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threo/erythro-Assignment of 1,3-Diol Derivatives Based on ^{13}C NMR Spectra

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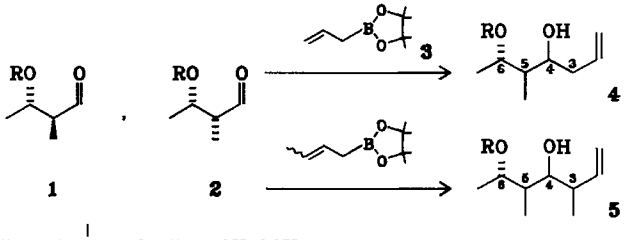
The NMR spectra of 1,3-diols and γ-alkoxy alcohols indicate that these compounds exist predominantly in a hydrogen bonded conformation. *threo*- and *erythro*-diastereomers show distinct differences in their ^{13}C NMR spectra which may be used to assign the relative configuration to each individual member of a pair of diastereomers.

***threo/erythro*-Zuordnung von 1,3-Diol-Derivaten auf der Basis von ^{13}C-NMR-Spektren**

Die NMR-Spektren von 1,3-Diolen und von γ-Alkoxyalkoholen ergeben Hinweise dafür, daß diese Verbindungen vorwiegend in einer Wasserstoff-verbrückten Konformation vorliegen. Die *threo*- und *erythro*-Diastereomeren zeigen nun charakteristische Unterschiede in den ^{13}C-NMR-Spektren, auf deren Basis die relative Konfiguration eines Paars von Diastereomeren zugeordnet werden kann.

Reaction of allylboronates, e.g. **3** with the aldehydes **1** or **2** led to all four diastereomers of the homoallyl alcohols **4**. The related reaction of the (*E*)- and (*Z*)-crotylboronates generated seven of the eight possible diastereomers of **5**[1].



In order to allow discussion of the diastereoselectivity of these reactions[1], the knowledge of the structures of each individual product was required. We therefore attempted to assign the structures of the resulting homoallyl alcohols directly using the ^{13}C and ^{1}H NMR spectra of the mixtures obtained.

6-Alkoxy-4-hydroxy-5-methyl-1-heptenes

Reaction of the aldehyde **2a** with the allylboronate **3** led to the homoallyl alcohols **6** and **8**[1]. While their relative configuration at C-5/C-6 is known from

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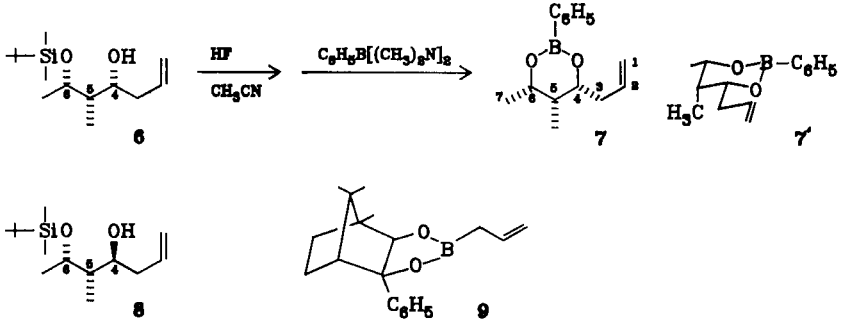
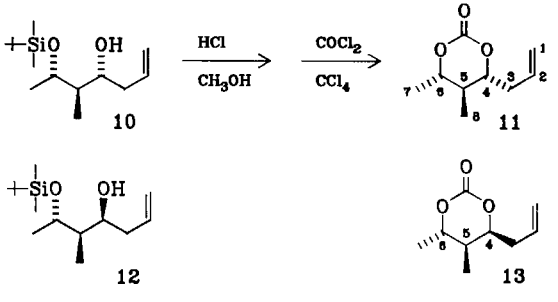
the structure of the educt **2a**, it remained to determine the relative configuration of the newly formed stereocenter at C-4. Since **6** and **8** are 1,3-diol derivatives, this can be done in the usual way by converting them into a 1,3-dioxane derivative, which is amenable to a direct analysis of its ^{1}H NMR spectrum[2-4]. When working with a mixture, this seems feasible, if the mixture is rich in one diastereomer.



Such a mixture of **6** and **8**, which contained 87% of one diastereomer was obtained[5] by reaction of **2a** with the chiral allylboronate **9**. After removal of the silyl group this mixture was converted into the cyclic phenylboronates, the major component of which was identified as **7** on the basis of its ^{13}C and ^{1}H NMR spectrum: Notably the signal of 5-CH_3 appeared at $\delta = 3.5$ characteristic of an axial methyl group between two equatorial substituents[6,7], cf. **7'**.

Moreover, a complete ^{1}H/^{1}H-decoupling experiment revealed the coupling constants for 4-H/5-H to be 2.2 Hz and for 5-H/6-H to be 2.0 Hz securing the conformation **7'** and hence the constitution as **7**. Its precursor homoallyl alcohol must therefore have structure **6** and by exclusion its epimer must have structure **8**.

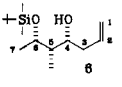
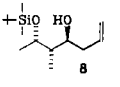
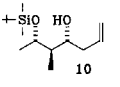
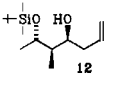
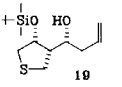
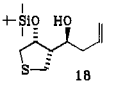
Similarly, reaction of the stereoisomeric aldehyde **1a** with the allylboronate **3** led to the alcohols **10** and **12**. This mixture, as well as the major diastereomer separated by HPLC, were desilylated and converted to the cyclic carbonates **11**, **13**.



An ^{1}H NMR decoupling experiment on the major carbonate showed the coupling constants 4-H/5-H and 5-H/6-H to be 10 Hz each. This is consistent with

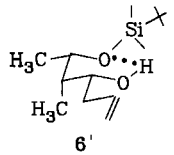
the structure **11**, but not with **13**. Hence, the major diastereomer of the homoallyl alcohols must have structure **10** and by exclusion the minor product must be its epimer **12**. Knowing the structures of the set of isomers **6**, **8**, **10**, and **12**, we hoped that their ^{13}C NMR spectra would contain features which might be diagnostic for each type of diastereomer. Table 1 shows that indeed distinctive shift values are recorded for **6**, **8**, and **12**. Since all these compounds possess the same constitution, the differences in the chemical shifts observed must reflect conformational effects imposed by the different stereo structures.

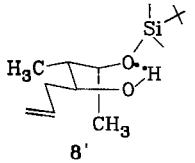
Table 1. ^{13}C NMR Data of β-silyloxy alcohols

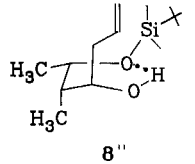
	 6	 8	 10	 12	 19	 18
C-1	117.1	116.7	117.5	116.6	117.7	118.4
C-2	135.5	135.2	135.2	135.6	134.5	134.3
C-3	39.7	39.6	38.8	39.9	39.7	39.1
C-4	73.4*	72.9*	72.1*	69.9	70.3	69.3
C-5	42.8	42.9	45.4	41.8	40.7	40.8
C-6	74.5*	72.4*	72.9*	74.4	78.0	75.0
C-7	21.8	21.1	21.1	22.2	53.1	54.0
5-CH_3	5.8	12.9	11.9	11.2	28.1	29.9

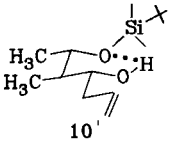
The signals of the *tert*-butyldimethylsilyl group occurred around −5.0, −4.2, 18.0 and 25.8 ± 0.2 ppm. – Assignments of the values with an asterisk may be interchanged.

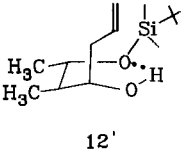
Most conspicuous is the δ = 5.8 value for 5-CH_3 in **6**. Because of its similarity to the chemical shift of 5-CH_3 in the corresponding cyclic compound **7** we assume that **6** exist in the similar conformation **6′**. This assumption is supported by the ^1H NMR spectrum of **6** in which the coupling constants 4-H/5-H = 2.2 Hz and 5-H/6-H = 3 Hz correspond closely to those of **7**. The conformation **6′** may be strongly favored by the intramolecular hydrogen bridge amounting to a 2 kcal stabilization[8]. However, this hydrogen bridged conformation is not necessarily the most stable conformation for 1,3-diols and their derivatives. Exemplary perusal


6'


8'


8''


10'

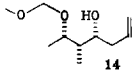
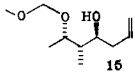
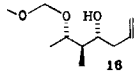
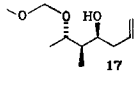

12'

of the literature reveals a number of X-ray structures containing a kinked 1,3-diol unit[9]. This appears to be the rule for alditols[10,11], where the conformation is most likely governed by dipole/dipole repulsion. However, cases favoring the hydrogen bonded conformation are found in similar number[6,11–13].

It is, hence, not unlikely that not only **6**, but also the other compounds **8**, **10**, and **12** exist predominantly in the hydrogen bonded conformation, as is the case for the related γ-amino alcohols[7,14] or β-hydroxycarbonylcompounds[15]. Thus, the high field position of the C-4 signal in the spectrum of **12** suggests the presence of an "axial" substituent, as illustrated by the conformation **12'**[16]. This high field position of the C-4 signal corresponds to that seen in the derived cyclic carbonate **13**. Its C-4 signal appears 3.3 ppm upfield relative to that of **11**. This suggest that **12** and **13** have related conformations. Needless to say, **10**, whose substituents can all occupy equatorial positions in the hydrogen bonded conformation **10'**, shows no remarkable features in its ^{13}C NMR spectrum.

All these observations would be of limited value, if they were restricted to the γ-silyloxy alcohols mentioned above. The related methoxymethyl-protected compounds **14** to **17** (see Table 2) were obtained similarly from the aldehydes **1b** and **2b**. In their ^{13}C NMR spectra the change from the silyloxy group to the methoxymethyl group becomes manifest at the signal of C-7 which moves 4 ppm upfield and at that of C-6 which moves approximately 2–4 ppm downfield. Otherwise the spectra closely correspond to those of the silyloxy compounds, especially in those details sensitive to the conformational aspects: E. g., the 5-CH_3 signal of **14** at 6.2 ppm documents the structural similarity of **14** with **6**. Likewise, the C-4 signal at 69.8 ppm links the structure of **17** with that of **12**.

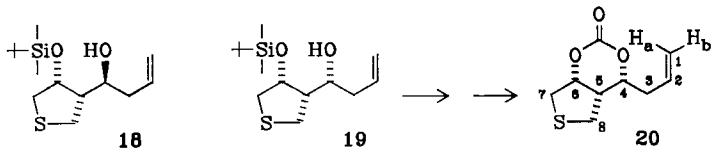
Table 2. ^{13}C NMR Data of β-methoxymethyl alcohols

	 14	 15	 16	 17
C-1	117.2	117.0	117.8	116.8
C-2	135.4	135.3	135.1	135.6
C-3	39.6	39.3	39.0	38.9
C-4	74.1*	72.4*	72.7*	69.8
C-5	41.9	42.2	43.5	42.3
C-6	77.2*	75.1*	77.5*	76.5
C-7	17.6	16.3	16.6	18.4
5-CH_3	6.2	11.5	11.4	10.3

The signals of the methoxymethyl group occurred around 55.7 and 95.0 ppm. – Assignment of values with an asterisk may be interchanged.

Since within the pairs **14**/**15** and **16**/**17** the relative configuration at C-5 and C-6 is the same because of a common precursor, assignment of the structure to one member of a pair **14** and **17**, respectively, establishes those of the remaining epimers **15** and **16**.

Another structural variation is involved in going from the homoallyl alcohols **6** and **8** to the tetrahydrothiophene derivatives **18** and **19**. Their structural assignment started from a sample, which contained 98% of one isomer. After desilylation it was converted into the cyclic carbonate **20**. A complete $^1H/^1H$ NMR decoupling experiment showed the coupling constants 4-H/5-H to be 2.5 Hz and 5-H/6-H to be 3 Hz.



This is consistent with the stereo structure **20**, in which the substituents at C-4 and C-6 are equatorial and that at C-5 is axial on the dioxane ring. This established the structure of its precursor as **19** and by exclusion that of its epimer as **18**.

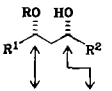
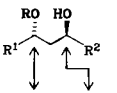
The ^{13}C NMR data of **18** and **19** are included in Table 1. Particularly the relative position of the C-4 and C-6 signals of **18** and **19** again closely corresponds to the situation found with **6** and **8**. Probably because of the folding of the five-membered ring the signal of 5-CH_2 in **19** does not show a highfield shift corresponding to 5-CH_3 in **6**.

Distinguishing *threo*- and *erythro*-1,3-Diol Derivatives

A fundamental study of the ^{13}C NMR spectra of γ-amino alcohols[7,14] showed that the signals of the backbone appear at higher field for the *threo*-isomers. This was attributed to the predominance of hydrogen bonded chair conformations, which in the case of the *threo*-isomers would have "axial" substituents[14]. It appears that these generalizations can be extended to the ^{13}C NMR spectra of the 1,3-diol derivatives[17]: In the *threo*-isomers **12** and **17** the signal of C-4 appears upfield shifted, suggestive of the presence of an axial substituent in the hydrogen bonded conformation **12′**. A similar effect would be expected for the other *threo*-isomers **8** or **15**. Unfortunately, the effect on the signal of C-6 expected from a predominant conformation **8′** is only 2 ppm, too small to be of diagnostic value. An effect of similar magnitude is seen at C-4 of **8** or **15** on comparison with the corresponding signals of **6** and **14**. It could well be that **8′** is not the only conformation of significant population. Perhaps another conformation with a kink at C-4 contributes also to the equilibrium. Maintaining the notion of hydrogen bonded conformations this could be **8″**, but this is by no means established nor important.

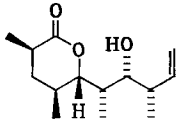
Even allowing for a certain extent of conformational flexibility in these compounds, in a *threo*-diol system conformations with a kink at either oxygen bearing carbon are more likely to be populated than in the corresponding *erythro*-isomers. Hence, like in the γ-amino alcohols[14] or β-hydroxycarbonyl compounds[15] the ^{13}C NMR signals of these carbons should in the average occur at higher field in the *threo*-isomers with respect to the corresponding *erythro*-isomers. To avoid any discussion at which of these two carbons kinks are more likely to occur, it is best

Table 3. ^{13}C NMR Data of *erythro/threo* pairs of 1,3-diols and β-alkoxy alcohols

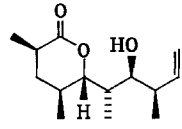
R	R^1	R^2			sum			sum	Structural assignment	Reference
H	CH_3	CH_3	68.3	68.3	136.6	64.8	64.8	129.6	a)	4,17)
H	CH_3	$-CH_2-CH=CH_2$	68.6	71.7	140.3	65.0	68.0	133.0	b)	17)
H	CH_3	$-[CH_2]_3-C(CH_3)=CH_2$	68.8	72.2	141.0	64.8	68.5	133.3	c)	18)
H	CH_3	$-CH_2-CHOH-CH_3$	66.3	67.0	133.3	65.0	65.6	130.6	d)	19)
H	CH_3	$-C(CH_3)_2CH=CH_2$	69.1	79.3	148.4	65.5	74.4	133.9	a)	20)
H	CH_3	$-CH_2CH_2CH_3$	68.5	72.1	140.6	64.9	68.5	133.4	b)	28)
H	$(CH_3)_2CH$	$-C(CH_3)_2CH=CH_2$	78.0	79.4	157.4	74.2	74.6	148.8	a)	20)
$C_6H_5CH_2-$	CH_3	CH_3	75.1	66.9	142.0	72.4	64.1	136.5	c)	17)
$C_6H_5CH_2-$	CH_3	$-CH_2-CH=CH_2$	75.7	70.7	146.4	72.5	67.5	140.0	c)	21)
$C_6H_5CH_2-$	$H_3C-CH(OCH_2-C_6H_5)-CH_2-$	CH_3	75.9	66.2	142.1	74.8	64.8	139.6	c)	19)
CH_3	CH_3	$-CH_2-CH=CH_2$	77.5	70.6	148.1	74.4	67.5	141.9	c)	21)
CH_3OCH_2	CH_3	$-CH_2-CH=CH_2$	73.1	70.1	143.2	71.7	67.2	138.9	c)	21)

[a] Structural assignment based on conversion to a cyclic derivative. – [b] Structural assignment by the method of *Gerlach*[3]. – [c] By conversion to compounds of known structure. – [d] Structural assignment based on symmetry arguments.

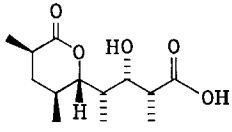
to look at the sum of the chemical shifts of the two oxygen bearing carbon atoms. This sum should be numerically smaller for the *threo*-1,3-diols than for their *erythro*-counterparts[17]. Whether or not this deduction is correct, this extension of the γ-amino alcohol rule[7,14] is clearly borne out by the spectra of a number of 1,3-diols and γ-alkoxy alcohols of known structure, cf. Table 3[22]. This set of data is amplified by the following two pairs of γ-hydroxy lactones[23] that also obey this rule:



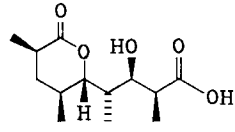
91.6 + 77.8 = 169.4



85.9 + 73.1 = 159.0

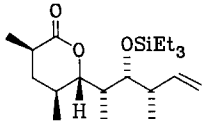


89.1 + 73.3 = 162.4

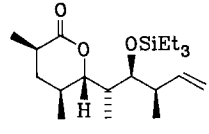


85.7 + 70.4 = 156.1

We note, however, that the corresponding pair of γ-silyloxy lactones[23] does not fit the above generalization:



84.8 + 75.5 = 160.3



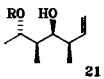
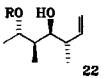
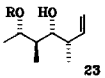
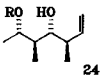
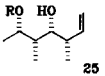
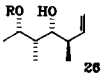
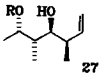
86.9 + 77.2 = 164.1

This suggests that the above rule is indeed restricted to γ-alkoxy alcohols that can and prefer to form hydrogen bonded conformations. We suggest, that with this "caveat" in mind the rule set forth above could be used for assigning the relative configuration of 1,3-diols and γ-alkoxy alcohols.

6-Alkoxy-4-hydroxy-3,5-dimethyl-1-heptenes

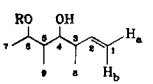
The impetus for this study was the necessity to assign the stereo structure to pairs of diastereomeric 6-alkoxy-4-hydroxy-1-heptenes **5**[1]. A set of ^{13}C NMR spectra was available, cf. Table 4, for seven of the eight possible diastereomeric methoxymethyl derivatives of **5b** and for five of the silylated derivatives **5a**. The relative configuration at C-5/C-6 was known from the nature of the starting aldehyde **1b** or **2b**, respectively. The relative configuration at C-3/C-4 depended on whether the products were derived from a (*Z*)- or (*E*)-crotylboronate[24]. Thus the task was reduced to establishing which compound in a given pair has the 4,6-*threo*- and which the 4,6-*erythro*-configuration. Based on the data discussed above,

Table 4. ^{13}C NMR Data of 3,5-dimethyl-1-heptene-4,6-diol derivatives

	 21 b	 22 a	b	 23 a	b	 24 b	 25 a	b	 26 a	b	 27 a	b
C-1	114.4	114.3	114.9	114.4	114.9	115.9	114.5	114.6	115.1	115.3	113.6	113.9
C-2	141.2	142.6	142.4	142.8	142.2	138.8	141.5	141.3	141.9	141.7	142.9	142.7
C-4	73.4	73.8	73.2	72.3	75.8	76.0	78.9	78.8*	77.2	77.3*	76.1	76.1
C-6	78.2	74.1	77.2	77.0	76.5	77.9	74.2	77.9*	72.8	77.2*	72.2	75.0
C-7	18.3	22.0	18.5	20.7	16.2	16.5	21.8	17.6	21.7	17.8	18.2	16.4
3-CH_3	17.7	16.5	16.5	12.4	10.9	17.7	17.0	17.8	16.7	16.7	12.8	12.4
5-CH_3	10.1	10.9	9.7	11.2	11.4	11.6	5.4	5.6	6.7	7.1	11.6	11.5

The signals of the remaining carbons were not assigned.

Table 5. ^1H NMR Coupling constants (Hz) of selected 3,5-dimethyl-1-heptene-4,6-diol derivatives



	1a/1b	1a/2	1a/3	1b/2	1b/3	2/3	3/4	3/8	4/5	5/6	5/9	6/7
21b	−1.5	10.5	0.5	17	0.5	9.2	9.2	6.5	2.0	5.0	7.0	6.0[a]
23b	−1.5	10.5	1.0	17	1.5	9.0	3.0	7.0	8.9	6.0	7.0	6.2[b]
25a	−1.5	10.5	0.5	17	1.0	9.0	10.5	6.6	2	2	6.3	6.3
27a	−1.5	10.5	1.0	17	1.5	6	3.4	6.8	9.0	2.7	7.1	6.5

[a] Further coupling 4/OH = 2.5 Hz. — [b] Further coupling 4/OH = 3.0 Hz, 2/4 = 1 Hz.

we anticipated that structural assignments could be made with a reasonable level of confidence.

Comparison of the data in Table 4 with those of Table 2 shows that the introduction of a C-3-methyl group led to a downfield shift of the C-2 and C-4 signals and an upfield shift at C-1. Otherwise the diagnostic features seen in Table 2 recur in Table 4. Thus the chemical shifts of the 5-CH_3 signals at 5–7 ppm of **25b** and **26b** derived from **2b** point to a conformation related to **6′** and links these structures to that of **14**. This in turn establishes the structure of the diastereomer **27b** formed alongside **25b**. The configurational assignment to **27b** is underscored by the position of the C-6 signal relative to that of **25b**, indicating the presence of an "axial" substituent in this position like in conformation **8′**.

Of the products derived from the aldehyde **1b** simple comparison of the ^{13}C NMR data shows the similarities of **23b** and **24b** with **16** and of **21b** and **22b** with **17**. In the latter cases the high field position of the C-4 signal is obvious.

Comparison of the data of the silylated derivatives in Table 4 with those of Table 1, as above, allowed the assignment of their stereo structures as **22a**, **23a**, **25a**, **26a**, and **27a**. The consistency of the data in Table 4 with those of Tables 1 and 2 leaves no doubt as to the correctness of these assignments. These were made without recourse to the rule set forth above. It is no surprise that these assignments turned out to be consistent with that rule.

These assignments are based on similarities of the chemical shifts, and are therefore practically independent of the assumption that most or all of these compounds prefer the hydrogen bonded conformation. Nevertheless a test of this hypothesis, and be it only in selected cases, seemed worthwhile. More information on the preferred conformation might be available from the coupling constants in the ^1H NMR spectra. We therefore subjected two mixtures of compounds **25a**, **27a**, and **21b**, **23b**, which showed not too extensive overlap of their ^1H NMR signals in the 400 MHz NMR spectrum, to a detailed decoupling experiment. Apart from the configuration at C-3, these four compounds are representative of the four diastereomers possible at C-4 to C-6 of **5**.

The coupling constants, cf. Table 5, along the backbone of **25a** are consistent with the hydrogen bonded conformation related to **6′**. The small *J*-values 4-H/5-H and 5-H/6-H and the large value for 3-H/4-H mirror the ones found in the structurally related erythronolide[25]. The backbone coupling constants of **27a** are consistent with a preferred conformation corresponding to **8′** but not to one corresponding to **8″**, viz. $J_{4/5} = 9.0$ Hz.

Turning to the compound **23b** the 9 to 6 Hz coupling constants $J_{4/5}$ and $J_{5/6}$ suggest an antiperiplanar arrangement of the hydrogen atoms along the backbone related to conformation **10′**, cf. the corresponding values for a pseudomonic acid derivative[13]. Less instructive were the coupling constants obtained for **21b**. While the values of 5 Hz for $J_{5/6}$ and of 2 Hz for $J_{4/5}$ are consistent with the hydrogen bonded conformation related to **12′**, other conformations could also lead to such values[16].

Thus, the ^1H NMR coupling constants show that the compounds **23b**, **25a**, and **27a** prefer the hydrogen bonded conformation. We feel that probably all the

compounds **4** and **5** prefer this conformation, because whenever coupling constants 4-H/5-H or 5-H/6-H could be estimated from unobscured multiplets in their ^{1}H NMR spectra, the values differed from those of the structurally related representative in Table 5 by less than 2 Hz. This lends credence to the hypothesis that all the γ-alkoxy alcohols studied here prefer the hydrogen bonded conformation.

We would like to thank the *Deutsche Forschungsgemeinschaft* and the *Fonds der Chemischen Industrie* for their support. We also thank Prof. *M. T. Reetz*, Marburg, for his permission to include unpublished data from the Diplomarbeit of *A. Jung* in Table 3. We are particularly grateful to Dr. *S. Berger*, *A. Mbonimana*, and *G. Haede* for their advice, patience and help in measuring the numerous NMR spectra.

Experimental Part

All temperatures quoted are non corrected. – ^{1}H NMR spectra: Bruker WH-400. – ^{13}C NMR spectra: Jeol FX 100. – Preparative gas chromatography: Aerograph A-90-P-3, 1.5 m × 0.6 cm column with 5% SE-30 on chromosorb G, AW-DMCS, (60–80 mesh) 130 ml He/min; similarly with 5% Apiezon M. – Analytical gas chromatography: Perkin-Elmer F-900, 40 m × 0.3 mm glas capillary column with SE 52. – HPLC: Dupont 830 liquid chromatograph, 16 × 250 mm column with Li-Chrosorb Si-60, 70 μm. – Optical rotations: Perkin-Elmer polarimeter 141.

1. *(4R,5R,6S)-5-Methyl-1-heptene-4,6-diol:* 0.68 g (2.6 mmol) of (4*R*,5*S*,6*S*)-6-(*tert*-butyldimethylsilyloxy)-5-methyl-1-hepten-4-ol (**6**)[1] (diastereomeric purity 87%) were stirred for 6 h in 15 ml of 30% HF/acetonitrile. After addition of 3 ml water the aqueous layer was saturated with NaCl and extracted 5 times with 10 ml of chloroform each. The extracts were dried over Na_2SO_4 and concentrated i. vac. The residue (0.6 g) was purified by g.c. (SE-30, 150°C) to give 0.25 g (66%) of a colourless liquid. Capillary g.c. (SE-30, 120°C) revealed the diastereomeric purity to be 90%. – ^{1}H NMR ($CDCl_3$): δ = 0.93 (d, *J* = 7.1 Hz, 3H), 1.19 (d, *J* = 6.4 Hz, 3H), 1.47 (m, 1H), 1.57 (s, 2H), 2.32 (m, 2H), 3.9 (t, 1H), 4.09 (m, 1H), 5.19 (m, 2H), 5.78 (m, 1H). – ^{13}C NMR ($CDCl_3$): δ = 4.2, 21.3, 39.9, 41.5, 72.4, 75.8, 117.2, 134.9.

$C_8H_{16}O_2$ (144.2) Calc. C 66.63 H 11.18 Found C 66.55 H 11.0

2. *(4S,5R,6S)-5,6-Dimethyl-2-phenyl-4-(2-propenyl)-1,3,2-dioxaborinane* (**7**)[26]: To a solution of 0.35 g (2.0 mmol) of bis(dimethylamino)phenylborane[27] in 25 ml of anhydrous ether were added 200 mg (1.38 mmol) of (4*R*,5*R*,6*S*)-5-methyl-1-heptene-4,6-diol. The next day the solution was filtered and concentrated i. vac. The residue was purified by g.c. (SE-30, 170°C) to give 238 mg (75%) of a colourless liquid. Its diastereomeric purity was determined by capillary g.c. (SE-30, 170°C) to be 84%. – ^{1}H NMR ($CDCl_3$) (the hydrogen atoms are numbered according to **7**): 1a-H δ = 5.14 (coupled to 1b-H *J* = 2.5 Hz; 2-H 9.9; 3a-H 0.5; 3b-H 1 Hz); 1b-H δ = 5.21 (2-H 16.5; 3a-H 0.5; 3b-H 1 Hz); 2-H δ = 5.92 (3a-H 6; 3b-H 6.5 Hz); 3a-H δ = 2.28 (3b-H –13.5; 4-H 6.8 Hz); 4-H δ = 4.27 (5-H 2.2 Hz); 5-H δ = 1.87 (6-H 2; 7-H 6.5; 8-H 7 Hz); 7-H δ = 1.32; 8-H δ = 0.87. – ^{13}C NMR ($CDCl_3$): δ = 3.5, 19.8, 36.6, 38.3, 72.1, 75.7, 117.2, 127.4, 130.5, 133.8, 133.9, 134.4.

$C_{14}H_{19}BO_2$ (230.1) Calc. C 73.07 H 8.32 Found C 72.97 H 8.10

3. *(4R,5R,6S)-6-(tert-Butyldimethylsilyloxy)-5-methyl-1-hepten-4-ol* (**10**): A 1:1 mixture of **10** and **12**[1] was separated by HPLC using CH_2Cl_2 as solvent. G.c. control of the eluates revealed the first fraction to contain **12** of 73% purity, the second fraction to contain **10** of

99% diastereomeric purity. This material was freed of solvent by preparative g.c. (apiezon M, 110°C).

10: ^{1}H NMR ($CDCl_3$): δ = 0.07 (s, 6H), 0.8 (d, J = 6.9 Hz, 3H), 0.88 (s, 9H), 1.13 (d, J = 6.2 Hz, 3H), 1.59 (m, 1H), 2.1 (m, 1H), 2.37 (m, 1H), 3.0 (broad s, 1H), 3.59 (q, 1H), 3.8 (q, 1H), 5.13 (m, 2H), 5.9 (m, 1H).

	λ = 589	578	546	436	365 nm
$[\alpha]_\lambda^{21}$ (c = 1.685, $CHCl_3$)	+12.1	+13.1	+14.8	+24.3	+38.6°

4. *(4R,5S,6S)-5-Methyl-1-heptene-4,6-diol:* A solution of 0.64 g (2.5 mmol) of **10** in 50 ml of 5 N methanolic HCl was left over night. The solvents were removed i. vac. and the residue distilled at 75–78°C/0.1 Torr to give 0.28 g (78%) of a faintly yellow oil. – ^{1}H NMR ($CDCl_3$): δ = 0.79 (d, J = 6.9 Hz, 3H), 1.18 (d, J = 6.2 Hz, 3H), 1.49 (sext, J = 7 Hz, 1H), 2.12 (pent, J = 7.7 Hz, 1H), 2.44 (broad d, J = 12 Hz, 1H); 3.57 (td, J = 8.5 and 3 Hz, 1H), 3.80 (mc, 1H), 5.14 (mc, 2H), 5.84 (mc, 1H). – ^{13}C NMR ($CDCl_3$): δ = 12.8, 21.4, 39.6, 44.8, 72.4, 75.4, 118.5, 134.5. = $[\alpha]_{365}^{21}$ = +3.58 (c = 2.43, $CDCl_3$).

$C_8H_{16}O_2$ (144.2) Calc. C 66.63 H 11.18 Found C 66.49 H 11.25

5. *(4R,5S,6S)-5,6-Dimethyl-4-(2-propenyl)-1,3-dioxan-2-one* (**11**)[26]: A solution of 0.28 g (1.9 mmol) of (4*R*,5*S*,6*S*)-5-methyl-1-heptene-4,6-diol in 2 ml of CCl_4 was added at –78°C to a solution of 1.97 g (20 mmol) of phosgene in 20 ml of CCl_4. The cooling bath was removed and the solvent was distilled off the next day. Preparative g.c. of the residue (SE-30, 170–190°C) furnished 198 mg (60%) of a colourless liquid. – ^{1}H NMR ($CDCl_3$) (the hydrogen atoms are numbered according to **11**): 1a-H δ = 5.18 (coupled to 1b-H J = 1.5 Hz; 2-H 10; 3a-H 1.5; 3b-H 1 Hz); 1b-H δ = 5.17 (2-H 17; 3a-H 1; 3b-H 0.5 Hz); 2-H δ = 5.86 (3a-H 5; 3b-H 9 Hz); 3a-H δ = 2.59 (3b-H –15; 4-H 3.5 Hz); 3b-H δ = 2.34 (4-H 6 Hz); 4-H δ = 4.17 (5-H 10 Hz); 5-H δ = 1.71 (6-H 10; 8-H 6.5 Hz); 6-H δ = 4.12 (7-H 6.7 Hz); 7-H δ = 1.38; 8-H δ = 0.96. – ^{13}C NMR ($CDCl_3$): δ = 11.9, 18.9, 36.4, 36.6, 79.8, 82.8, 118.2, 131.4, 149.2. – $[\alpha]_D^{23}$ = –6.21; $[\alpha]_{365}^{23}$ = –16.6 (c = 2.415, $CDCl_3$).

$C_9H_{14}O_3$ (170.2) Calc. C 63.51 H 8.29 Found C 63.59 H 8.60

In a mixture of **11** and **13** the following signals of **13** could be seen in the ^{13}C NMR spectrum: δ = 11.6, 20.1, 34.3, 34.8, 78.2, 79.4, 118.7, 132.0, 148.5.

6. *(3S,4R,1'R)-4-Hydroxy-3-(1'-hydroxy-3'-butenyl)tetrahydrothiophene:* A solution of 500 mg (1.7 mmol) of (3*S*,4*R*,1'*R*)-4-(*tert*-butyldimethylsilyloxy)-3-(1'-hydroxy-3'-butenyl)-tetrahydrothiophene (**19**) (material of 93% diastereomeric purity[5]) in 50 ml 5 N HCl in methanol was stirred over night. The solvent was removed i. vac. and the residue triturated with 1 ml of water. Solid $NaHCO_3$ was added until the mixture had a pH = 5–6. The solution was extracted 10 times with 20 ml each of diethylether. The combined extracts were dried over Na_2SO_4. Removal of the solvent and distillation at 120–130°C/0.05 Torr furnished 196 mg (65%) of a colourless liquid. – ^{1}H NMR ($CDCl_3$): δ = 1.6 (broad s, 2H), 2.04 (m, 1H), 2.3 (m, 2H), 2.9 (m, 3H), 3.06 (m, 1H), 4.19 (m, 1H), 4.5 (broad s, 1H), 5.15 (m, 2H), 5.8 (m, 1H). – ^{13}C NMR ($CDCl_3$): δ = 26.7, 40.2, 41.3, 52.1, 70.5, 77.4, 118.4, 134.1.

	λ = 589	578	546	436	365 nm
$[\alpha]_\lambda^{22}$ (c = 0.52, $CDCl_3$)	–13	–12	–11	–17	–27°

$C_8H_{14}O_2S$ (174.3) Calc. C 55.14 H 8.09 S 18.39 Found C 54.91 H 8.33 S 18.08

7. *(4R,4aS,7aR)-4-(2-Propenyl)tetrahydrothieno[3,4-d]-1,3-dioxan-2-one* (**20**)[26]: A solution of 0.32 g (1.8 mmol) of the diol prepared under 6. in 10 ml of anhydrous $CHCl_3$ was added to a solution of 1.0 g (11 mmol) of phosgene in 10 ml of chloroform at –50°C. After

2 h at −50°C the mixture was allowed to reach room temperature. The next day the solvent was removed i. vac. leaving a yellow oil which contained (^{13}C NMR) still starting material. Therefore the oil was taken up in 10 ml of chloroform and treated once more as above. Removal of the solvent and distillation at 30°C/0.05 Torr furnished 356 mg (70%) of **20** as a slightly yellow oil. The crude product gave the following analysis.

$C_9H_{12}O_3S$ (200.3) Calc. C 53.98 H 6.07 S 16.01 Found C 54.09 H 7.80 S 15.94

^{1}H NMR ($CDCl_3$) (the hydrogen atoms are numbered according to **20**): 1a-H δ = 5.19 (coupled to 1b-H J = 1.5 Hz; 2-H 17.5; 3a-H 3.0; 3b-H 2 Hz); 1b-H δ = 5.16 (2-H 10; 3a-H 3.0; 3b-H 2 Hz); 2-H δ = 5.73 (3a-H 7.8; 3b-H 6 Hz); 3a-H δ = 2.26 (3b-H −13.5; 4-H 7 Hz); 3b-H δ = 2.53 (4-H 6.5 Hz); 4-H δ = 4.72 (5-H 2 Hz); 5-H δ = 2.64 (6-H 3; 8a-H 9.2; 8b-H 9.0 Hz); 6-H δ = 5.3 (7a-H 4; 7b-H 1.1 Hz); 7a-H δ = 3.07 (7b-H −13.2 Hz); 7b-H δ = 3.11; 8a-H δ = 2.90 (8b-H 9 Hz); 8b-H δ = 2.92. − ^{13}C NMR ($CDCl_3$): δ = 26.4, 37.4, 37.6, 43.3, 76.6, 84.7, 119.6, 130.9, 147.9.

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