideration is tertiary, and so an SN1-like process is even more likely. A complicating factor is the equilibrium **16** ⇌ **17**. As anions are poorly solvated in DMF, this equilibrium may lie towards **17**. In addition, **16** is probably an ion-pair in DMF. Alternatively, an SN2-like process could be followed, proceeding either from **15** to **18** or from **17** to **18**. An SN2 process would be more favored in DMF than in water or aqueous 1,4-dioxane, in which systems most acetal hydrolyses have been studied. Stereoelectronic considerations may also be important.

Baldwin[26] has discussed stereoelectronic control of ring-forming reactions. Additions to double bonds are termed endo-trig processes if both atoms of the double bond end up in the ring. Baldwin[26] suggested that the 5-endo-trig process was not favorable because the attacking group could not attain the correct 109° angle to the double bond. However, the 6-endo-trig process is favorable. As the

carbocation in **16** is resonance stabilized by the adjacent oxygen atom, the step **16** $\rightleftharpoons$ **18** is formally a 5-endo-trig process. Calculations[27] later showed that the rotational barrier for the methoxymethyl cation was about 20 kcal.mol^{-1}, considerably less than the 60 kcal.mol^{-1} of a C=C double bond. This barrier is likely to be considerably less in the alkoxydialkylmethyl cations cyclized here. Easier rotation about this bond facilitates approach at a better angle to the carbocationic center. In addition, as the center being attacked takes on more of the character of a carbocation and less that of a double bond, the favored angle of attack should change from 109° towards 90°. It is also possible that there is a reasonably wide window of angles where attack is not seriously retarded[28]. Thus it is probable that the reaction proceeds through an open cation here.

The rates of the different ring-closure reactions from an intermediate reflect the energy differences between it and the various transition states as well as the probabilities of the cationic center in the intermediate encountering the particular hydroxyl groups leading to the individual transition-states at an angle that allows reaction. The probability factor includes terms related to the size of ring to be formed (preference 5 > 6 > 7) and the populations of the conformations leading to the products. The latter factor should affect the relative amounts of the minor products.

The conformations of many acyclic aldose derivatives have been determined[18,29,30]. Most studies have been performed by consideration of $^3J_{H,H}$ values[29], although more recently the analysis of ^{13}C-n.m.r. chemical shifts has given conformational information[18,30]. In general, these compounds adopt planar zig-zag conformations unless OH groups on β-carbon atoms are parallel. D-Xylose diethyl dithioacetal (**12a**), gave a product-distribution different than the others and will be considered in more detail.

D-Xylose diethyl dithioacetal has OH-2 and OH-4 parallel in the zig-zag conformation. Compound **12a** and its derivatives have been found to exist in $_3G^+$, or $_2G^-$ conformations or as conformational mixtures possibly including the zig-zag conformation[18,29,30]. The ^{1}H-n.m.r. spectrum of **12a** was measured here in dimethyl sulfoxide-d_6, a solvent having similar properties to that in which the reactions were performed, *N,N*-dimethylformamide. The relevant part of the spectrum, a 10-spin system, was analyzed in segments, using an iterative n.m.r. simulation program, LAME[31]. The values obtained for the important vicinal coupling constants, $J_{1,2}$ 5.6 Hz, $J_{2,3}$ 4.5 Hz, $J_{3,4}$ 3.8 Hz, were consistent only with a conformational mixture. Compound **12a** was the sole aldose diethyl dithioacetal to yield substantial amounts of seven-membered ring acetals in the acetalation reactions. Fig. 3 shows one conformation that could lead to a seven-membered acetal ring. Such conformations will be more highly populated if the acyclic polyol under consideration has configurations that make the planar zig-zag conformation unstable (as with **12a**).

The isopropylidenation reaction consistently gave significantly greater yields of the minor products than did cyclohexylidenation. It is likely that this difference was caused by steric effects in the transition state. Steric effects will be more

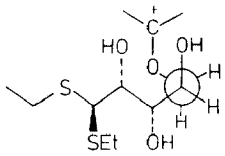


Fig. 3. A conformation of D-xylose diethyl dithioacetal from which seven-membered ring acetals could form.

significant in the transition states leading to six- and probably seven-membered rings where one substituent at the acetal center being formed must adopt an axial or near-axial orientation. When both groups attached to this center are linked as in the cyclohexylidenation reaction, the axial group will be more inflexible and the hydrogen atoms on the α-carbon will be less able to move to avoid steric effects. In contrast, the methyl groups are more able to rotate and bend into conformations that minimize steric effects.

EXPERIMENTAL

General methods. — Melting points were determined by using a Fisher–Johns melting point apparatus and are uncorrected. The ^{1}H- and ^{13}C-n.m.r. spectra were recorded for samples dissolved in chloroform-*d* with tetramethylsilane present as the internal reference using Varian T-60 and CFT-20 spectrometers operating at 60 and 20 MHz, respectively, unless otherwise indicated. ^{1}H-N.m.r. spectra at 361.08 MHz were recorded with a Nicolet NT-360 NB spectrometer. ^{1}H-N.m.r. coupling constants were obtained from first-order analyses. ^{13}C-N.m.r. chemical shifts were obtained from spectra recorded using 8K data points, 0.9 sec acquisition times, and 34° pulse angles. Mass spectra were measured with a CEC 21-104 mass spectrometer operating at 70-eV ionizing voltage and an inlet temperature of 150°, unless otherwise specified. Bath temperatures (0°) were controlled with a Haake FK circulating bath. T.l.c. was performed on 0.25-mm thick Merck Silica Gel 60F-254 glass plates cut to be ~7 cm long. Plates were developed by spraying with 2% ceric sulfate solution in M sulfuric acid and heating for a few min at 150°. The term petroleum ether refers to petroleum ether b.p. 30–60°, unless otherwise indicated. Eluent systems used were petroleum ether–ethyl acetate mixtures: *A*, 11:5; *B*, 1:1; *C*, 3:1; *D*, 4:1; *E*, 3:2; *F*, 1:2; and *G*, 2:1. 1-Ethoxycyclohexene (b.p. 58–61/20 torr) was prepared from cyclohexanone[32]. Anhydrous *p*-toluenesulfonic acid was obtained from the commercial monohydrate by heating the hydrate for 5 h at 56° in a drying pistol under vacuum (0.5 torr) in the presence of phosphorous pentaoxide. *N*,*N*-Dimethylformamide (DMF) was purified by distillation from calcium hydride. Microanalyses were performed by the Canadian Microanalytical Service Ltd., Vancouver, B.C.

Synthesis of model compounds. — The model cyclohexylidene derivatives were prepared either by stirring a diol with 1-ethoxycyclohexene and *p*-toluene-

sulfonic acid or by boiling the diol under reflux with an equivalent amount of cyclohexanone in benzene containing *p*-toluenesulfonic acid in a device for the azeotropic removal of water. 1,4-Dioxaspiro[4.5]decane (**3a**) had b.p. 123°/140 torr (lit.[33] 73.0°/16 torr), n_D^{28} 1.4549 (lit.[33] n_D^{20} 1.4583); ^{1}H-n.m.r.: δ 1.50 (br, s, 10 H, cyclohexyl group) and 3.90 (s, 4 H, -OCH_2CH_2O-). 1,5-Dioxaspiro[5.5]undecane (**4c**) had b.p. 94°/20 torr (lit.[33] 91.5–93.0°/16 torr), n_D^{24} 1.4675 (lit.[33] n_D^{20} 1.4692); ^{1}H-n.m.r.: δ 1.25–1.95 (complex m, 12 H, cyclohexyl group and -$OCH_2CH_2CH_2O$-) and 3.80 (t, 4 H, *J* 5.7 Hz, -$OCH_2CH_2CH_2$-). 7,12-Dioxaspiro[5.6]dodecane (**5d**) had b.p. 101–103°/20.5 torr, (lit.[34] 117–118°/40 torr), n_D^{27} 1.4682 (lit.[34] n_D^{30} 1.4681); ^{1}H-n.m.r.: δ 1.27–1.73 (br m, 14 H, cyclohexyl group and -$OCH_2CH_2CH_2CH_2O$-) and 3.53–3.73 (complex m, 4 H, -$OCH_2CH_2CH_2CH_2O$-).

1,3-Dioxolane was a commercial sample; 1,3-dioxane and 1,3-dioxepane were prepared from the appropriate diol and paraformaldehyde by literature methods[35,36]. 1,3-Dioxane had b.p. 104–105° (lit.[35] 105°/755 torr), n_D^{25} 1.4159 (lit.[35] n_D^{20} 1.4165). 1,3-Dioxepane had b.p. 117–119° (lit.[36] 119°), n_D^{24} 1.4258 (lit.[36] n_D^{20} 1.4275).

General method for acetalation reactions. — To the solution of the dry aldose diethyl dithioacetal (2.5 mmol) and the enol ether (1.2 eq) in anhydrous DMF (20 mL) at the specified temperature was added *p*-toluenesulfonic acid (25 mg). The homogeneous mixture was kept with exclusion of moisture until t.l.c. indicated that all of the starting material had reacted, and then poured into a solution of sodium hydrogencarbonate (2% w/v, 60 mL). This mixture was extracted with ether (4 × 30 mL). The combined ether extracts were washed with water (2 × 30 mL), dried (magnesium sulfate), and evaporated.

Cyclohexylidenation of D-*arabinose diethyl dithioacetal* (**10a**). — Compound **10a** (1.6 g, 6.25 mmol), 1-ethoxycyclohexene (**1a**) (0.95 g, 7.5 mmol), and *p*-toluenesulfonic acid (**2**) (50 mg) were stirred at room temperature in DMF (30 mL) for 3.67 h. Standard isolation gave a yellowish solid (1.79 g) from which colorless crystals (**10b**) were obtained by recrystallization from petroleum ether; yield 1.02 g. The mother liquors were fractionated by column chromatography on silica gel (22 g) with solvent *A* as eluent to give a first solid fraction (0.22 g), R_F 0.69 (solvent *B*), identical to the previous crystals (**10b**), and a second syrupy fraction (**10c**) (0.17 g, 8%), R_F 0.47 (solvent *B*).

Compound **10b**, 4,5-*O*-cyclohexylidene-D-arabinose diethyl dithioacetal (total yield, 1.19 g, 59%), was recrystallized from petroleum ether; m.p. 75°, $[\alpha]_D^{24}$ −60° (*c* 2.40, chloroform), ^{1}H-n.m.r.: δ 1.28 (t, 6 H, *J* 7 Hz, 2 SCH_2CH_3), 1.58 (br s, 10 H, cyclohexyl group), 2.40 (br d, 1 H, *J* 7.5 Hz, exchanged with D_2O, OH-3), 2.73 (q, 2 H, *J* 7 Hz, 2 SCH_2CH_3), 3.26 (d, 1 H, *J* 2.3 Hz, exchanged with D_2O, OH-2), 3.77 (dd, 1 H, $J_{1,2}$ 8.3, $J_{2,OH}$ 2.3 Hz, H-2), and 3.90–4.23 (complex m, 5 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 336 (18, M^+), 275 (4, M − ·SEt), 177 (35), 135 (100, $(EtS)_2CH^+$), 107 (10), 105 (24), and 75 (29).

Anal. Calc. for $C_{15}H_{28}O_4S_2$: C, 53.54; H, 8.39. Found: C, 53.40; H, 8.41.

Compound **10c**, 3,5-*O*-cyclohexylidene-D-arabinose diethyl dithioacetal, was

a syrup, $[\alpha]_D^{25}$ −24° (*c* 1.30, chloroform), ^{1}H-n.m.r.: δ 1.28 (t, 6 H, *J* 7 Hz, 2 SCH_2CH_3), 1.58 (br s, 10 H, cyclohexyl group), 2.85 (distorted q, 5 H, normal q on D_2O exchange, *J* 7 Hz, SCH_2CH_3 and OH), 3.06 (br s, 1 H, exchanged with D_2O, OH), and 3.57–4.20 (complex m, 6 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 336 (26, M^+), 275 (4, M − ·SEt), 257 (7, 275 − H_2O), 213 (4, 275 − HSEt), 177 (26), 135 (100, $(EtS)_2CH^+$), 107 (8), 105 (7), and 75 (16).

Cyclohexylidenation of D-*ribose diethyl dithioacetal* (**11a**). — Compounds **11a** (0.80 g, 3.1 mmol), **1a** (0.476 g, 3.8 mmol), and **2** (25 mg) were stirred at room temperature in DMF (15 mL) for 30 min. Standard isolation gave a colorless oil (0.888 g) that was purified by column chromatography on silica gel (35 g) using solvent *D* as eluent to give 4,5-*O*-cyclohexylidene-D-ribose diethyl dithioacetal (**11b**), (0.736 g, 70%), (R_F 0.79 in solvent *B*) as a syrup, $[\alpha]_D^{24}$ +6° (*c* 2.43, chloroform); ^{1}H-n.m.r.: δ 1.30, 1.34 (2 t, 6 H, *J* 7.7 Hz, 2 SCH_2CH_3), 1.62 (br m, 10 H, cyclohexyl group), 2.60 (br s, 1 H, exchanged with D_2O, OH), 2.79, 2.75 (2 q, 4 H, *J* 7.7 Hz, 2 SCH_2CH_3), 3.14 (d, 1 H, exchanged with D_2O, OH), and 3.64–4.57 (complex m, 6 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 336 (21, M^+), 275 (3, M − ·SEt), 257 (5, 275 − H_2O), 213 (3, 275 − HSEt), 177 (26), 135 (100, $(EtS)_2CH^+$), 107 (9), 105 (26), and 75 (37).

Cyclohexylidenation of D-*xylose diethyl dithioacetal* (**12a**). — Compounds **12a** (0.8 g, 3.1 mmol), **1a** (0.476 g, 3.8 mmol) and **2** (25 mg) were stirred at room temperature in DMF (10 mL) for 25 h. Standard isolation gave an oil (0.845 g) that was fractionated by column chromatography on silica gel (50 g) using solvent *C* as eluent into fraction A (0.464 g), R_F 0.34 (solvent *C*), fraction *B* (0.127 g), R_F 0.24 (solvent *C*), and fraction C (0.111 g), R_F 0.18 (solvent *C*).

Fraction A crystallized and was recrystallized from dichloromethane–petroleum ether to give colorless crystals of 4,5-*O*-cyclohexylidene-D-xylose diethyl dithioacetal (**12b**) (44% yield), m.p. 66–67°, $[\alpha]_D^{24}$ +21° (*c* 1.02, chloroform); ^{1}H-n.m.r. (361.08 MHz): δ 1.29 (t, 6 H, *J* 7.8 Hz, 2 SCH_2CH_3), 1.35–1.45 (br m, 10 H, cyclohexyl group), 1.96 (br s, 1 H, exchanged with D_2O, OH-3), 2.63–2.82 (complex m, 4 H, SCH_2CH_3), 3.38 (d, 1 H, $J_{OH,2}$ 2.99 Hz, exchanged with D_2O, OH-2), 3.55 (ddd, 1 H, $J_{2,OH}$ 2.74, $J_{1,2}$ 8.51, $J_{2,3}$ 1.79 Hz, H-2, dd after exchange with D_2O), 3.87 (dd, 1 H, $J_{4,5}$ 6.99, $J_{5,5'}$ 8.13 Hz, H-5), 4.00 (ddd, 1 H, $J_{OH,3}$ 7.1, $J_{3,4}$ 5.28, $J_{2,3}$ 1.75 Hz, H-3), 4.067 (d, 1 H, $J_{1,2}$ 8.58 Hz, H-1), 4.074 (dd, 1 H, $J_{4,5'}$ 6.23, $J_{5,5'}$ 8.15 Hz, H-5′), and 4.28 (m, 1 H, $J_{3,4}$ 5.28, $J_{4,5}$ 6.99, $J_{4,5'}$ 6.01 Hz, H-4); for ^{13}C-n.m.r. data, see Table II; *m/z* 336 (17, M^+), 275 (3, M − ·SEt), 213 (4, 275 − HSEt), 177 (23), 135 (100, $(EtS)_2CH^+$), 107 (9), 105 (18), and 75 (26).

Anal. Calc. for $C_{15}H_{28}O_4S_2$: C, 53.54; H, 8.39; S, 19.06; O, 19.02. Found: C, 53.67; H, 8.54; S, 18.65; O, 18.95.

Fraction B was shown by ^{13}C-n.m.r. (see Table II) to be a mixture of two compounds, probably 3,5-*O*-cyclohexylidene-D-xylose diethyl dithioacetal (**12c**) (4.6%) and 3,4-*O*-cyclohexylidene-D-xylose diethyl dithioacetal (**12d**) (7.6%).

Fraction C crystallized and was recrystallized from dichloromethane–petroleum ether to give colorless crystals of 2,5-*O*-cyclohexylidene-D-xylose diethyl

dithioacetal (**12e**) (11% yield); m.p. 82–84°, $[\alpha]_D^{24}$ −4° (*c* 1.37, chloroform); ^{1}H-n.m.r.: δ 1.25 (t, 6 H, *J* 7.3 Hz, 2 SCH_2CH_3), 1.51–1.71 (br m, 10 H, cyclohexyl group), 2.40 (br s, 2 H, exchanged with D_2O, 2 OH), 2.67 (q, 4 H, *J* 7.3 Hz, 2 SCH_2CH_3, and 3.30–4.20 (complex m, 6 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 336 (63, M^+), 275 (6, M − ·SEt), 257 (29, 275 − H_2O), 177 (100), 135 (46, $(EtS)_2CH^+$), 107 (5), 105 (12), and 75 (32).

Cyclohexylidenation of D-*glucose diethyl dithioacetal* (**13a**). — Compounds **13a** (5.005 g, 17.5 mmol), **1a** (2.667 g, 21 mmol), and **2** (175 mg) were kept at 0° in DMF (175 mL) for 21 h. Standard isolation gave a yellow oil (4.907 g) that was fractionated by column chromatography on silica gel (200 g) using solvent *E* as eluent into 2 fractions.

The first fraction (3.781 g, 59%), R_F 0.48 (solvent *B*) crystallized and was recrystallized twice from dichloromethane–petroleum ether to give colorless crystals of 5,6-*O*-cyclohexylidene-D-glucose diethyl dithioacetal (**13b**), m.p. 67–68°, $[\alpha]_D^{24}$ +42° (*c* 4.00, chloroform); ^{1}H-n.m.r.: δ 1.31 (t, 6 H, *J* 7 Hz, 2 SCH_2CH_3), 1.57 (br s, 10 H, cyclohexyl group), 2.70, 2.73 (2 q, 4 H, *J* 7 Hz, 2 SCH_2CH_3), 2.87 (br, 1 H, exchanged with D_2O, OH), 3.18 (br s, 1 H, exchanged with D_2O, OH), 3.55 (br s, 1 H, exchanged with D_2O, OH), and 3.55–4.30 (complex m, 7 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 366 (15, M^+), 275 (2, M − ·SEt), 213 (7, 275 − HSEt), 177 (4), 135 (100), 107 (11), 105 (20), and 75 (20).

The second fraction (0.80 g, 13%), R_F 0.32 (solvent *B*) was shown by ^{13}C-n.m.r. (see Table II) to be a mixture of two compounds, probably 4,6-*O*-cyclohexylidene-D-glucose diethyl dithioacetal (**13c**) (9%) and 3,6-*O*-cyclohexylidene-D-glucose diethyl dithioacetal (**13d**) (4%).

Cyclohexylidenation of D-*galactose diethyl dithioacetal* (**14a**). — Compounds **14a** (1.43 g, 5 mmol), **1a** (0.762 g, 6 mmol), and **2** (50 mg) were kept at 0° in DMF (30 mL) for 25.5 h. Standard isolation gave a white solid (1.042 g) that was recrystallized from dichloromethane–petroleum ether 65–76° to give colorless crystals of 5,6-*O*-cyclohexylidene-D-galactose diethyl dithioacetal (**14b**) (0.736 g). The mother liquor (0.301 g) was fractionated by column chromatography on silica gel (12 g) using solvent *F* as eluent. The first fraction (38 mg), R_F 0.65 (solvent *F*) contained compound **14b**. A second fraction (53 mg) was a mixture of a compound **14d** (probably 3,6-*O*-cyclohexylidene-D-galactose diethyl dithioacetal (see Table II)) and another compound (**14c**) that was obtained pure in the third fraction (147 mg).

5,6-*O*-Cyclohexylidene-D-galactose diethyl dithioacetal (**14b**) (total yield 42%) was recrystallized twice more from dichloromethane–petroleum ether to give colorless crystals, m.p. 101–101.5°, $[\alpha]_D^{24}$ +63° (*c* 1.00, chloroform); ^{1}H-n.m.r.: δ 1.27 (t, 6 H, *J* 7.5 Hz, 2 SCH_2CH_3), 1.58 (br s, 10 H, cyclohexyl group), 2.53–2.70 (2 OH signals obscured by SCH_2CH_3), 2.66–2.68 (2 q after D_2O exchange, 4 H, *J* 7.5 Hz, 2 SCH_2CH_3), 3.33 (br s, exchanged with D_2O, OH), 3.83 (dd, 1 H, *J* 8, 3.5 Hz), and 3.70–4.37 (complex m, 6 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 366 (21, M^+), 275 (1, M − ·SEt), 257 (3, 275 − H_2O), 213 (8, 275 − HSEt), 177 (7), 135 (100), 107 (10), 105 (18), and 75 (21).

Anal. Calc. for $C_{16}H_{30}O_5S_2$: C, 52.43; H, 8.25; S, 17.50. Found: C, 52.14; H, 8.41; S, 17.11.

4,6-*O*-Cyclohexylidene-D-galactose dithioacetal (**14c**), total yield (0.174 g, 10%) was obtained as a syrup, $[\alpha]_D^{25}$ −3° (*c* 1.33, chloroform); ^{1}H-n.m.r.: δ 1.30 (t, 6 H, *J* 7.7 Hz, 2 SCH_2CH_3), 1.42–1.72 (br m, cyclohexyl group), 2.05, 2.92, 3.15 (3 br s, exchanged with D_2O, OH), 2.73 (q, 4 H (after exchange), *J* 7.5 Hz, 2 SCH_2CH_3), and 3.49–4.35 (complex m, 7 H); *m/z* 366 (30, M^+), 275 (4, M − ·SEt), 257 (7, 275 − H_2O), 213 (9, 275 − HSEt), 177 (10), 135 (100), 107 (13), 105 (21), and 75 (23).

Reaction using **14a** (0.715 g, 2.5 mmol) and the same proportions of the other reagents as above at room temperature for 51 h gave, after recrystallization, compound **14b**, yield (0.370 g, 41%), m.p. 100°, and a mother liquor (yield 0.189 g, 21%)) shown by a combination of t.l.c. and ^{13}C-n.m.r. to contain a mixture of compounds, **14b** and **14c**.

Isopropylidenation of D-*arabinose diethyl dithioacetal* (**10a**). — Compounds **10a** (4.8 g, 18.8 mmol), **2** (120 mg), and 2-methoxypropene (**1b**) (1.63 g, 22.3 mmol) were kept at 0° in DMF (60 mL) for 24 h. Standard isolation gave yellowish crystals (5.098 g, 93%), which contained a major and a minor component by t.l.c. (solvent *B*). Column chromatography on silica gel using solvent *B* as eluent gave fraction *A* (3.438 g, 62%) and fraction *B* (0.843 g, 15%).

Fraction *A* was recrystallized from dichloromethane–petroleum ether to give colorless crystals of 4,5-*O*-isopropylidene-D-arabinose diethyl dithioacetal (**10f**), m.p. 75.0–75.5° (lit.[22] 70–72°), $[\alpha]_D^{24}$ −58.5° (*c* 1.03, chloroform) (lit.[22] −68.9°); for ^{13}C-n.m.r. data, see Table II; *m/z* 296 (8, M^+), 235 (2, M − ·SEt), 177 (20), 173 (4, 235 − HSEt), 135 (100), 107 (11), 105 (24), and 75 (20).

Fraction B was a mixture of 2 compounds in the ratio of 82/18 from peak heights in the ^{13}C-n.m.r. spectrum. The major component was 3,5-*O*-isopropylidene-D-arabinose diethyl dithioacetal (**10g**) (see Table II for ^{13}C-n.m.r. chemical shifts) whereas the minor component was probably 2,5-*O*-isopropylidene-D-arabinose diethyl dithioacetal, from the chemical shifts of those ^{13}C-n.m.r. signals that could be assigned to it [δ 52.50 (d, C-1), 60.46 (t, C-5), and 102.48 (s, acetal C)].

Isopropylidenation of D-*xylose diethyl dithioacetal* (**12a**). — *(a) At room temperature.* Compounds **12a** (4.8 g, 18.6 mmol), **1b** (1.627 g, 22.3 mmol), and **2** (120 mg) were stirred in DMF (60 mL) for 24 h. Standard isolation gave a yellowish oil (4.47 g) which was fractionated by chromatography on silica gel (250 g) with solvent *C* as eluent into six components.

2,3:4,5-Di-*O*-isopropylidene-D-xylose diethyl dithioacetal was obtained as a syrup (0.385 g, 6%), $[\alpha]_D^{24}$ −54° (*c* 1.44, acetone), (lit.[21] −67°, lit.[37] −62°), ^{13}C-n.m.r.: δ 110.1, 109.5 (acetal C), 75.6 (C-2), 78.7, 77.2 (C-3 and C-4), 66.0 (t in off-resonance spectrum, C-5), 53.2 (C-1), 25.7, 25.0, 27.4, 27.2, 26.2, 25.4 (2 SCH_2CH_3 and isopropylidene C), 14.4, and 14.4 (2 SCH_2CH_3).

2,4:3,5-Di-*O*-isopropylidene-D-xylose diethyl dithioacetal (0.129 g, 2%)

solidified and was recrystallized twice from ethanol–water, m.p. 112–114.5° (lit.[22] 113.5–114°), $[\alpha]_D^{24}$ 8° (*c* 1.04, acetone) (lit.[22] 8°); ^{13}C-n.m.r.: δ 99.2, 98.6 (acetal C), 75.6 (C-2), 64.1, 62.3 (C-3 and C-4), 63.6 (t in off-resonance spectrum, C-5), 50.5 (C-1), 29.6, 29.3, 19.2, 18.9 (isopropylidene C), 25.6, 24.9 (2 S*C*H_2CH$_3$), 14.8, and 14.1 (2 SCH$_2$*C*H_3).

4,5-*O*-Isopropylidene-D-xylose diethyl dithioacetal (**12f**) (1.702 g, 31%) solidified and was recrystallized from dichloromethane–petroleum ether, m.p. 77.5–78° (lit.[21] 78–79°), $[\alpha]_D^{24}$ +48° (*c* 1.54, chloroform) (lit.[21] +48°); for ^{13}C-n.m.r. data, see Table II; *m/z* 296 (12, M$^+$), 235 (12, M − ·SEt), 177 (14), 135 (100), 107 (8), 105 (16), and 75 (20).

3,4-*O*-Isopropylidene-D-xylose diethyl dithioacetal (**12g**) (1.335 g, 24%) was obtained as a syrup $[\alpha]_D^{24}$ +47° (*c* 1.54, chloroform) (lit.[38] +45°); for ^{13}C-n.m.r. data, see Table II; *m/z* 296 (43, M$^+$), 235 (11, M − ·SEt), 217 (14, 235 − H_2O), 177 (7), 135 (100), 107 (9), 105 (4), and 75 (12).

3,5-*O*-Isopropylidene-D-xylose diethyl dithioacetal (**12h**) (0.137 g, 2%) was a syrup $[\alpha]_D^{24}$ +1° (*c* 1.47, chloroform); ^{1}H-n.m.r.: δ 1.30 (t, 6 H, *J* 7.5 Hz, 2 SCH$_2$*C*H_3), 1.47, 1.52 (2 s, isopropylidene CH$_3$ groups), 2.72, 2.75 (2 q, 4 H, *J* 7.5 Hz, 2 S*C*H_2CH$_3$), 3.26, 3.44 (2 br s, 2 H, exchanged with D_2O, 2 OH), and 3.50–4.40 (complex m, 6 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 296 (78, M$^+$), 235 (12, M − ·SEt), 177 (53), 173 (15, 235 − HSEt), 135 (100), 107 (12), 105 (23), and 75 (35).

The slowest-moving fraction (0.689 g, 13%) was a mixture of two components, which appeared to be 2,3- and 2,4-*O*-isopropylidene-D-xylose diethyl dithioacetal (**12i** and **12j**, respectively) from their ^{13}C-n.m.r. spectra (see Table II).

(b) At 0°. Compounds **12a** (4.8 g, 18.8 mmol), **1b** (1.627 g, 22.3 mmol), and **2** (120 mg) were kept in DMF (60 mL) for 24 h at 0°. Standard isolation gave a white semisolid (4.81 g, 87%) that was fractionated by chromatography on silica gel (250 g) into four fractions, A (2.069 g, 37%, a solid), B (0.476 g, 9%, a syrup), C (0.736 g, 13%, a syrup), and D (1.332 g, 24%, a solid). Fractions A, B, and C were shown to be identical to compounds **12f, 12g,** and **12h** respectively from their ^{13}C-n.m.r. spectra.

Fraction D was recrystallized from dichloromethane–petroleum ether to give colorless prisms of 2,5-*O*-isopropylidene-D-xylose diethyl dithioacetal (**12k**), m.p. 78.5–80.0°; $[\alpha]_D^{26}$ −3.6° (*c* 2.26, chloroform); ^{1}H-n.m.r.: δ 1.27, 1.28 (2 t, 6 H, *J* 7.2, 7.4 Hz, 2 SCH$_2$*C*H_3), 1.38, 1.43 (2 s, 6 H, isopropylidene CH$_3$ groups), 2.69 (q, 4 H, *J* 7.3 Hz, 2 S*C*H_2CH$_3$), 3.16 (br s, 2 H, exchanged with D_2O, 2 OH), and 3.30–4.30 (complex m, 6 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 296 (41, M$^+$), 235 (7, M − ·SEt), 217 (17, 235 − H_2O), 177 (68), 135 (100), 107 (12), 105 (37), and 75 (58).

Reaction at 0° exactly as before but for 2 h gave product (4.47 g, 81%) that was separated by chromatography as before into four fractions, A (1.135 g, 20%), B (0.250 g, 4%), C (0.482 g, 9%), and D (1.170 g, 21%), shown to be identical to the previous fractions A–D by ^{13}C-n.m.r. spectroscopy. Reaction as before but for

30 min on one-quarter of the scale gave a product (0.847 g, 61%), again separated into four fractions A (0.239 g, 17%), B (0.061 g, 4%), C (0.101 g, 7%), and D (0.255 g, 18%) identical to the the previous fractions.

Isopropylidenation of D-*glucose diethyl dithioacetal* (**13a**). — Compounds **13a** (10.725 g, 37.5 mmol), **1b** (3.245 g, 45 mmol) and **2** (375 mg) in DMF (130 mL) were kept for 68 h at 0°. Standard isolation gave yellowish crystals (8.275 g, 68%) that were recrystallized twice from dichloromethane–petroleum ether to give colorless crystals of 5,6-*O*-isopropylidene-D-glucose diethyl dithioacetal (**13f**); yield 5.735 g (47%), m.p. 73.5–74.5° (lit.[20] 68–69°), $[\alpha]_D^{24}$ −11° (*c* 2.027, methanol) (lit.[20] −11°); for ^{13}C-n.m.r. data, see Table II; *m/z* 326 (32, M^+), 265 (3, M − ·SEt), 247 (4, 265 − H_2O), 203 (5, 265 − HSEt), 177 (3), 135 (100), 107 (11), 105 (17), and 75 (16).

Anal. Calc. for $C_{13}H_{26}O_5S_2$: C, 47.79; H, 8.03; S, 19.64; O, 24.50. Found: C, 47.84; H, 8.18; S, 19.53; O, 24.44.

Isopropylidenation of D-*galactose diethyl dithioacetal* (**14a**). — *(a) At room temperature.* Compounds **14a** (2.146 g, 7.5 mmol), **1b** (0.657 g, 9 mmol), and **2** (75 mg) were stirred in DMF (65 mL) at room temperature. T.l.c. after 2 h indiçated that some starting material was present and three products (R_F values 0.12, 0.23, and 0.36) had been obtained. The fastest- and slowest-moving components gave the most intense spots on t.l.c. After 24 h, when the reaction was stopped, the two fastest spots were most intense. Standard isolation gave a white solid (1.325 g). Fractionation by column chromatography on silica gel (50 g) with solvent *B* as eluent gave three pure components, fraction *A* [0.597 g, 24%, R_F 0.36 (solvent *B*)], fraction B [0.5209 g, 21%, R_F 0.23 (solvent *B*)], and fraction C (0.032 g, 1%, R_F 0.12 (solvent *B*)].

Fraction A crystallized and was recrystallized twice from dichloromethane–petroleum ether to give colorless crystals of 5,6-*O*-isopropylidene-D-galactose diethyl dithioacetal (**14f**), m.p. 84.5°, $[\alpha]_D^{24}$ +15° (*c* 2.04, methanol), ^{1}H-n.m.r.: δ 1.24 (t, 6 H, *J* 8 Hz, 2 SCH_2CH_3), 1.40, 1.43 (2 s, 2 isopropylidene CH_3), 2.53, 2.67 and 3.47 (3 br signals, exchanged with D_2O, 3 OH), 2.72, 2.70 (2 q after D_2O exchange, 4 H, *J* 7.5, 7.7 Hz, 2 SCH_2CH_3), 3.58 (dd, 1 H, *J* 8 and 3.5 Hz), and 3.77–4.53 (complex m, 6 H); for ^{13}C-n.m.r. data, see Table II; *m/z* 326 (8, M^+), 265 (1, M − ·SEt), 247 (3, 265 − H_2O), 203 (5, 265 − HSEt), 177 (5), 135 (100), 107 (12), 105 (17), and 75 (22).

Fraction B was recrystallized twice from dichloromethane–petroleum ether to give colorless crystals of 4,5-*O*-isopropylidene-D-galactose diethyl dithioacetal (14 g) m.p. 85–86.5°, (lit.[20] 82–83°), $[\alpha]_D^{24}$ +22° (*c* 1.06, methanol) (lit.[20] +19°); for ^{13}C-n.m.r. data, see Table II; *m/z* 326 (14, M^+), 265 (3, M − ·SEt), 247 (5, 265 − H_2O), 203 (5, 265 − HSEt), 177 (4), 135 (100), 107 (12), 105 (27), and 75 (16).

Fraction C, a syrup, was 4,6-*O*-isopropylidene-D-galactose diethyl dithioacetal (**14h**), $[\alpha]_D^{24}$ +19° (*c* 1.44, chloroform) ^{1}H-n.m.r.: δ 1.28 (t, 6 H, *J* 7 Hz, 2 SCH_2CH_3), 2.00, 2.82, 3.15 (3 br s, exchanged with D_2O, 3 OH), 2.73 (q after D_2O exchange, 4 H, *J* 7.5 Hz, 2 SCH_2CH_3), and 3.50–4.40 (complex m, 7 H);

for ^{13}C-n.m.r. data, see Table II; *m/z* 326 (26, M^+), 265 (2, M − ·SEt), 247 (7, 265 − H_2O), 203 (9, 265 − HSEt), 177 (13), 135 (100), 107 (21), 105 (27), and 75 (35).

(b) At 0°. Compounds **14a** (2.145 g, 7.5 mmol), **1b** (0.657 g, 9 mmol), and **2** (75 mg) were kept at 0° in DMF (65 mL) for 23.5 h. Standard isolation yielded a yellowish oil that solidified (2.155 g). The solid was fractionated by chromatography on silica gel (108 g) to give 3 fractions, A (0.899 g, 36%), B (97 mg, 4%), and C (0.429 g, 17%), identical to compounds **14f, 14g,** and **14h**, respectively, obtained in the reaction at room temperature.

^{1}H-N.m.r. spectrum at 361.07 MHz of D-*xylose diethyl dithioacetal* (**12a**) *in dimethyl sulfoxide*-d_6. — With internal Me_4Si (10 mg in 0.6 mL). Selective homonuclear decoupling experiments at the positions of OH-2, OH-4, OH-5, OH-3, H-1, H-3, H-2, H-4, and H-5 were performed to assign signals. The spectrum was analyzed by preliminary simulation of parts of the ten-spin system using a LAOCOON program on an IBM PC computer, then by iterative calculation of line positions using the program LAME[31] on a Cyber 173 computer. The following results were obtained: segment-1 (H-1, H-2, H-3, OH-2), H-1 (4.0143 ±0.0002 p.p.m., $J_{1,2}$ 5.56 ±0.09 Hz), H-2 (3.6958 ±0.0002 p.p.m., $J_{2,3}$ 5.23 ±0.13, $J_{2,OH\text{-}2}$ 5.50 ±0.09 Hz), OH-2 (4.8242 ±0.0002 p.p.m.), segment-2 (H-2, H-3, H-4, OH-3), H-3 (3.7580 ±0.0001 p.p.m., $J_{2,3}$ 4.52 ±0.05, $J_{3,4}$ 3.84 ±0.05, $J_{3,OH\text{-}3}$ 6.44 ±0.24 Hz), OH-3 (4.3019 ±0.0001), segment-3 (H-3, H-4, H-5, H-5′, OH-4, OH-5), H-4 (3.5134 ±0.0001 p.p.m., $J_{3,4}$ 3.82 ±0.07, $J_{4,5}$ 5.58 ±0.05, $J_{4,5'}$ 5.57 ±0.04, $J_{4,OH\text{-}4}$ 5.64 ±0.05 Hz), H-5 (3.4461 ±0.0001 p.p.m., $J_{5,5'}$ −10.99 ±0.04 Hz, $J_{5,OH\text{-}5}$ 5.57 ±0.04 Hz), H-5′ (3.3631 ±0.0001 p.p.m., $J_{5',OH\text{-}5}$ 5.53 ±0.04 Hz), OH-4 (4.4983 ±0.0001 p.p.m.), and OH-5 (4.4627 ±0.0001 p.p.m.). Additional signals were observed at δ 1.177, 1.184 (2 t, *J* 7.43, 7.41 Hz, 2 $SCH_2\mathit{CH}_3$), 2.619 (q, *J* 7.49 Hz, $S\mathit{CH}_2CH_3$), 2.647 (AB part of ABX_3 pattern, $S\mathit{CH}_2CH_3$), 3.326, and 3.349 (2 s, H_2O and HOD signals).

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REFERENCES

1 J. GELAS AND D. HORTON, *Heterocycles*, 16 (1981) 1587–1601 and papers cited therein.
2 D. M. CLODE, *Chem. Rev.*, 79 (1979) 491–513.
3 A. N. DE BELDER, *Adv. Carbohydr. Chem. Biochem.*, 34 (1977) 199–241; J. F. STODDART, *Stereochemistry of Carbohydrates*, Wiley–Interscience, New York, 1971, pp. 186–220.
4 P. GAREGG, T. IVERSEN, AND T. NORBERG, *Carbohydr. Res.*, 73 (1979) 313–314.

5 W. A. R. VAN HEESUIK, J. B. GOEDHART, AND J. F. G. VLIEGENTHART, *Carbohydr. Res.*, 58 (1977) 337–344.
6 M. MILJKOVIC AND P. HAGEL, *Carbohydr. Res.*, 111 (1983) 319–324.
7 M. L. WOLFROM AND G. C. PAREKH, *Carbohydr. Res.*, 11 (1969) 547–557.
8 N. BAGGETT, K. W. BUCK, A. B. FOSTER, M. H. RANDALL, AND J. M. WEBBER, *J. Chem. Soc.*, (1965) 3394–3400.
9 I. J BURDEN AND J. F. STODDART, *J. Chem. Soc. Perkin Trans. I*, (1975) 675–682.
10 T. B. GRINDLEY AND V. GULASEKHARAM, *Carbohydr. Res.*, 74 (1979) 7–30.
11 A. NESZMELYI, A. LIPTÁK, AND P. NÁNÁSI, *Carbohydr. Res.*, 58 (1977) c7–c9.
12 J. P. CLAYTON, R. S. OLIVER, N H. ROGERS, AND T. J. KING, *J. Chem. Soc. Perkin Trans. I*, (1979) 838–846.
13 J. G. BUCHANAN, A. R. EDGAR, D. I. RAWSON, P. SHAHIDI, AND R. H. WIGHTMAN, *Carbohydr. Res.*, 100 (1982) 75–86.
14 E. L. ELIEL, V. S. RAO, AND K. M. PIETRUSIEWICZ, *Org. Magn. Reson.*, 12 (1979) 461–466.
15 K. PIHLAJA AND T. NURMI, *Isr. J. Chem.*, 20 (1980) 160–167.
16 J. B. STOTHERS, *Carbon-13 NMR Spectroscopy*, Academic Press, New York, 1972, p. 56 and 60.
17 D. F. BOCIAN AND H. L. STRAUSS, *J. Am. Chem. Soc.*, 99 (1977) 2876–2882; F. SAURIOL-LORD AND T. B. GRINDLEY, *J. Am. Chem. Soc.*, 103 (1981) 936–938.
18 G. W. SCHNARR, D. M. VYAS, AND W. A. SZAREK, *J. Chem. Soc. Perkin Trans. I*, (1979) 496–503.
19 D C DE JONGH, *J. Org. Chem.*, 30 (1965) 1563–1570.
20 P. A. J. GORIN, *Can. J. Chem* , 43 (1965) 2078–2084.
21 D. G. LANCE AND J. K. N. JONES, *Can. J. Chem.*, 45 (1967) 1533–1538.
22 H. ZINNER, G. REMBARZ, AND H. KLÖCKING, *Chem. Ber.*, 90 (1957) 2688–2699.
23 T. B. GRINDLEY AND R. PONNAMPALAM, *Can. J. Chem.*, 58 (1980) 1365–1371.
24 A. V. WILLI, in C. H. BAMFORD AND C. H. F. TIPPETT (Eds.), *Comprehensive Chemical Kinetics*, Elsevier, Amsterdam, 1977, pp. 1–93.
25 E. H. CORDES, *Prog. Phys. Org. Chem.*, 4 (1967) 1–44.
26 J. E. BALDWIN, *J. Chem. Soc., Chem. Commun.*, (1976) 734–736; 736–738.
27 M. J. PERKINS, P. C. WONG, J. BARRETT, AND G. DHALIWAL, *J. Org. Chem.*, 46 (1981) 2196–2199.
28 F. M. MENGER AND D. Y. WILLIAMS, *Tetrahedron Lett.*, (1982) 3879–3882.
29 D. HORTON AND J. D. WANDER, *Carbohydr. Res.*, 10 (1968) 279–288.
30 S. J. ANGYAL AND R. LE FUR, *Carbohydr. Res.*, 84 (1980) 201–209.
31 C. W. HAIGH, *Annu. Rep NMR Spectrosc.*, 4 (1971) 311–362.
32 A. JOHANNISSIAN AND E AKUNIAN, *Bull. Univ. Etat. R.S.S. Armenie*, 5 (1930) 245–249; *Chem. Abstr.*, 25A (1931) 921–922.
33 E. J. SALMI, *Ber.*, 71 (1938) 1803–1808.
34 E. D BERGMANN AND A. KALUSZYNER, *Recl. Trav. Chim. Pays-Bas*, 78 (1959) 337–342.
35 H. T. CLARKE, *J. Chem. Soc.*, 101 (1912) 1788–1809.
36 D. B. PATTISON, *J. Org. Chem.*, 22 (1957) 662–664.
37 O T. DALLEY AND R. J. MCILROY, *J. Chem. Soc.*, (1949) 555–557.
38 T. VAN ES, *Carbohydr. Res.*, 32 (1974) 370–374.