120. Glyconothio-*O*-lactones

Part II

Cycloaddition to Dienes, Diazomethane, and Carbenoids

by **Marianne Hürzeler**[a]), **Bruno Bernet**[b]), **Thomas Mäder**[b]), and **Andrea Vasella**[b])* [1])

[a]) PRPV Bau 15, *F. Hoffmann-La Roche AG*, CH–4002 Basel
[b]) Organisch-chemisches Institut, Universität Zürich, Winterthurerstrasse 190, CH–8057 Zürich

(4.III.93)

The addition of dienes, diazomethane, and carbenoids to the *manno*- and *ribo*-configurated thio-γ-*O*-lactones **1** and **2** was investigated. Thus, **1** (*Scheme 1*) reacted with 2,3-dimethylbutadiene (→ **4**, 73%), cyclopentadiene (→ **5a/b** 1:1, 70%), cyclohexa-1,3-diene (→ **9a/b** 2:3, 92%), and the electron-rich butadiene **6** (→ **7a/b** 3:1, 82%). Wheras **5a/b** was separated by flash chromatography, **7a/b** was desilylated leading to the thiapyranone **8**. Selective hydrolysis of one isopropylidene group of **9a/b** and flash chromatography gave **10a** and **10b**. The stuctures of the adducts were elucidated by X-ray analysis (**4**), by NOE experiments (**4**, **5a**, **5b**, **7a/b**, **10a**, and **10b**), and on the basis of a homoallylic coupling (**7a/b**). The additions occurred selectively from the '*exo*'-side of **1**. Only a weak preference for the '*endo*'-adducts was observed. Hydrogenation of **9a/b** with *Raney*-Ni (EtOH, room temperature) gave the thiabicyclo[2.2.2]octane **11**. Under harsher conditions (dioxane, 110°), **9a/b** was reduced to the cyclohexyl β-D-*C*-glycoside **12** which was deprotected to **13**. X-Ray analysis of **13** proved that the desulfuration occurred with inversion of the anomeric configuration. The regioselective addition of the dihydropyridine **14** to **1** (*Scheme 2*) and the methanolysis of the crude adduct **15** gave the lactams **16a** (32%) and **16b** (38%). Desilylation of **15** with $Bu_4NF \cdot 3H_2O$, however, gave the unsaturated piperidinedione **17** (92%) which was deprotected to the tetrol **18** (65%). Similarly, **2** was transformed *via* **19** (62%) into the triol **20** (74%). The cycloaddition of **1** with CH_2N_2 (*Scheme 3*) gave a 35:65 mixture of the 2,5-dihydro-1,3,4-triazole **21** and the crystalline 4,5-dihydro-1,2,3-triazole **22**. Treatment of **21** and **22** with base gave the hydroxytriazoles **23** and **24**, respectively. The structure of **24** was established by X-ray analysis. The triazole mixture **21/22** was separated by prep. HPLC at 5°. At room temperature, **21** already decomposed (half-life 21.6 h) leading in $CDCl_3$ solution to a complex mixture (containing *ca.* 20–25% of the spirothiirane **27** and *ca.* 7–10% of its anomer) and in MeOH solution exclusively to the *O*,*O*,*S*-ortholactone **26**. Crystals of **22** proved be stable at 105°. Upon heating in petroleum ether at 100°, **22** was transformed into a *ca.* 1:1 mixture of **27** and the enol ether **28**. The reaction of **1** with ethyl diazoacetate (*Scheme 4*) in the presence of $Rh_2(OAc)_4 \cdot 2H_2O$ gave the unsaturated esters **29** (33%) and **30** (26%), whereas the analogous reaction with diethyl diazomalonate afforded the spirothiirane **31** (68%) and the enol ether **32** (29%). Complete transformation of **31** into **32** was achieved by the treatment with $P(NEt_2)_3$. Similarly, **33** (69%) was prepared from **2**.

Introduction. – We have recently described the synthesis of glyconothio-*O*-lactones by photolysis of phenacyl thioglycosides or by thermolysis of *S*-glycosyl thiosulfinates, and the addition of nucleophiles to the *manno*-thio-*O*-lactone **1** [1].

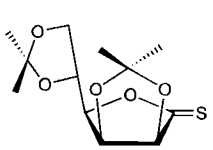
[1]) Present address: Laboratorium für Organische Chemie, ETH-Zentrum, Universitätstrasse 16, CH–8092 Zürich

Thiocarbonyl compounds undergo cycloadditions with a variety of unsaturated compounds. The hetero-*Diels-Alder* reactions of thioketones and thioaldehydes were investigated in detail [2] [3a] [4–6]. A range of thioaldehydes and thioketones were prepared *in situ* and trapped at low temperature with simple dienes [3a] [4] [7][2]). Thio-*O*-esters and dithioesters are less reactive and require higher reaction temperatures. *O,O*-Dimethyl dithiooxalate reacted with 2,3-dimethylbuta-1,3-diene (**3**) at room temperature to slowly generate the mono-*Diels-Alder*-addition product in quantitative yield [8]. *O*-Methyl thioacetate, lacking an activating, electron-withdrawing group, gave the corresponding addition product (73%) only under harsh conditions (3 days at 160°) [9].

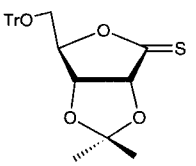
Thiocarbonyl compounds are also highly reactive towards 1,3-dipolar compounds, such as nitrile oxides, nitrile ylides, and diazo compounds [4] [5] [10–15]. The main primary products of the reaction between thioketones or thioaldehydes and diazo compounds are 2,5-dihydro-1,3,4- and 4,5-dihydro-1,2,3-thiadiazoles. In some cases, the ratio of the regioisomers depends strongly on the solvent [16]. The dihydro-thiadiazoles are unstable at higher temperatures where they lose N_2 and S to yield thiiranes or alkenes. The less stable isomers, the 2,5-dihydro-1,3,4-thiadiazoles, may lose N_2 readily under conditions of their formation, and yield 1,3-dithiolanes by a 1,3-dipolar cycloaddition between the intermediate thiocarbonyl ylide and the thiocarbonyl compound [2] [13] [17] [18]. Dithioesters and trithiocarbonate react with diazoalkanes to form 2,5-dihydro-1,3,4-thiadiazoles and their derivatives [17] [19–21], while the analogous reaction of thio-*O*-esters leads to 5-alkoxy-4,5-dihydro-1,2,3-thiadiazoles [21] and, after elimination of ROH, to 1,2,3-thiadiazoles [21] [22]. A diadduct possessing both a 4,5-dihydro-1,2,3-thiadiazole and a 2,5-dihydro-1,3,4-thiadiazole moiety was obtained from the reaction of CH_2N_2 to *O,O*-dimethyl dithiooxalate [19]. Other cycloadditions of thiocarbonyl compounds include their reaction with alkenes to give thietanes under photolytic conditions [4] [23], and with carbenes or carbenoids, leading to thiiranes and further, with loss of the S-atom, to the corresponding alkenes [4] [24].

In spite of this impressive synthetic potential, only two reports refer to cycloadditions of carbohydrate-derived thiocarbonyl compounds. Both describe the synthesis of 5-deoxy-5-thiopyranosides, namely the synthesis of monosaccharides from methyl cyanodithioformate and buta-1,3-diene [25] and the synthesis of disaccharides from monosaccharide-derived thio-*O*-formates and buta-1,3-dienes [26], without, in the second case, determining the configuration of the cycloadducts.

To explore the preparative potential of glyconothio-*O*-lactones, we examined the cycloaddition of the thio-1,4-*O*-lactones **1** and **2** with dienes, diazomethane, and carbenoids.



1



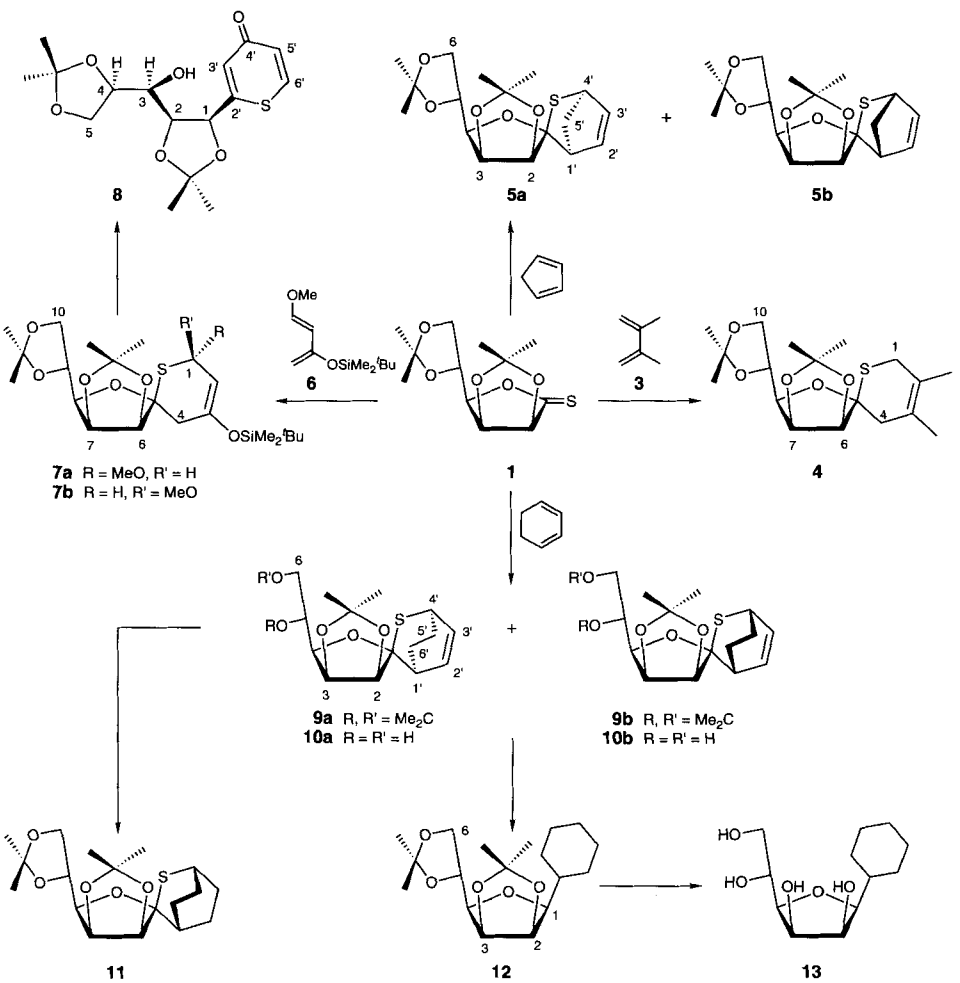
2

[2]) For hetero-*Diels-Alder* reactions of α,β-unsaturated thioketones or of 1,2-dithioketones with alkenes, see [3b] [8].

Results and Discussion. – *[1,4]-Cycloadditions.* To the best of our knowledge, only a few [1,4]-cycloadditions of thio-*O*-esters [8] [27], but none of thio-*O*-lactones were described. We, therefore, investigated the reaction of **1** with reactive dienes, *viz.* 2,3-dimethylbuta-1,3-diene (**3**), cyclopentadiene, cyclohexa-1,3-diene, and the electron-rich butadiene **6** [7] [28]. In all cases, the diene was used as solvent.

The reaction of **1** with **3** at 150° yielded 75% of **4**. Cyclopentadiene gave already at 80° a 1:1 mixture of diastereoisomers. Flash chromatography yielded pure samples of **5a** (34%) and **5b** (36%). Attack of the diene on **1** is expected to occur from the '*exo*'-side. Thus, the formation of one adduct from **3** and of two adducts from cyclopentadiene is expected.

Scheme 1



The structure of **4** was established by X-ray analysis (Fig. *1*, *Table 1*). The β-D-configuration of the thioglycoside is in keeping with the attack of the diene from the '*exo*'-side of the trioxabicyclo[3.3.0]octane system. The C(1)–S(1) and C(2)–O(5) bonds are synperiplanar (dihedral angle of 8.1°; arbitrary numbering, see *Fig. 1*). An *exo*-anomeric effect is sterically possible (dihedral angle O(1)–C(1)–S(1)–C(16) of –63.6°), and its existence is indicated by a lengthening of the C(1)–O(1) bond and a shortening of the C(1)–S(1) bond. The furanose ring possess a $^{O}T_{4}$ and the thiopyran ring a $^{S}H_{1}$ conformation.

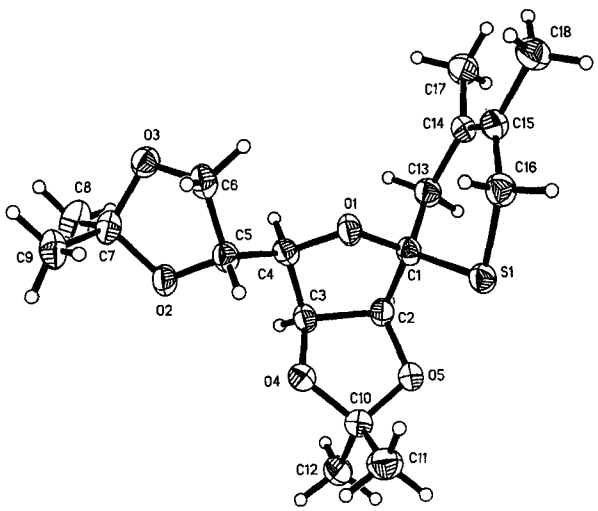


Fig. 1. *X-Ray structure of* **4**

In the ^{1}H-NMR spectrum of **4**, 2 *s* at 1.77 and 1.71 ppm are assigned to the olefinic Me groups. An *AB* system (J = 15 Hz) at 3.24 and 2.97 ppm and a *s* at 2.32 ppm are due to the two allylic CH_2 groups. The neighborhood of the allylic CH_2(4) with H–C(6) and H–C(8) is evidenced by NOE experiments (*Table 3*). The diastereoisomers **5a/b** exhibit similar chemical shifts and coupling constants in the mannose moiety as **4** (*Table 2*). NOE Experiments with **5a/b** prove the neighborhood of the more strongly shielded bridgehead H-atom with H–C(2) and H–C(4) (*Table 3*). In addition, NOE's between H–C(2) and the olefinic H–C(2') of **5a**, and, for **5b**, between H–C(2) and H–C(5') and between H–C(4) and H–C(2') allow an unambiguous configurational assignment.

The electron-rich butadiene **6** added to **1** already at 110°, *i.e.* 40° below **3**, leading in an expected, regioselective addition [7] to a 3:1 mixture of the *O,S*-acetals **7a/b** in 82% yield. Desilylation of **7a/b** with Bu_4NF yielded 49% of the crystalline hydroxy-thiopyranone **8** by twofold β-elimination. The *Diels-Alder* reaction of **1** with cyclohexa-1,3-diene at 180° gave a 2:3 mixture **9a/b** which could not be separated by flash chromatography. Regioselective hydrolysis of the 5,6-*O*-isopropylidene group by aq. AcOH gave a mixture of the diols **10a/b**. Upon chromatography, pure samples of **10a** and **10b** were obtained. Hydrogenation of **9a/b** with *Raney*-Ni in EtOH for 4 h at room temperature led in 53% yield to a single compound, the thiabicyclo[2.2.2]octane **11**. Harsher conditions (1 h at 110° in dry dioxane) gave the cyclohexyl *C*-glycoside **12** (77%). The reduction occurred with inversion of the configuration at C(1). Deprotection of **12** in aq. AcOH at 110° and crystallization from AcOEt led to the tetrol **13** in 54% yield.

Table 1. *Selected Bond Lengths, H,H Distances, and Bond and Dihedral Angles of* **4**. For numbering, see *Fig.1*.

Bond Lengths or H,H Distances [Å]				Bond or Dihedral Angles [°]			
C(1)–C(2)	1.536 (10)	C(14)–C(15)	1.301 (12)	O(1)–C(1)–C(2)	104.9 (5)	C(3)–C(4)–C(5)–O(2)	–61.4
C(2)–C(3)	1.537 (10)	C(15)–C(16)	1.512 (12)	C(1)–C(2)–C(3)	105.7 (6)	C(4)–O(1)–C(1)–C(13)	94.4
C(3)–C(4)	1.499 (11)	C(16)–S(1)	1.776 (8)	C(3)–C(4)–O(1)	105.7 (5)	C(4)–O(1)–C(1)–S(1)	–143.2
C(4)–C(5)	1.498 (12)	C(14)–C(17)	1.506 (12)	C(4)–O(1)–C(1)	109.7 (5)	O(5)–C(2)–C(1)–S(1)	8.1
C(1)–O(1)	1.446 (9)	C(15)–C(18)	1.508 (11)	O(1)–C(1)–S(1)	108.8 (5)	C(1)–C(13)–C(14)–C(15)	14.8
C(2)–O(5)	1.407 (9)	*H*–C(16),*H*–C(2)	2.29	C(1)–S(1)–C(16)	97.7 (4)	C(13)–C(14)–C(15)–C(16)	3.1
C(3)–O(4)	1.417 (10)	*H*–C(16),*H*–C(3)	4.23	S(1)–C(16)–C(15)	116.9 (7)	C(14)–C(15)–C(16)–S(1)	15.7
C(4)–O(1)	1.424 (8)	*H*–C(16),*H*–C(4)	3.78	C(1)–C(2)–C(3)–C(4)	13.2	C(15)–C(16)–S(1)–C(1)	–41.8
C(1)–C(13)	1.508 (11)	*H'*–C(16),*H*–C(2)	2.50	C(2)–C(3)–C(4)–O(1)	–27.6	H–C(2)–C(3)–H	18.2
C(1)–S(1)	1.771 (7)	*H'*–C(16),*H*–C(3)	2.54	C(3)–C(4)–O(1)–C(1)	33.0	H–C(3)–C(4)–H	–34.5
C(13)–C(14)	1.498 (10)	*H'*–C(16),*H*–C(4)	3.64	O(1)–C(4)–C(5)–O(2)	–179.0	H–C(4)–C(5)–H	–177.7

Table. 2. *Selected ^{1}H-NMR* ($CDCl_3$) *Chemical Shifts* [ppm] *and Coupling Constants* [Hz] *of the Mannose Part* [a]) *of the Cycloadducts to* **1** *and of Their Derivatives*

	H–C(2)	H–C(3)	H–C(4)	H–C(5)	H–C(6)	H'–C(6)	*J*(2,3)	*J*(3,4)	*J*(4,5)	*J*(5,6)	*J*(5,6')	*J*(6,6')
1	4.86	4.89	4.68	4.45	4.13	4.08	5.1	2.9	8.0	6.0	4.2	9.2
4	4.52	4.88	3.78	4.48	4.10	4.03	6.1	4.0	8.5	6.0	4.1	8.7
5a	4.49	4.88	3.76	4.46–4.50	4.13	4.13	6.0	3.9	8.4	[b])	[b])	[b])
b	4.70	4.92	3.59	4.38	4.08	3.96	5.9	3.8	8.7	6.2	3.4	8.9
7a	4.59	4.88	3.82	4.50	4.00–4.08	4.00–4.08	6.0	4.5	7.5	5.3	5.3	[b])
b	4.59	4.86	3.74	4.44	4.09	4.00–4.08	6.0	4.0	8.3	6.1	4.0	8.8
9a	4.52	4.84	3.65	4.45	3.95–4.20	3.95–4.20	6.0	4.0	9.0	6.0	3.5	[b])
b	4.96	4.85	3.64	4.37	3.95–4.20	3.95–4.20	6.0	4.0	9.0	6.0	3.5	[b])
10a	4.51	4.87	3.80	3.76–4.04	3.76–4.04	3.76–4.04	5.9	4.2	8.5	[b])	[b])	[b])
b	4.96	4.89	3.81	3.58–3.96	3.58–3.96	3.58–3.96	6.0	4.0	8.0	[b])	[b])	[b])
11	4.74	4.79	3.52	4.45	4.15	4.04	6.0	3.3	8.3	6.2	3.8	9.1
12[c])	4.64	4.70	3.41	4.40	4.08	4.08	6.0	3.5	7.4	5.3	5.3	[b])
13[d])[e])	3.87	4.24	3.51	3.72	3.54	3.33	5	7	7	3.8	6.5	11.0
16a	4.74	4.84	3.58	4.44	4.14	4.05	5.8	3.9	8.1	6.0	3.7	8.9
b	4.73	4.86	3.79	4.37	4.10	3.98	5.8	3.6	8.8	6.2	4.2	8.8
21	4.97	5.18	4.40	4.44	4.08	3.98	5.8	3.5	8.3	5.7	3.7	8.9
22	4.84	4.87	3.70	4.40	4.06	3.96	5.8	3.4	8.0	6.1	3.9	9.0
26	4.56	4.82	3.80	4.40	4.11	4.01	5.8	3.8	7.9	6.2	4.3	8.8
27	4.57	4.96	3.79	4.50	4.10	4.02	5.9	3.7	8.2	6.0	3.9	8.9
31	5.37	4.95	3.90	4.45	4.06	3.86	5.8	3.4	8.4	6.1	3.8	8.9
8[d])	5.29	4.54	3.30	3.78–3.97	3.78–3.97	3.78–3.97	7.5	2.0	8.0	[b])	[b])	[b])
23	5.75	4.85	3.58	3.98	4.03	3.87	7.8	0.9	8.3	6.1	4.7	8.0
24	5.76	4.65	3.13	3.95	4.03	3.83	7.5	1.9	8.2	6.2	5.4	8.5
17	5.86	4.91	4.27	4.52	4.16	4.08	6.0	4.2	7.0	6.1	4.7	8.8
18[d])	4.97	4.34	4.20	3.81–3.90	3.63	3.46	4.0	4.0	9.0	2.8	5.5	12.0
29	5.14	4.78	4.38	4.47–4.54	4.08–4.24	4.08–4.24	6.0	3.5	8.0	[b])	[b])	[b])
30	5.76	4.86	4.04–4.24	4.44–4.51	4.04–4.24	4.04–4.24	6.1	4.0	[b])	[b])	[b])	[b])
32	5.75	4.84	4.33	4.50	4.07–4.19	4.07–4.19	5.7	3.7	7.5	6.0	4.5	[b])

[a]) Numbering as in **1**. [b]) Not determined. [c]) H–C(1) at 3.08 ppm, *J*(1,2) = 3.0, *J*(1,1') = 9.5 Hz. [d]) In (D_6)DMSO. [e]) H–C(1) at 3.12 ppm, *J*(1,2) = 3.8, *J*(1,1') = 10.0 Hz.

Table. 3. *NOE Experiments on the Adducts* **4**, **5**, **7**, **10**, *and* **16**

	Irradiation [ppm] (assignment)		NOE [ppm] (enhancement in %, assignment)					
4	4.52	(H–C(6))	4.88	(10.0, H–C(7))	2.32	(3.8, 2 H–C(4))		
	2.32	(2 H–C(4))	4.52	(13.8, H–C(6))	3.78	(13.8, H–C(8))		
5a	6.73	(H–C(3'))	5.93	(6.4, H–C(2'))	3.99	(5.8, H–C(4'))		
	5.93	(H–C(2'))	6.73	(7.9, H–C(3'))	3.24	(4.6, H–C(1'))	4.49	(6.7, H–C(2))
	4.49	(H–C(2))	4.88	(11.0, H–C(3))	5.93	(8.6, H–C(2'))	3.24	(2.0, H–C(1'))
	3.99	(H–C(4'))	6.73	(7.1, H–C(3'))	2.21	(2.9, H–C(5'))	1.94	(2.5, H'–C(5'))
	3.24	(H–C(1'))	5.93	(6.7, H–C(2'))	2.21	(2.1, H–C(5'))	1.94	(3.8, H'–C(5'))
			3.76	(11.3, H–C(4))	4.49	(2.5, H–C(2))		
	2.21	(H–C(5'))	1.94	(24.2, H'–C(5'))	3.99	(5.2, H–C(4'))	3.24	(1.9, H–C(1'))
	1.94	(H'–C(5'))	2.21	(22.5, H–C(5'))	3.99	(4.2, H–C(4'))	3.24	(4.2, H–C(1'))
5b	6.62	(H–C(3'))	5.95	(7.7, H–C(2'))	4.02	(7.4, H–C(4'))		
	5.95	(H–C(2'))	6.62	(8.2, H–C(3'))	3.26	(4.3, H–C(1'))	3.59	(1.6, H–C(4))
	4.70	(H–C(2))	4.92	(6.0, H–C(3))	3.26	(6.3, H–C(1'))	1.91	(4.3, 2 H–C(5'))
	4.02	(H–C(4'))	6.62	(8.2, H–C(3'))	1.91	(4.0, 2 H–C(5'))	5.95	(1.4, H–C(2'))
	3.26	(H–C(1'))	5.95	(6.8, H–C(2'))	1.91	(4.5, 2 H–C(5'))	3.59	(7.4, H–C(4))
			4.70	(6.8, H–C(2))				
	1.91	(2 H–C(5'))	4.02	(10.8, H–C(4'))	3.26	(10.5, H–C(1'))	4.70	(8.8, H–C(2))
7a	4.59	(H–C(6))	4.88	(6.9, H–C(7))	2.47	(4.5, H–C(4))		
	2.47	(H–C(4))	4.59	(3.1, H–C(6))	5.27	(1.0, H–C(1))	5.16	(1.0, H–C(2))
	2.38	(H'–C(4))	3.82	(2.1, H–C(8))	4.59	(1.1, H–C(6))		
7b	4.59	(H–C(6))	4.86	(6.9, H–C(7))	2.42	(4.5, H–C(4))		
10a	4.87	(H–C(3))	4.51	(7.7, H–C(2))	3.80	(7.7, H–C(4))		
	4.51	(H–C(2))	4.87	([a]) , H–C(3))	6.19	(4.6, H–C(2'))	2.80	(4.2, H–C(1'))
	3.50	(H–C(4'))	6.77	(9.5, H–C(3'))				
10b	4.96	(H–C(2))	1.80	(6.4, H–C(6'))	2.97	(4.3, H–C(1'))		
	3.59	(H–C(4'))	6.64	(9.9, H–C(3'))				
	2.97	(H–C(1'))	6.10	(10.3, H–C(2'))	3.81	(6.0, H–C(4))	4.96	(3.4, H–C(2))
16a	4.74	(H–C(2))	2.80	(4.4, H–C(3'))				
	3.58	(H–C(4))	2.80	(11.3, H–C(3'))	4.84	(8.8, H–C(3))	4.44	(3.1, H–C(5))
			4.05	(2.5, H–C(6))				
	2.80	(H–C(3'))	3.58	(12.5, H–C(4))	4.74	(7.5, H–C(2))	1.84	(2.5, H–C(4'))
16b	4.73	(H–C(2))	3.79	(3.5, H–C(4))	2.15	(6.9, H–C(4'))	2.91	(4.9, H–C(3'))
	3.79	(H–C(4))	2.91	(10.4, H–C(3'))	4.86	(9.7, H–C(3))		
	2.91	(H–C(3'))	3.79	(13.2, H–C(4))	4.73	(4.9, H–C(2))	1.95	(2.8, H–C(4'))

[a]) Strong NOE, intensity not measured.

The EI-MS of **7a/b** shows signals typical for methyl glycosides ([M – MeO]$^+$ at *m/z* 457) and isopropylidene acetals ([*M* – Me]$^+$ at *m/z* 473). The enol-ether moiety absorbs at 1674 cm^{-1}. In the ^{1}H-NMR spectrum, integration of the signals for H–C(7) at 4.88 and 4.86 ppm, for H–C(9) at 4.50 and 4.44 ppm, for H–C(8) at 3.82 and 3.74 ppm, and for MeO at 3.33 and 3.36 ppm allows to determine the ratio of anomers. The configuration of the spiro centre C(5) is assigned on the basis of NOE experiments (*Table 3*). Irradiation at H–C(6) of **7a** and **7b**, respectively, leads to intensity enhancements of the more complex signal of H–C(4), the *td* at 2.47 (**7a**) and the *dd* at 2.42 ppm (**7b**), whereas no effect is observed for the *d*'s at 2.61 (**7b**) and 2.38 ppm (**7a**). This suggests that in **7a** and **7b** H–C(4), *cis* to C(6) and showing an allylic coupling [29] with H–C(2), is axial, and that the *trans*-oriented H–C(4) (no allylic coupling) is equatorial. This is the case in a $^5H_1$ conformation of the thiopyran ring, similar to the one which is observed for the solid state of **4**. This conformation is corroborated by the NOE values obtained upon irradiation at both H–C(4) of **7a** (compare with the H,H distances in **4**, *Table 1*). H–C(1) of **7a** appears as a *dd* at 5.16 (J = 1.7, 4.6 Hz), while H–C(1) of **7b** resonates as a br. *d* at 5.19 ppm (J = 5.6 Hz). The H–C(1) signal of **7a** shows a homoallylic coupling [29] with H–C(4) at 2.47 ppm. Homoallylic coupling is maximal, when both H are *cis*-oriented and in the π-plane of a double bond (*e.g.* in the flag-pole positions of the boat conformer of cyclohexa-1,3-dienes) [30]. The $^5H_1$ conformation of **7a** is destabilized by the *cis*-diaxial orientation of O–C(5) and MeO. Therefore, the $^{1,4}B$ conformation (H–C(1) and H–C(4) in flag-pole positions) should be favored. The assignment is in keeping with a weak NOE between H–C(4) and H–C(1) of **7a**. The isomeric **7b** lacks this unfavorable interaction and should adopt a $^5H_1$ conformation, where only a weak homoallylic coupling (visible as line broadening) between the *trans*-diaxial H–C(1) and H–C(4) is expected.

The UV and the IR spectrum of **8** show the typical bands for 4-thiopyranones at 301 and 292 nm [31] and at 1620 cm^{-1} [32]. The OH band appears at 3385 cm^{-1}. In agreement with the aromatic character of the thiopyranone ring, H–C(6'), H–C(3'), and H–C(5') resonate at low field (8.18, 6.88, and 6.83 ppm ((D$_6$)DMSO), resp.) as it was observed for the 2'-ethyl analogue of **8** [32]. The vicinal coupling constants of **8** are different from the ones of the furanoid derivatives (*Table 2*).

The ratio of **9a/b** is best determined by integration of the signals for H–C(2) (4.52 and 4.96 ppm) and for H–C(5) (4.45 and 4.37 ppm). The assignment of the configuration at C(1') and C(4') is based upon NOE experiments with the diols **10a** and **10b** (*Table 3*). Irradiation of H–C(2) of **10a** leads to enhancements of the intensity for H–C(1') and the olefinic H at 6.19 ppm; irradiation of the corresponding signal of **10b**, however, results in enhancements of the intensity for H–C(1') and the aliphatic H at 1.80 ppm. The ^{1}H-NMR spectrum of **11** is characterized by the absence of signals for olefinic H's. H–C(4') resonates at 2.90 ppm, *ca.* 0.6 ppm upfield relative to H–C(4') of **9a/b** and **10a/b**. A stronger upfield shift ($\Delta\delta$ *ca.* 1.4 ppm) is observed for H–C(1'). These chemical shifts and the MS prove the presence of the S-atom in **11**.

Elemental analysis and the MS show the absence of an S-atom in **12**. No signals for bridgehead H's are found in the ^{1}H-NMR spectrum, and m's between 1.6 and 0.75 ppm (11 H) evidence the cyclohexyl moiety. H–C(1) resonates as a *dd* at 3.08 ppm with J(1,2) = 3.0 and J(1,1') = 9.5 Hz. The vicinal coupling constants (*Table 2*) do not allow to assign the configuration at C(1). They are compatible, on the one hand, with a $^0T_4$ conformation for an α-D-*C*-glycoside (similar to the conformation of **4** in the solid state and the preferred conformations of the cycloadducts in $CDCl_3$ solution) and, on the other hand, with a ^0E conformation for a β-D-*C*-glycoside. In the ^{1}H-NMR spectrum ((D$_6$)DMSO) of the tetrol **13**, signals for 4 OH appear between 4.94 and 4.36 ppm. The *dd* of H–C(1) with J(1,2) = 3.8 and J(1,1') = 10 Hz resonates at 3.12 ppm. Again, the configuration at C(1) cannot be assigned on the basis of vicinal coupling constants.

The structure of **13** was finally established by X-ray analysis (*Fig. 2*, *Table 4*). All substituents of the furanose ring are *cis* to each other, showing that the reduction of **9a/b** to **12** occurred with inversion of configuration. The cyclohexane ring of **13** adopts a chair and the furanose ring a southern conformation (between $^2T_3$ and ^2E), which is also observed in solution (D_2O). No intramolecular H-bonds are observed (smallest distance of 2.38 Å between H–O(2) and O(4), but bond angle O(2)–H···O(4) of 103°).

The electron-rich dihydropyridine **14** was used before in [1,4]-cycloadditions to electron-poor dienophiles [33] [34]. The reactive primary adducts, bridged tetrahydropyridines, are easily transformed into the corresponding lactams by selective desilylation with MeOH. Reaction of **1** with **14** at 100°, followed by methanolysis of the crude **15a/b** and by chromatographic separation of the diastereoisomers gave the lactams

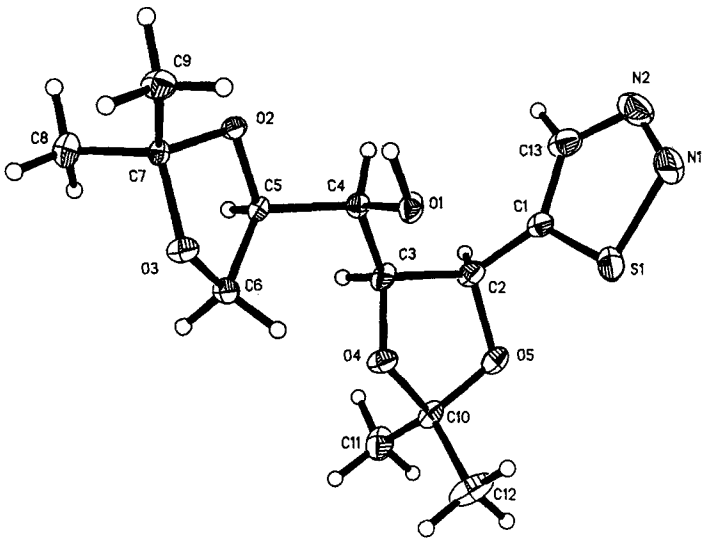


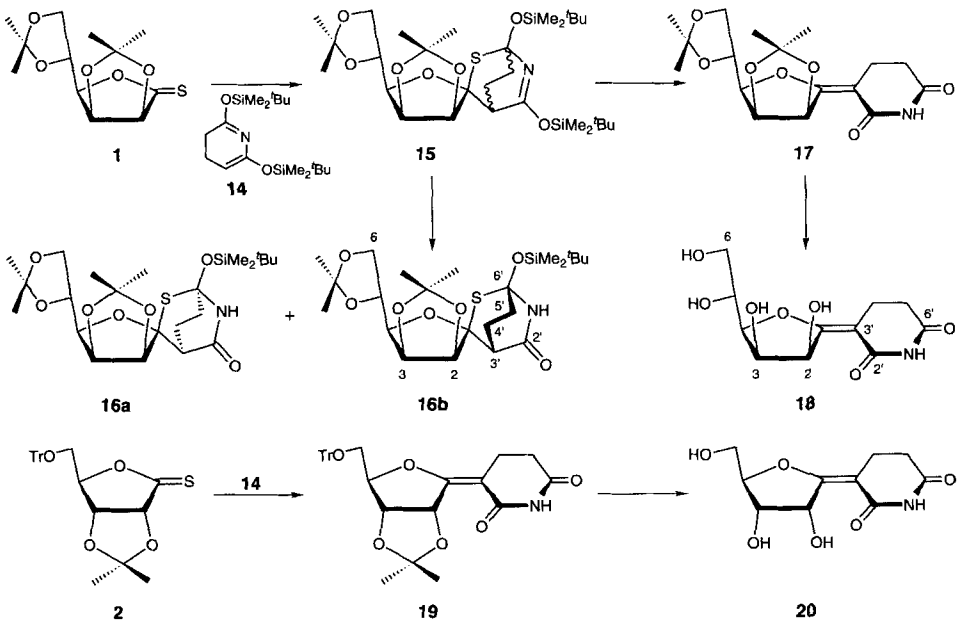
Fig. 2. *X-Ray structure of* **13**

Table 4. *Selected Bond Lengths, and Bond and Dihedral Angles of* **13**. For numbering, see *Fig. 2*.

Bond Lengths [Å]		Bond or Dihedral Angles [°]			
C(1)–C(2)	1.533 (8)	O(1)–C(1)–C(2)	105.0 (4)	C(3)–C(4)–C(5)–C(6)	169.5
C(2)–C(3)	1.516 (7)	C(1)–C(2)–C(3)	101.9 (4)	O(2)–C(5)–C(6)–O(3)	–56.3
C(3)–C(4)	1.539 (8)	C(2)–C(3)–C(4)	103.7 (4)	C(4)–O(1)–C(1)–C(7)	–142.9
C(4)–C(5)	1.532 (7)	C(3)–C(4)–O(1)	105.1 (4)	C(3)–C(2)–C(1)–C(7)	155.3
C(5)–C(6)	1.518 (9)	C(4)–O(1)–C(1)	111.3 (5)	H–C(1)–C(7)–H	–175.4
C(1)–O(1)	1.440 (8)	O(1)–C(1)–C(7)	111.2 (6)	H–C(1)–C(2)–H	34.0
C(2)–O(5)	1.443 (6)	C(1)–C(2)–C(3)–C(4)	–35.0	H–C(2)–C(3)–H	–35.6
C(3)–O(4)	1.424 (6)	C(2)–C(3)–C(4)–O(1)	25.3	H–C(3)–C(4)–H	26.2
C(4)–O(1)	1.435 (7)	C(3)–C(4)–O(1)–C(1)	–4.6	H–C(4)–C(5)–H	108.9
C(5)–O(2)	1.436 (6)	O(1)–C(4)–C(5)–O(2)	171.0	H–C(5)–C(6)–H	63.6
C(1)–C(7)	1.514 (8)	C(3)–C(4)–C(5)–O(2)	–71.9	H–C(5)–C(6)–H'	–53.8

16a (32%) and **16b** (38%; *Scheme 2*). Treatment of crude **15a/b** with $Bu_4NF \cdot 3H_2O$ in THF, however, led to the unsaturated piperidinedione **17** (92%) which was deprotected (aq. AcOH, 100°) to the tetrol **18** (65%). The exclusive formation of **17** from the diastereoisomers **15a/b** indicates the intermediate formation of the mannofuranose *O,S*-hemiacetal and the subsequent β-elimination of H_2S. Similarly, the cycloaddition of **14** to the *ribo*-thio-*O*-lactone **2** followed by treatment with $Bu_4NF \cdot 3H_2O$ gave **19** (62%), which was deprotected to the triol **20** (74%).

Scheme 2



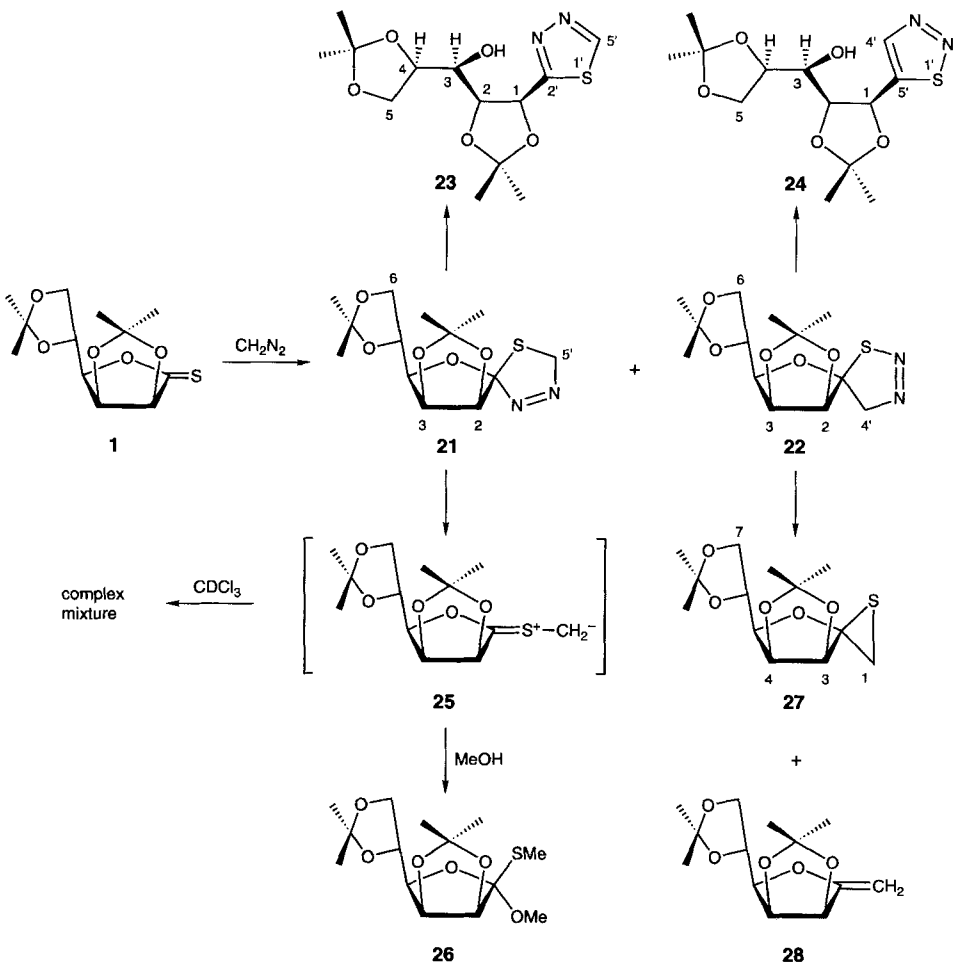
The mixture **16a/b** is characterized by a strong amide band at 1699 cm^{-1}. NOE experiments revealed the neighborhood of H–C(2) and of H–C(4) with the bridgehead H–C(3'), both for **16a** and **16b** (*Table 3*). This evidences the completely regioselective addition (analogous to the one of **6**), *i.e.* formation of a bond between the S- and the imino C-atom. The configurational assignment is based upon the NOE observed for the signal of one H of the ethylene bridge of **16b** upon irradiation at H–C(2) (*Table 3*).

The strong deshielding of H–C(2) of **17** (5.86 ppm), **19** (6.06 ppm), **18** (4.97 ppm), and **20** (5.01 ppm) is due to an anisotropy effect of O=C(2') (*cf.* [35] and **27/28**) and indicates the (*E*)-configuration. Strong bands at 1693, 1666, and 1598 cm^{-1} (**18**) and at 1689 and 1634 cm^{-1} (**20**) characterize the unsaturated imide function.

The addition of the dienes to **1** always occurred from the less hindered side. The preference for an '*endo*'-orientation of the dienes (central atoms of the diene on the same side as O(5)) is low. It increases in the series cyclopentadiene (50%), **14** (53%), cyclohexa-1,3-diene (60%), and **6** (75%). Except for the heterodiene **14**, the '*endo*'-preference parallels the increasing electron-density of the dienes.

[1,3]-Dipolar Cycloaddition of Diazomethane and Cycloaddition of Carbenoids. The reaction of **1** (*Scheme 3*) with CH_2N_2 at –10° in THF gave exclusively a 35:65 mixture of the the dihydrothiadiazoles **21** and **22**. At –78°, only slow addition (ratio **21/22** *ca.* 1:10) was observed. The 1,3,4-isomer **21** decomposed slowly at room temperature, whereas the dihydro-1,2,3-thiadiazole **22** was stable. This mixture was separated by preparative HPLC at 5°. In an attempt to separate **21** and **22** by prep. HPLC on a *Zorbax*-NH_2 column, **21** was transformed completely into **23**, and **22** partially (*ca.* 30%) into **24**. The 1,3,4-thiadiazole **23** was also obtained by treating a CH_2Cl_2 solution of **21** with Et_3N, and the 1,2,3-thiadiazole **24** by warming **22** in pyridine for 2 h at 80°.

Scheme 3



The decomposition of a solution of **21** in $CDCl_3$ at 20° was monitored by ^{1}H-NMR spectroscopy. The decomposition was of first order with a half-life of 21.6 h. It led to a complex mixture, where the spirothiirane **27** (*ca.* 20–25%, see below) and probably its anomer (*ca.* 7–10%) were identified by their characteristic *d*'s (**27**: 2.63 and 2.50 ppm, J = 1.5 Hz; anomer of **27**: 3.00 and 2.82 ppm, J = 3.0 Hz). The same complex mixture was obtained, when methyl acrylate (30 equiv.) was added, and no cycloaddition of the acrylate to **25** was observed. Thermolysis of **21** in MeOH, however, gave exclusively the *O*,*O*,*S*-ortholactone **26**. The intermediate thiocarbonylio methylide **25** even reacted partially with a slight excess of MeOH (1.2 equiv.) in $CDCl_3$ (*ca.* 20% of **26**). This reactivity is in contrast to the one which was reported for thiocarbonylio-methylides derived from thioketones. These methylides cycloadded to methyl acrylate already at

$-40°$, but did not react with MeOH at $-40°$ in the absence of an acid, such as CF_3CO_2H [20] [36]. These findings show the reduced enophilicity and the enhanced basicity of thiocarbonylio-methylides derived from thio-*O*-lactones.

In the solid state, **22** was stable at 105°. Melting at 115° was immediately followed by N_2 evolution and decomposition. In petroleum ether at 100°, **22** was slowly (half-life *ca.* 6.5 h) transformed to the spirothiirane **27** and the known enol ether **28** [37]. As expected, no trace of the anomer of **27** could be detected by ^{1}H-NMR spectroscopy.

The different stabilities of the cycloadducts to CH_2N_2 allow an easy assignment of the thiadiazole structures of **21** and **22** [2] [13] [17] [18]. This assignment is corroborated by the UV spectra (**21**: 245 nm; **22**: 270 nm). The azo group of **22** absorbs at 1505 cm^{-1}, typical for 4,5-dihydro-1,2,3-thiadiazoles [16b], while no azo absorption of **21** can be detected. The 2,5-dihydro-1,3,4-thiadiazoles are characterized by the low-field shift of the CH_2 signals [16] [21] (**21**: 5.90 and 5.67 ppm; **22**: 5.54 and 4.28 ppm) and of the spiro C-atom [19] (**21**: 140.8 ppm; **22**: 103.7 ppm). A large $\Delta\delta$ value (1.26 ppm) is observed for the two H–C(4') signals of **22**. NOE's between the signal at 5.54 ppm and H–C(4) and between the signal at 4.28 ppm and H–C(2)/H–C(3) show that the more deshielded signal is on the same side as O–C(1). In addition, these NOE's evidence the (*R*)-configuration of the spiro center and thus the addition of CH_2N_2 to the *'exo'*-side of **1**. Maxima in the UV spectrum of **24** at 251 and 221 nm are characteristic for 1,2,3-thiadiazoles [38]. The aromatic H's of **23** and **24** exhibit the same relative chemical shifts (**23**: 9.10 ppm; **24**: 8.65 ppm) as the ones of their 5'-methyl analogues [21]. Similar vicinal J(H,H) for **8**, **23**, and **24** (*Table 2*) indicate that these compounds adopt about the same conformation in solution, which is similar to the one of **24** in the solid state (see below) as evidenced by the small J(3,4) (0.9–2.0 Hz). Except the aromatic signals, the ^{13}C-NMR spectra of **23** and **24** differ only slightly (*Table 5*). The CI-MS of **26** shows peaks for $[M - Me]^+$, $[M - MeO]^+$, and $[M - MeS]^+$. The ^{1}H-NMR spectrum of **26** is characterized by the signals for MeO and MeS (3.31 and 2.08 ppm). A comparison with the spectra of the anomeric methyl demethoxy analogues [1] suggests the *'endo'*-position of the MeS group. Indeed, a NOE of 1.7% between MeO and H–C(4) corroborates the (1*R*)-configuration of **26**. High-field shifts of the signals for H–C(1), H'–C(1), C(1), and C(2) of **27** (2.63, 2.50, 29.52, and 84.94 ppm, resp.) are due to the thiirane ring. The high-field shift of H–C(5) (3.79 ppm) indicates the β-D-configuration of **27**. The spectroscopic data of **28** agree well with published data [37].

X-Ray analysis (*Fig. 3*, *Table 6*) established the hydroxy-1,2,3-thiadiazole structure of **24** and thus the expected regioselectivity of the 1,3-dipolar cycloaddition. The thiadiazole ring is completely flat. The *S*-atom lies above the dioxolane ring. No intramolecular H-bond is formed.

Treatment of **1** with 3 equiv. of diethyl diazomalonate and a catalytic amount of $Rh_2(OAc)_4 \cdot 2H_2O$ [24] [41] in toluene at 80° was accompanied by evolution of N_2 and yielded **31** (68%) as the main product (*Scheme 4*). The minor product was the expected, known alkene **32** [35] (29%). Complete transformation of **31** into **32** was achieved by treatment of the crude product with $P(NMe_3)_3$ at 80° [42]. Similarly, the *ribo*-thio-*O*-lactone **2** gave the alkene **33** (69%). As carbenoids derived from ethyl diazoacetate show a strong tendency to dimerize, a solution of ethyl diazoacetate was added slowly to a solution of **1** and a catalytic amount of $Rh_2(OAc)_4 \cdot 2H_2O$ in boiling toluene. Even so, the complete conversion of **1** into **29** (33%) and **30** (26%) required 15 equiv. of the diazoacetate.

Table. 5. *^{13}C-NMR* (50.6 ppm, $CDCl_3$) *Chemical Shifts* [ppm] *of* **1**, **21**–**24**, **26**, *and* **27**[a])

	1	**21**	**22**	**23**[b])	**24**[b])	**27**[b])
C(1)	218.98	140.82	103.72	171.03	154.89	84.94
C(2)	86.57[c])	84.59	85.69	75.88[c])	75.98[c])	83.89
C(3)	76.85	80.40	79.88	77.48[c])	77.45[c])	80.46
C(4)	86.50[c])	82.74	79.88	68.96	69.76	82.03
C(5)	72.13	72.89	72.61	74.76	73.00	72.89
C(6)	66.26	66.91	66.77	66.98	66.92	66.89
3,4-*O*-Me_2C	114.62, 27.13, 25.96	113.71, 26.16, 24.87	114.03, 25.99, 24.46	110.31, 26.45, 24.31	109.95, 26.37, 24.37	113.66, 26.08, 25.11
5,6-*O*-Me_2C	109.78, 26.82, 24.94	109.49, 26.94, 25.18	109.40, 26.95, 25.00	109.55, 26.75, 25.29	109.49, 26.67, 25.14	109.39, 27.02, 25.11
CH_2N_2 or CHN_2	–	81.97	87.84	152.14	145.92	–
CH_2S	–	–	–	–	–	29.52

[a]) The assignment is based upon comparison with the spectra of 3,4:5,6-di-*O*-isopropylidene-α-D-mannofuranose [39] and related compounds [1] [40]. [b]) Same numbering as for **1**. [c]) Assignment may be interchanged.

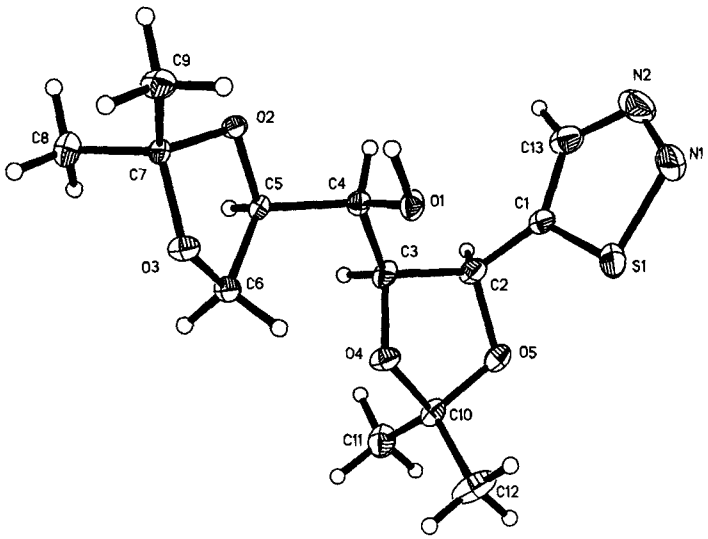


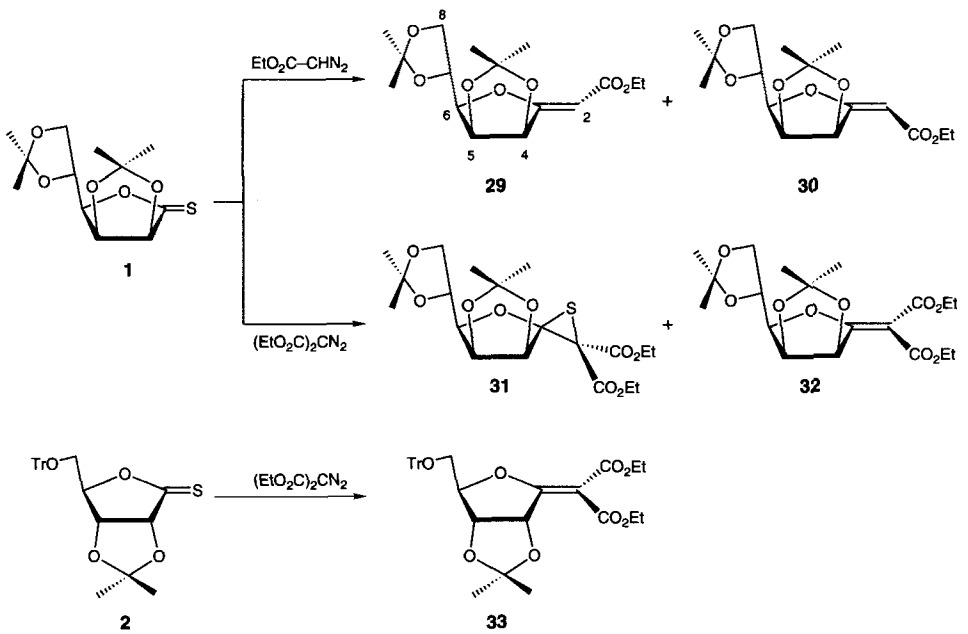
Fig. 3: *X-Ray Structure of* **24**

Table 6. *Selected Bond Lengths, Bond and Dihedral Angles of* **24**. For numbering see *Fig. 3*.

Bond Lengths [Å]		Bond or Dihedral Angles [°]			
C(1)–C(2)	1.481 (11)	S(1)–C(1)–C(2)	125.0 (6)	O(1)–C(4)–C(5)–O(2)	62.9
C(2)–C(3)	1.549 (11)	C(1)–C(2)–C(3)	117.5 (6)	C(3)–C(4)–C(5)–O(2)	–172.7
C(3)–C(4)	1.525 (10)	C(2)–C(3)–C(4)	118.7 (6)	O(5)–C(2)–C(1)–S(1)	–32.9
C(4)–C(5)	1.513 (9)	C(3)–C(4)–O(1)	111.2 (6)	C(3)–C(2)–C(1)–S(1)	84.4
C(2)–O(5)	1.437 (7)	C(1)–S(1)–N(1)	94.0 (4)	C(1)–S(1)–N(1)–N(2)	–0.1
C(3)–O(4)	1.431 (9)	S(1)–N(1)–N(2)	111.1 (6)	S(1)–N(1)–N(2)–C(13)	–0.9
C(4)–O(1)	1.420 (9)	N(1)–N(2)–C(13)	113.3 (7)	H–C(2)–C(3)–H	21.3
C(1)–S(1)	1.691 (8)	C(1)–C(13)–N(2)	115.4 (8)	H–C(3)–C(4)–H	–72.2
S(1)–N(1)	1.678 (7)	C(1)–C(2)–C(3)–C(4)	20.9	H–C(4)–C(5)–H	64.6
N(1)–N(2)	1.275 (13)	C(2)–C(3)–C(4)–O(1)	–64.6	H–C(4)–O(1)–H	62.2
N(2)–C(13)	1.378 (13)	C(2)–C(3)–C(4)–C(5)	170.7	H–C(5)–C(6)–H	123.2
C(1)–C(13)	1.356 (11)	C(3)–C(4)–C(5)–C(6)	71.9	H–C(5)–C(6)–H'	2.0

The structure of **31** was stablished by the MS and by ^{1}H-NMR spectroscopy. *'exo'*-Attack of diazomalonate on **1** is evidenced by the shift values of H–C(6) (3.90 ppm) and H–C(4) (5.37 ppm) (*Table 2*). The spectroscopic data of **32** are in agreement with the published ones [35]. The crystalline **31** shows characteristic IR bands at 1722 and 1630 cm^{-1} and a strong deshielding of H–C(4), resonating at 5.99 ppm. The (*E/Z*)-isomers **29** and **30** are characterized by similar EI-MS with $[M - 15]^+$ at *m/z* 313. In the ^{1}H-NMR spectra, **29** and **30** show signals for one olefinic H (5.11 (**29**) and 5.43 (**30**) ppm) appearing as *d* (W-coupling with H–C(4)). The assignment of the configuration is based upon the deshielding of H–C(4) in **30** (5.76 ppm, **29**: 5.14 ppm).

Scheme 4



We thank *F. Hoffmann-La Roche AG*, Basle, for financial support, Dr. *J. J. Daly*, and *P. Schönholzer* for the X-ray analyses, and Dr. *W. Arnold*, Dr. *A. Dirscherl*, Dr. *M. Grosjean*, *W. Meister*, and *W. Walther* for spectroscopic and analytical measurements.

Experimental Part

General. See [1]. The cycloadditions were performed in a pressure-stable, closed vessel. Excess diene was distilled off and the products were purified by flash chromatography. Prep. HPLC: 250×20 mm column (*Bischoff*) with *Si60 Spherisorb* (5 μm) or with a 250 × 20 mm *Zorbax*-NH_2 column, flow rate 10 and 15 ml/min, respectively, UV detection (250 nm).

*1,5-Anhydro-2,3,4-trideoxy-6,7:9,10-di-*O*-isopropylidene-2,3-di-*C*-methyl-1-thio-β-*D*-manno-dec-2-en-5-ulofuranose* (= *(1S)-3',6'-Dihydro-2,3:5,6-di-*O*-isopropylidene-4',5'-dimethylspiro[[1,4]anhydro-*D*-mannitol-1,2'-[2H]thiopyran]*; **4**). A mixture of **1** (274 mg, 1 mmol) and **3** (1 ml) was stirred in a closed vessel for 3.5 h at 150°. FC (25 g, hexane/AcOEt 7:1) of the residue gave **4** (260 mg, 73%). R_f (hexane/AcOEt 7:1) 0.21. M.p. 92°. IR (KBr): 2980*w*, 2938*s*, 2879*m*, 2809*w*, 1454*w*, 1406*w*, 1374*s*, 1275*m*, 1251*m*, 1208*s*, 1165*m*, 1095*s*, 1071*s*, 1042*m*, 1007*w*, 977*w*, 891*w*, 839*m*, 801*w*, 795*w*, 509*w*. ^{1}H-NMR (250 MHz, $CDCl_3$): 4.88 (*dd*, *J* = 4.0, 6.1, H–C(7)); 4.52 (*d*, *J* = 6.1, H–C(6)); 4.48 (*ddd*, *J* = 4.1, 6.0, 8.5, H–C(9)); 4.10 (*dd*, *J* = 6.0, 8.7, H–C(10)); 4.03 (*dd*, *J* = 4.1, 8.7, H'–C(10)); 3.78 (*dd*, *J* = 4.0, 8.5, H–C(8)); 3.24 (*d*, *J* = 15.0, H–C(1)); 2.97 (*d*, *J* = 15.0, H'–C(1)); 2.32 (*s*, 2 H–(4)); 1.77, 1.71 (2 *s*, Me–C(2), Me–C(3)); 1.57 (*s*, Me); 1.46 (*s*, Me); 1.37 (*s*, 2 Me). NOE:

Table 3. EI-MS: 341 (21, $[M - Me]^+$), 298 (17), 259 (7), 167 (58), 141 (39), 125 (55), 101 (72), 82 (56), 68 (35), 59 (42), 43 (100). Anal. calc. for $C_{18}H_{28}O_5S$ (356.48): C 60.65, H 7.92, S 8.99; found: C 60.56, H 7.99, S 8.96.

*(1'S,4'R)- and (1'R,4'S)-1,1⁴-Anhydro-2,3:5,6-di-*O*-isopropylidene-1-*C*-(4'-mercaptocyclopent-2'-en-1'-yl)-β-*D*-mannofuranose* (= *(1S,1'R,4'S)- and (1S,1'S,4'R)-2,3:5,6-di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,3'-[2]thiabicyclo[2.2.1]hept[5]ene]*; **5a/b**). A soln. of **1** (274 mg, 1 mmol) in cyclopentadiene (1 ml) was stirred in a closed vessel for 3 h at 80°. FC (25 g, hexane/AcOEt 4:1) gave **5a/b** (313 mg). An additional FC (50 g, hexane/AcOEt 5:1) gave **5a** (115 mg, 34%) and **5b** (123 mg, 36%).

Data of **5a**: R_f (hexane/AcOEt 5:1) 0.18. M.p. 110–111°. IR (KBr): 2995*m*, 2940*m*, 2879*w*, 1459*w*, 1375*m*, 1334*w*, 1275*m*, 1260*s*, 1206*s*, 1164*m*, 1095*s*, 1062*s*, 1030*m*, 998*m*, 972*m*, 931*w*, 885*w*, 847*m*, 801*w*, 749*m*, 512*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): 6.73 (*dd*, *J* = 2.8, 5.5, H–C(3')); 5.93 (*dd*, *J* = 3.0, 5.5, H–C(2')); 4.88 (*dd*, *J* = 3.9, 6.0, H–C(3)); 4.49 (*d*, *J* = 6.0, H–C(2)); 4.46–4.50 (*m*, H–C(5)); 4.13 (*d*, *J* = 4.8, 2 H–C(6)); 3.98–4.00 (*m*, H–C(4')); 3.76 (*dd*, *J* = 3.9, 8.4, H–C(4)); 3.23–3.25 (*m*, H–C(1')); 2.21 (*d*, *J* = 8.4, H–C(5')); 1.94 (*td*, *J* = 2.2, 8.4, H'–C(5')); 1.49 (*s*, Me); 1.48 (*s*, Me); 1.39 (*s*, Me); 1.32 (*s*, Me); NOE: *Table 3*. CI-MS: 340 (1, M^+)), 325 (2), 275 (19), 259 (18), 141 (12), 101 (34), 85 (15), 66 (52), 43 (100). Anal. calc. for $C_{17}H_{24}O_5S$ (340.43): C 59.98, H 7.11, S 9.42; found: C 60.04, H 7.14, S 9.36.

Data of **5b**. R_f (hexane/AcOEt 5:1) 0.15. M.p. 127–129°. IR (KBr): 2993*m*, 2942*m*, 2875*w*, 1463*w*, 1376*m*, 1337*w*, 1271*m*, 1260*s*, 1206*s*, 1168*m*, 1095*s*, 1065*s*, 1025*m*, 993*m*, 977*m*, 931*w*, 884*w*, 847*m*, 801*w*, 749*m*, 513*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): 6.62 (*dd*, *J* = 2.8, 5.5, H–C(3')); 5.95 (*dd*, *J* = 3.2, 5.5, H–C(2')); 4.92 (*dd*, *J* = 3.8, 5.9, H–C(3)); 4.70 (*d*, *J* = 5.9, H–C(2)); 4.38 (*ddd*, *J* = 3.4, 6.2, 8.7, H–C(5)); 4.08 (*dd*, *J* = 6.2, 8.9, H–C(6)); 4.01–4.03 (*m*, H–C(4')); 3.96 (*dd*, *J* = 3.4. 8.9, H'–C(6)); 3.59 (*dd*, *J* = 3.8, 8.7, H–C(4)); 3.25–3.27 (*m*, H–C(1')); 1.91 (*s*, 2 H–C(5')); 1.50 (*s*, Me); 1.48 (*s*, Me); 1.40 (*s*, Me); 1.37 (*s*, Me); NOE: *Table 3*. CI-MS: 340 (3, M^+), 325 (5), 275 (15), 259 (23), 141 (21), 101 (48), 85 (8), 66 (61), 43 (100).

*Methyl (1R)- and (1S)-3-*O*-[(*tert*-Butyl)dimethylsilyl]-2,4-dideoxy-6,7:9,10-di-*O*-isopropylidene-5-thio-β-*D*-manno-dec-2-en-5-ulo-5,8-furano-1,5-pyranoside* (= *(1S,6'S)- and (1S,6'R)-4'-[(*tert*-Butyl)dimethylsilyloxy]-3',6'-dihydro-2,3:5,6-di-*O*-isopropylidene-6'-methoxyspiro[[1,4]anhydro-*D*-mannitol-1,2'-[2H]thiopyran]*; **7a/b**). A mixture of **1** (274 mg, 1 mmol) and **6** [28] (1 ml) was stirred in a closed vessel for 4 h at 110°. FC (25 g, hexane/AcOEt 9:1) gave a 3:1 mixture (^{1}H-NMR) **7a/b** (402 mg, 82%). R_f (hexane/AcOEt 9:1) 0.21. IR (film): 2987*m*, 2932*m*, 2858*m*, 1674*m*, 1622*w*, 1467*w*, 1373*m*, 1256*s*, 1210*s*, 1161*m*, 1069*s*, 979*w*, 897*m*, 841*s*, 781*m*, 726*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): 5.27 (*dd*, *J* = 1.7, 4.6, 0.75 H), 5.21 (*dd*, *J* = 1.0, 5.6, 0.25 H, H–C(2)); 5.19 (br. *d*, *J* = 5.6, 0.25 H), 5.16 (*dd*, *J* = 1.7, 4.6, 0.75 H, H–C(1)); 4.88 (*dd*, *J* = 4.5, 6.0, 0.75 H), 4.86 (*dd*, *J* = 4.0, 5.9, 0.25 H, H–C(7)); 4.59 (*d*, *J* = 6.0, H–C(6)); 4.50 (*td*, *J* ≈ 5.3, 7.7, 0.75 H), 4.44 (*ddd*, *J* = 4.0, 6.1, 8.4, 0.25 H, H–C(9)); 4.09 (*dd*, *J* = 6.1, 8.8, 0.25 H), 4.00–4.08 (*m*, 1.75 H, 2 H–C(10)); 3.82 (*dd*, *J* = 4.1, 7.7, 0.75 H), 3.74 (*dd*, *J* = 3.9, 8.3, 0.25 H, H–C(8)); 3.36 (*s*, 0.75 H), 3.33 (*s*, 2.25 H, MeO); 2.61 (br. *d*, *J* = 16.0, 0.25 H), 2.47 (*td*, *J* = 1.7, 16.0, 0.75 H), 2.42 (*dd*, *J* = 1.7, 16.0, 0.25 H), 2.38 (*d*, *J* = 10.0, 0.75 H, 2 H–C(4)); 1.62 (*s*, 2.25 H), 1.56 (*s*, 0.75 H, Me); 1.43 (*s*, 0.75 H), 1.42 (*s*, 2.25 H, Me); 1.37 (*s*, 2 Me); 0.92 (*s*, *t*-Bu); 0.20 (*s*, 1.5 H), 0.19 (*s*, 2.25 H), 0.17 (*s*, 2.25 H, 2 MeSi). NOE: *Table 3*. EI-MS: 473 (9, $[M - Me]^+$), 457 (6, $[M - MeO]^+$), 253 (13), 241 (14), 199 (8), 157 (49), 143 (100), 101 (17), 85 (75), 73 (73), 43 (54). Anal. calc. for $C_{23}H_{40}O_7SSi$ (488.71): C 56.53, H 8.25, S 6.56; found: C 56.77, H 8.38, S 6.30.

*(1S)-1,2:4,5-Di-*O*-isopropylidene-1-C-(4-oxo-4*H*-thiopyran-2-yl)-*D*-arabinitol* (**8**). A soln. of **7a/b** (136 mg, 0.28 mmol) in CH_2Cl_2 (3 ml) was treated with Bu_4NF on silica gel (28 mg, 0.028 mmol) and stirred for 1 h at r.t. Filtration, evaporation of the filtrate, and crystallization of the residue from AcOEt gave **8** (47 mg, 49%). R_f (AcOEt) 0.23. M.p. 184–185°. $[\alpha]_D^{20} = -21.7$ (*c* = 0.25, $CHCl_3$). UV ($CHCl_3$): 292 (17700), 301 (14600). IR (KBr): 3385*w*, 2988*w*, 2898*w*, 1620*s*, 1564*m*, 1376*m*, 1301*w*, 1257*m*, 1212*s*, 1161*s*, 1051*s*, 977*w*, 888*s*, 853*w*, 827*w*, 739*w*. ^{1}H-NMR (250 MHz, (D_6)DMSO): 8.18 (*d*, *J* = 10.2, H–C(6')); 6.88 (*d*, *J* = 1.0, H–C(3')); 6.83 (*dd*, *J* = 1.0, 10,2, H–C(5')); 5.29 (*d*, *J* = 7.5, H–C(1)); 4.67 (*d*, *J* = 8.0, OH–C(3)); 4.54 (*dd*, *J* = 2.0, 7.5, H–C(2)); 3.78–3.97 (*m*, 3 H); 3.30 (*dt*, *J* = 2.0, 8.0, H–C(3)); 1.55 (*s*, Me); 1.36 (*s*, Me); 1.29 (*s*, Me); 1.24 (*s*, Me). CI-MS: 343 (2, $[M + 1]^+$), 327 (16), 284 (4), 269 (15), 241 (9), 155 (32), 142 (100), 125 (12), 111 (14), 101 (58), 97 (23), 85 (25), 71 (28), 59 (34), 57 (36), 55 (31), 43 (99). Anal. calc. for $C_{16}H_{22}O_6S$ (342.41): C 56.13, H 6.48, S 9.36; found: C 55.90, H 6.53, S 9.07.

*(1'S,4'R)- and (1'R,4'S)-1,1⁴-Anhydro-2,3:5,6-di-*O*-isopropylidene-1-*C*-(4'-mercaptocyclohex-2'-en-1'-yl)-β-*D*-mannofuranose* (= *(1S,1'R,4'S)- and (1S,1'S,4'R)-2,3:5,6-Di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,3'-[2]thiabicyclo[2.2.2]oct[5]ene]*; **9a/b**). A mixture of cyclohexa-1,3-diene (1 ml) and **1** (274 mg, 1

mmol) was stirred in a closed vessel for 3 h at 180°. FC (25 g, hexane/AcOEt 5:1) gave a 2:3 mixture (^{1}H-NMR) **9a/b** (326 mg, 92%). R_f (hexane/AcOEt 5:1) 0.17. IR (KBr): 3050*w*, 2986*m*, 2898*w*, 1620*w*, 1457*w*, 1374*s*, 1268*m*, 1211*s*, 1166*s*, 1114*m*, 1036*s*, 985*m*, 924*w*, 895*w*, 847*m*, 759*w*, 722*w*, 512*w*. ^{1}H-NMR (250 MHz, $CDCl_3$): 6.80 (*t*, *J* = 8.0, 0.4 H), 6.68 (*t*, *J* = 8.0, 0.6 H, H–C(3')); 6.19 (*t*, *J* = 8.0, 0.4 H), 6.16 (*t*, *J* = 8.0, 0.6 H, H'–C(2')); 4.96 (*d*, *J* = 6.0, 0.6 H), 4.52 (*d*, *J* = 6.0, 0.4 H, H–C(2)); 4.85 (*dd*, *J* = 4.0, 6.0, 0.6 H), 4.84 (*dd*, *J* = 4.0, 6.0, 0.4 H, H–C(3)); 4.45 (*ddd*, *J* = 3.5, 6.0, 9.0, 0.4 H), 4.37 (*ddd*, *J* = 3.5, 6.0, 9.0, 0.6 H, H–C(5)); 3.95–4.20 (*m*, 2 H–C(6)); 3.65 (*dd*, *J* = 4.0, 9.0, 0.4 H), 3.64 (*dd*, *J* = 4.0, 9.0, 0.6 H, H–C(4)); 3.48–3.62 (*m*, H–C(4')); 2.87–3.05 (*m*, H–C(1')); 1.16–2.35 (*m*, 4 H); 1.51 (*s*, 1.8 H), 1.48 (*s*, 1.2 H, Me); 1.46 (*s*, Me); 1.39 (*s*, 1.8 H), 1.38 (*s*, 1.2 H, Me); 1.36 (*s*, 1.8 H), 1.34 (*s*, 1.2 H, Me). EI-MS: 354 (3, M^+), 339 (9), 321 (3), 296 (4), 275 (31), 141 (44), 126 (16), 101 (48), 98 (25), 85 (14), 80 (100), 72 (16), 68 (24), 59 (31), 43 (100). Anal. calc. for $C_{18}H_{26}O_5S$ (354.46): C 60.99, H 7.39, S 9.04; found: C 60.73, H 7.50, S 8.93.

*(1'S,4'R)- and (1'R,4'S)-1,1^4-Anhydro-2,3-*O*-isopropylidene-1-*C*-(4'-mercaptocyclohex-2'-en-1'yl)-β-*D*-mannofuranose* (= *(1S,1'R,4'S)- and (1S,1'S,4'R)-2,3-*O*-Isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,3'-[2]thiabicyclo[2.2.2]oct[5]ene];* **10a/b**). A soln. of **9a/b** (100 mg, 0.28 mmol) in AcOH/H_2O 1:1 (5 ml) was stirred for 16 h at r.t. FC (25 g, hexane/AcOEt 1:4) gave **10a** (20 mg, 21%), **10a/b** (24 mg, 27%), and **10b** (20 mg, 21%).

Data of **10a**: R_f (hexane/AcOEt 1:4) 0.17. ^{1}H-NMR (400 MHz, $CDCl_3$): 6.77 (*t*, *J* = 7.4, H–C(3')); 6.19 (*t*, *J* = 7.4, H–C(2')); 4.87 (*dd*, *J* = 4.2, 5.9, H–C(3)); 4.51 (*d*, *J* = 5.9, H–C(2)); 3.76–4.04 (*m*, H–C(5), 2 H–C(6)); 3.80 (*dd*, *J* = 4.2, 8.5, H–C(4)); 3.49–3.51 (*m*, H–C(4')); 2.79–2.85 (*m*, OH, H–C(1')); 2.18–2.31 (*m*, OH, 2 CH); 1.67–1.76 (*m*, 1 H); 1.17–1.24 (*m*, 1 H); 1.46 (*s*, Me); 1.33 (*s*, Me); NOE: *Table 3*.

Data of **10b**: ^{1}H-NMR (400 MHz, $CDCl_3$): 6.64 (*t*, *J* = 7.4, H–C(3')); 6.10 (*t*, *J* = 7.4, H–C(2')); 4.96 (*d*, *J* = 6.0, H–C(2)); 4.89 (*dd*, *J* = 4.0, 6.0, H–C(3)); 3.58–3.96 (*m*, H–C(5), 2 H–C(6), H–C(4')); 3.81 (*dd*, *J* = 4.0, 8.0, H–C(4)); 2.96–2.99 (*m*, H–C(1')); 2.75–2.85 (*m*, OH); 2.19–2.25 (*m*, OH); 2.01–2.08 (*m*, 1 H); 1.77–1.83 (*m*, 1 H); 1.56–1.64 (*m*, 1 H); 1.44–1.48 (*m*, 1 H); 1.51 (*s*, Me); 1.39 (*s*, Me); NOE: *Table 3*.

*1,1^4-Anhydro-2,3:5,6-di-*O*-isopropylidene-1-*C*-(4'-mercaptocyclohex-1'-yl)-β-*D*-mannofuranose* (= *(1S)-2,3:5,6-Di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,3'-[2]thiabicyclo[2.2.2]octane];* **11**). A soln. of **9a/b** (100 mg, 0.28 mmol) in EtOH (10 ml) was treated with *Raney*-Ni (*Degussa B 113 Z*; *ca.* 300 mg, washed with EtOH) and stirred for 4 h at r.t. The catalyst was filtered off and washed with EtOH. Evaporation of the combined filtrates and FC (25 g, hexane/AcOEt 7:1) of the residue gave **11** (59 mg, 53%). R_f (hexane/AcOEt 7:1) 0.25. ^{1}H-NMR (250 MHz, $CDCl_3$): 4.79 (*dd*, *J* = 3.3, 6.0, H–C(3)); 4.74 (*d*, *J* = 6.0, H–C(2)); 4.45 (*ddd*, *J* = 3.8, 6.2, 8.3, H–C(5)); 4.15 (*dd*, *J* = 6.2, 9.1, H–C(6)); 4.04 (*dd*, *J* = 3.8, 9.1, H'–C(6)); 3.52 (*dd*, *J* = 3.3, 8.3, H–C(4)); 2.82–2.88 (*m*, H–C(4')); 1.72–2.11 (*m*, 8 H); 1.36–1.49 (*m*, 1 H); 1.53 (*s*, Me); 1.45 (*s*, Me); 1.38 (*s*, Me); 1.37 (*s*, Me). CI-MS: 341 (20, $[M - Me]^+$), 325 (2), 298 (3), 255 (3), 214 (20), 141 (71), 101 (66), 81 (44), 68 (54), 43 (100).

*(1S)-1,4-Anhydro-1-*C*-cyclohexyl-2,3:5,6-di-*O*-isopropylidene-*D*-mannitol* (**12**). A mixture of **9a/b** (354 mg, 1 mmol) and *Raney*-Ni (*Degussa B 113 Z*; 1 g, washed several times with MeOH and once with dry dioxane) in dry dioxane (10 ml) was stirred for 1 h at 110°. The catalyst was filtered off (*Celite*) and washed with dioxane. Evaporation of the combined filtrates and FC (25 g, hexane/AcOEt 9:1) of the residue gave **12** (251 mg, 77%). R_f (hexane/AcOEt 9:1) 0.17. $[\alpha]_D^{20} = -5.7$ (*c* = 0.58, $CHCl_3$). IR (film): 2985*m*, 2929*s*, 2852*m*, 1451*w*, 1374*m*, 1262*m*, 1209*s*, 1161*m*, 1102*m*, 1071*s*, 991*w*, 924*w*, 891*w*, 847*w*, 747*w*. ^{1}H-NMR (250 MHz, $CDCl_3$): 4.70 (*dd*, *J* = 3.5, 6.0, H–C(3)); 4.64 (*dd*, *J* = 3.0, 6.0, H–C(2)); 4.40 (*td*, *J* = 5.3, 7.5, H–C(5)); 4.08 (*d*, *J* = 5.3, 2 H–C(6)); 3.41 (*dd*, *J* = 3.5, 7.5, H–C(4)); 3.08 (*dd*, *J* = 3.0, 9.5, H–C(1)); 0.9–2.3 (*m*, 11 H); 1.47 (*s*, Me); 1.44 (*s*, Me); 1.38 (*s*, Me); 1.32 (*s*, Me). CI-MS: 311 (37, $[M - Me]^+$), 193 (12), 149 (8), 141 (8), 111 (11), 101 (100), 83 (28), 72 (8), 59 (18), 55 (21), 43 (53), 29 (7). Anal. calc. for $C_{18}H_{30}O_5$ (326.43): C 66.23, H 9.26; found: C 66.40, H 9.37.

*(1S)-1,4-Anhydro-1-*C*-cyclohexyl-*D*-mannitol* (**13**). A soln. of **12** (700 mg, 2.15 mmol) in AcOH/H_2O 1:1 (25 ml) was stirred for 1 h at 100°. Evaporation and crystallization of the residue from AcOEt gave **13** (287 mg, 54%). R_f (AcOEt/MeOH/H_2O 90:9:1) 0.29. M.p. 131–132°. IR (KBr): 3470*s* (br.), 3414*s* (br.), 3187*s* (br.), 2920*s*, 2851*s*, 1449*m*, 1400*w*, 1376*w*, 1312*m*, 1281*w*, 1241*w*, 1214*m*, 1137*m*, 1115*m*, 1094*m*, 1050*s*, 925*w*, 889*w*, 746*w*, 662*w*. ^{1}H-NMR (250 MHz, (D_6)DMSO): 4.94 (*d*, *J* = 6.5, exchanged with D_2O, OH–C(3)); 4.70 (*d*, *J* = 4.5, exchanged with D_2O, OH–C(5)); 4.64 (*d*, *J* = 6.0, exchanged with D_2O, OH–C(2)); 4.36 (*t*, *J* = 6.0, exchanged with D_2O, OH–C(6)); 4.24 (br. *q*, *J* ≈ 6.0; after addn. of D_2O: br. *t*, *J* ≈ 6.0, H–C(3)); 3.87 (br. *dt*, *J* ≈ 4.0, 5.5; after addn. of D_2O: br. *t*, *J* ≈ 4.3, H–C(2)); 3.72 (br. *tt*, *J* ≈ 4.0, 6.5; after addn. of D_2O: signal hidden by

D_2O, H–C(5)); 3.54 (*ddd*, *J* = 3.8, 6.0, 11.0; after addn. of D_2O: signal hidden by D_2O, H–C(6)); 3.51 (*t*, *J* = 7.0, H–C(4)); 3.33 (*td*, *J* = 6.0, 11.0; after addn. of D_2O: *dd*, *J* = 6.5, 11.0, H'–C(6)); 3.12 (*dd*, *J* = 3.8, 10.0, H–C(1)); 1.58–1.90 (*m*, 6 H); 1.05–1.30 (*m*, 3 H); 0.75–0.98 (*m*, 2 H). CI-MS: 215 (0.5, $[M - CH_2OH]^+$), 185 (8), 168 (9), 149 (7), 125 (18), 95 (22), 81 (16), 73 (100), 55 (34), 41 (23), 29 (16). Anal. calc. for $C_{12}H_{22}O_5$ (246.30): C 58.52, H 9.00; found: C 58.62, H 8.97.

*2,6-Bis[(*tert*-butyl)dimethylsilyloxy]-3,4-dihydropyridine* [33] (**14**). A cooled (0°) soln. of glutarimide (1.13 g, 10 mmol) and Et_3N (3.1 ml, 22 mmol) in dry Et_2O (10 ml) was treated dropwise with (*tert*-butyl)dimethylsilyl trifluoromethanesulfonate (4.6 ml, 20 mmol) and stirred for 1 h at 0°. The org. layer was separated (pipette) and the aq. layer extracted with Et_2O (3x). After drying ($MgSO_4$) and evaporation of the combined org. layers, bulb-to-bulb distillation (140–150°, 0.5 mbar) gave **14** (3.04 g, 89%), which was directly used for the next step.

*(3'S,6'R)- and (3'R,6'S)-1,1⁴-Anhydro-2,3:5,6-di-*O*-isopropylidene-1-C-{6'-[(*tert*-butyl)dimethylsilyloxy]-6'-mercapto-2'-oxopiperidin-3'-yl)-β-*D*-mannofuranose* (= *(1S,1'R,4'S)- and (1S,1'S,4'R)-1'[(*tert*-Butyl)-dimethylsilyloxy]-2,3:5,6-di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,3'-[2]thia[6]aza-bicyclo[2.2.2]octan]-5'-one;* **16a/b**). A mixture of **1** (274 mg, 1 mmol) and **14** (513 mg, 1.5 mmol) was stirred under Ar for 30 min at 100°, cooled to 20°, dissolved in MeOH (10 ml), stirred for 1 h at r.t., and then evaporated. FC (25 g, hexane/AcOEt 1:2) gave **16a/b** (423 mg, 85%). A second FC (25 g, hexane/AcOEt 1:1) gave **16a** (159 mg, 32%) and **16b** (189 mg, 38%).

Data of **16a/16b**: IR (KBr): 3076*w*, 2986*w*, 2934*m*, 2858*w*, 1699*s*, 1465*w*, 1411*w*, 1375*m*, 1319*w*, 1259*s*, 1202*s*, 1124*m*, 1068*s*, 990*w*, 950*m*, 849*s*, 783*m*. EI-MS: 486 (7, $[M - Me]^+$), 468 (9), 410 (11), 342 (12), 288 (13), 227 (57), 199 (22), 170 (14), 115 (11), 101 (24), 73 (100), 59 (20), 43 (52).

Data of **16a**: R_f (hexane/AcOEt 1:1) 0.17. ^{1}H-NMR (400 MHz, $CDCl_3$): 6.25 (*s*, NH); 4.84 (*dd*, *J* = 3.9, 5.8, H–C(3)); 4.74 (*d*, *J* = 5.8, H–C(2)); 4.44 (*ddd*, *J* = 3.6, 6.0, 8.1, H–C(5)); 4.14 (*dd*, *J* = 6.0, 8.9, H–C(6)); 4.05 (*dd*, *J* = 3.7, 8.9, H'–C(6)); 3.58 (*dd*, *J* = 3.8, 8.1, H–C(4)); 2.80 (br. *s*, H–C(3')); 2.57 (*dt*, *J* = 5.0, 11.8, 1 H); 2.35–2.41 (*m*, 1 H); 2.15 (*dt*, *J* = 3.4, 11.9, 1 H); 1.80–1.88 (*m*, 1 H); 1.48 (*s*, Me); 1.46 (*s*, Me); 1.38 (*s*, Me); 1.34 (*s*, Me); 0.91 (*s*, *t*-Bu); 0.29 (*s*, MeSi); 0.24 (*s*, MeSi); NOE: *Table 3*.

Data of **16b**: R_f (hexane/AcOEt 1:1) 0.15. ^{1}H-NMR (400 MHz, $CDCl_3$): 6.28 (*s*, NH); 4.86 (*dd*, *J* = 3.6, 5.8, H–C(3)); 4.73 (*d*, *J* = 5.8, H–C(2)); 4.37 (*ddd*, *J* = 4.2, 6.2, 8.8, H–C(5)); 4.10 (*dd*, *J* = 6.2, 8.8, H–C(6)); 3.98 (*dd*, *J* = 4.2, 8.8, H'–C(6)); 3.79 (*dd*, *J* = 3.6, 8.8, H–C(4)); 2.91–2.92 (*m*, H–C(3')); 2.36–2.41 (*m*, 1 H); 1.91–2.09 (*m*, 3 H); 1.52 (*s*, Me); 1.45 (*s*, Me); 1.39 (*s*, Me); 1.36 (*s*, Me); 0.90 (*s*, *t*-Bu); 0.27 (*s*, MeSi); 0.24 (*s*, MeSi); NOE: *Table 3*.

*(E)-1,4-Anhydro-1-(2,6-dioxopiperidin-3-ylidene)-2,3:5,6-di-*O*-isopropylidene-*D*-mannitol* (= *(E)-3-(2,3:5,6-Di-*O*-isopropylidene-*D*-mannofuranosylidene)piperidine-2,6-dione*; **17**). A mixture of **1** (822 mg, 3 mmol) and **14** (1.539 g, 4.5 mmol) was stirred under Ar for 30 min at 100°, cooled to 20°, dissolved in CH_2Cl_2 (25 ml), treated with $Bu_4NF{\cdot}3H_2O$ (2.8 g, 9 mmol), stirred for 30 min at r.t., and then evaporated. FC (50 g, hexane/AcOEt 1:3) gave **17** (975 mg, 92%). R_f (hexane/AcOEt 1:3) 0.21. ^{1}H-NMR (250 MHz, $CDCl_3$): 7.86 (*s*, NH); 5.86 (*d*, *J* = 6.0, H–C(2)); 4.91 (*dd*, *J* = 4.2, 6.0, H–C(3)); 4.52 (*ddd*, *J* = 4.7, 6.1, 7.0, H–C(5)); 4.27 (*dd*, *J* = 4.2, 7.0, H–C(4)); 4.16 (*dd*, *J* = 6.1, 8.8, H–C(6)); 4.08 (*dd*, *J* = 4.7, 8.8, H'–C(6)); 2.54–2.83 (*m*, 4 H); 1.48 (*s*, Me); 1.46 (*s*, Me); 1.44 (*s*, Me); 1.41 (*s*, Me). CI-MS: 338 (41, $[M - Me]^+$), 280 (16), 238 (41), 270 (19), 178 (9), 164 (8), 153 (7), 140 (10), 101 (100), 81 (10), 73 (13), 59 (16), 43 (78).

*(E)-1,4-Anhydro-1-(2,6-dioxopiperidin-3-ylidene)-*D*-mannitol* (= *(E)-3-(*D*-Mannofuranosylidene)piperidine-2,6-dione*; **18**). A soln. of **17** (530 mg, 1.5 mmol) in AcOH/H_2O 1:1 (25 ml) was stirred for 30 min at 100°. Evaporation and crystallization of the residue from H_2O (6 ml) gave **18** (269 mg, 65%). M.p. 210° (dec.). IR (KBr): 3472*s*, 3357*w*, 3120*w*, 2978*w*, 2915*w*, 2864*w*, 1693*s*, 1666*s*, 1598*s*, 1451*w*, 1423*w*, 1388*w*, 1344*m*, 1295*s*, 1251*w*, 1197*s*, 1132*s*, 1084*m*, 1031*m*, 972*w*, 887*m*, 834*w*, 774*w*, 698*w*, 667*w*. ^{1}H-NMR (250 MHz, (D_6)DMSO): 10.70 (*s*, NH); 6.77 (*d*, *J* = 1.0, OH–C(2)); 5.05 (*d*, *J* = 4.0, OH–C(3)); 4.97 (*dd*, *J* = 1.0, 4.0, H–C(2)); 4.94 (*d*, *J* = 5.9, OH–C(5)); 4.59 (*t*, *J* = 5.5, OH–C(6)); 4.34 (*q*, *J* = 4.0, H–C(3)); 4.20 (*dd*, *J* = 4.0, 9.0, H–C(4)); 3.81–3.90 (*m*, H–C(5)); 3.63 (*ddd*, *J* = 2.8, 5.5, 12.0, H–C(6)); 3.46 (*td*, *J* = 5.5, 12.0, H'–C(6)); 2.42–2.58 (*m*, 4 H). Anal. calc. for $C_{11}H_{15}NO_7$ (273.24): C 48.35, H 5.53, N 5.13; found: C 48.17, H 5.71, N 5.16.

*(E)-1,4-Anhydro-1-(2,6-dioxopiperidin-3-ylidene)-2,3-*O*-isopropylidene-5-*O*-trityl-*D*-ribitol* (= *(E)-3-(2,3-*O*-Isopropylidene-5-*O*-trityl-*D*-ribofuranosylidene)piperidine-2,6-dione*; **19**). A mixture of **2** (1.34 g, 3 mmol) and **14** (3.07 g, 9 mmol) was stirred under Ar for 3 h at 180°. The mixture solidified upon cooling to r.t. It was

dissolved in CH_2Cl_2 (25 ml), treated with $Bu_4NF·3H_2O$ (6.6 g, 13 mmol), stirred for 1 h at r.t., and taken to dryness. FC (75 g, hexane/AcOEt 2:1) gave **19** (978 mg, 62%). R_f (hexane/AcOEt 2:1) 0.16. ^{1}H-NMR (250 MHz, $CDCl_3$): 7.69 (*s*, NH); 7.22–7.50 (*m*, 15 arom. H); 6.06 (*d*, *J* = 6.3, H–C(2)); 4.70–4.74 (*m*, H–C(4)); 4.66 (*dd*, *J* = 0.8, 6.3, H–C(3)); 3.60 (*dd*, *J* = 2.5, 10.5, H–C(5)); 3.04 (*dd*, *J* = 2.0, 10.5, H'–C(5)); 2.78–2.99 (*m*, 2 H); 2.58–2.64 (*m*, 2 H); 1.45 (*s*, Me); 1.40 (*s*, Me).

*(*E*)-1,4-Anhydro-1-(2,6-dioxopiperidin-3-ylidene)-*D*-ribitol* (= *(*E*)-3-(*D*-Ribofuranosylidene)piperidine-2,6-dione*; **20**). A soln. of **19** (500 mg, 0.95 mmol) in AcOH/H_2O 1:1 (10 ml) was stirred for 30 min at 100°. Evaporation and FC (25 g, AcOEt/MeOH 95:5) of the residue gave **20** (170 mg, 74%) which was crystallized from EtOH. R_f (AcOEt/MeOH/H_2O 90:9:1) 0.28. M.p. 148–150°. IR (KBr): 3418*s*, 2924*w*, 2867*w*, 1689*s*, 1634*s*, 1450*w*, 1384*m*, 1343*m*, 1297*s*, 1200*s*, 1146*s*, 1069*m*, 1036*m*, 974*w*, 947*w*, 865*w*, 765*w*, 623*w*, 530*w*. ^{1}H-NMR (250 MHz, (D_6)DMSO): 10.48 (*s*, NH); 5.56 (*d*, *J* = 3.6, OH–C(2)); 5.08 (*d*, *J* = 6.7, OH–C(3)); 5.01 (*dd*, *J* = 3.6, 5.0, H–C(2)); 4.96 (*t*, *J* = 5.5, OH–C(5)); 4.22 (*ddd*, *J* = 2.5, 5.5, 7.0, H–C(4)); 3.95 (*dt*, *J* = 5.5, 7.0, H–C(3)); 3.73 (*ddd*, *J* = 2.5, 5.5, 13.0, H–C(5)); 3.50 (*td*, *J* = 5.5, 13.0, H'–C(5)); 2.38–2.58 (*m*, 4 H). Anal. calc. for $C_{10}H_{13}NO_6$ (243.22): C 49.38, H 5.39, N 5.76; found: C 49.26, H 5.56, N 5.73.

Treatment of **1** *with* CH_2N_2. A soln. of **1** (409 mg, 1.49 mmol) in dry THF (10 ml) was cooled to –10°, treated dropwise with 2.5% CH_2N_2/Et_2O (prepared from *N*-nitroso-*N*-methyl-4-toluenesulfonamide [43]; 2.5 ml), stirred for 3 h at –10°, treated with a second portion of the CH_2N_2 soln. (0.5 ml), and stirred for further 2 h. Evaporation at < 30° gave a 35:65 mixture (^{1}H-NMR) **21/22** (498 mg). Prep. HPLC (hexane/AcOEt 2:1) at 5° gave **21** (152 mg, 32%) and crystalline **22** (262 mg, 55%) which was recrystallized in Et_2O/hexane.

*(1*R*)-2′,5′-Dihydro-2,3:5,6-di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,2′-[1,3,4]thiadiazole]* (**21**). Colorless oil. R_f (hexane/AcOEt 2:1) 0.20 (partial decomposition). $[\alpha]_D^{25}$ = = +80.0 (*c* = 1.1, $CHCl_3$). UV ($CHCl_3$): 305 (sh, *ca.* 345) 245 (*ca.* 880). IR ($CHCl_3$): 2990*m*, 2940*w*, 1375*m*, 1160*m*, 1150*m*, 1120*m*, 1070*s*, 1040*m*, 1000*w*, 970*m*, 960*w*, 910*m*, 890*m*, 860*m*, 840*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 5.90 (*d*, *J* = 17.7, H–C(5′)); 5.67 (*d*, *J* = 17.7, H'–C(5′)); 5.18 (*dd*, *J* = 3.5, 5.8, H–C(3)); 4.97 (*d*, *J* = 5.8, H–C(2)); 4.44 (*ddd*, *J* = 3.7, 5.6, 8.3, H–C(5)); 4.40 (*dd*, *J* = 3.4, 8.3, H–C(4)); 4.08 (*dd*, *J* = 5.7, 8.9, H–C(6)); 3.98 (*dd*, *J* = 3.7, 8.9, H'–C(6)); 1.56 (*s*, Me); 1.45 (*s*, Me); 1.43 (*s*, Me); 1.38 (*s*, Me). ^{13}C-NMR: *Table 5*.

*(1S)-4′,5′-Dihydro-2,3:5,6-di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,5′-[1,2,3]thiadiazole]* (**22**). M.p. 114.5–115° (foaming after melting). R_f (hexane/AcOEt 2:1) 0.18. R_f (HPTLC precoated plates NH_2 (*Merck*), hexane/AcOEt 1:1) 0.39. $[\alpha]_D^{25}$ = –14.0, $[\alpha]_{436}^{25}$ = +17.4, $[\alpha]_{365}^{25}$ = +262.1 (*c* = 0.84, $CHCl_3$). UV ($CHCl_3$): 311 (315), 270 (1560). IR ($CHCl_3$): 3000*m*, 2945*m*, 2890*m*, 1505*m*, 1455*m*, 1395*w*, 1385*m*, 1375*m*, 1290*m*, 1160*m*, 1150*m*, 1125*m*, 1110*m*, 1070*s*, 1025*m*, 995*w*, 975*m*, 900*m*, 890*m*, 875*m*, 865*m*, 840*s*. ^{1}H-NMR (400 MHz, $CDCl_3$): 5.54 (*d*, *J* = 17.7; irrad. at 4.28: NOE of 4.4%; H–C(4′)); 4.87 (*dd*, *J* = 3.4, 5.8, H–C(3)); 4.84 (*d*, *J* = 5.8; irrad. at 4.28: NOE of 1.2% (incl. integration of H–C(3)); H–C(2)); 4.40 (*ddd*, *J* = 3.9, 6.1, 8.0, H–C(5)); 4.28 (*d*, *J* = 17.7; irrad. at 5.54: NOE of 4.3%; H'–C(4′)); 4.06 (*dd*, *J* = 6.1, 9.0, H–C(6)); 3.96 (*dd*, *J* = 3.9, 9.0, H'–C(6)); 3.70 (*dd*, *J* = 3.4, 8.0; irrad. at 5.54: NOE of 1.2%; H–C(4)); 1.50 (*s*, Me); 1.44 (*s*, Me); 1.36 (*s*, Me); 1.34 (*s*, Me). ^{13}C-NMR: *Table 5*. CI-MS (NH_3): 334 (69, $[M + NH_4]^+$), 317 (42, $[M + 1]^+$), 306 (100, $[M - N_2 + NH_4]^+$), 289 (10, $[M - N_2 + 1]^+$), 274 (8), 248 (24), 231 (27). Anal. calc. for $C_{13}H_{20}N_2O_5S$ (316.38): C 49.35, H 6.37, N 8.85, S 10.13; found: C 49.41, H 6.51, N 8.82, S 10.00.

*(1S)-1,2:4,5-Di-*O*-isopropylidene-1-*C*-(1,3,4-thiadiazol-2-yl)-*D*-arabinitol* (**23**). A soln. of **21** (100 mg, ca. 0.3 mmol) and Et_3N (250 µl, 4.77 mmol) in $CHCl_3$ (25 ml) was stirred at r.t. for 2 d. Evaporation gave crystalline **23** (103 mg, > 95% pure by ^{1}H-NMR) which was recrystallized in Et_2O/hexane. M.p. 139°. R_f (hexane/AcOEt 2:1) 0.05. R_f (HPTLC precoated plates NH_2 (*Merck*), hexane/AcOEt 1:1) 0.17. $[\alpha]_D^{25}$ = +15.9 (*c* = 1.1, $CHCl_3$). UV ($CHCl_3$): 239 (635). IR ($CHCl_3$): 3560*w*, 2990*s*, 2960*m*, 2890*m*, 1450*m*, 1400*m*, 1375*s*, 1150*m*, 1110*m*, 1070*s*, 1010*s*, 1075*s*, 985*m*, 970*m*, 910*m*, 890*m*, 880*m*, 845*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 9.10 (*s*, H–C(5′)); 5.75 (*d*, *J* = 7.8, H–C(1)); 4.85 (*dd*, *J* = 0.9, 7.8, H–C(2)); 4.03 (*dd*, *J* = 6.1, 8.0, H–C(5)); 3.98 (*td*, *J* ≈ 5.4, 8.3, H–C(4)); 3.87 (*dd*, *J* = 4.7, 8.0, H'–C(5)); 3.58 (br. *t*, *J* ≈ 8.7; after addn. of D_2O: br. *d*, *J* = 7.9, H–C(3)); 1.90 (*d*, *J* = 9.7, exchanged with D_2O, OH–C(3)); 1.67 (*s*, Me); 1.52 (*s*, Me); 1.40 (*s*, Me); 1.34 (*s*, Me). ^{13}C-NMR: *Table 5*. CI-MS (NH_3): 318 (16), 317 (100, $[M + 1]^+$).

*(1S)-1,2:4,5-Di-*O*-isopropylidene-1-*C*-(1,2,3-thiadiazol-5-yl)-*D*-arabinitol* (**24**). A soln. of **22** (100 mg, 0.32 mmol) in pyridine (5 ml) was stirred for 2 h at 80°. Evaporation and crystallization of the residue from petroleum ether (b.p. 50–70°, 3 ml) gave pure **24** (93 mg, 93%). M.p. 115°. R_f (hexane/AcOEt 2:1) 0.18. $[\alpha]_D^{25}$ = –3.5, $[\alpha]_{436}^{25}$ = 0, $[\alpha]_{365}^{25}$ = +17.8 (*c* = 0.96, $CHCl_3$). UV ($CHCl_3$): 251 (3160). IR ($CHCl_3$): 3560*w*, 2990*m*, 2940*w*, 2910*w*, 2890*w*, 1455*w*, 1385*s*, 1375*s*, 1155*s*, 1110*m*, 1075*s*, 1060*s*, 1040*m*, 1000*w*, 970*w*, 900*m*, 890*m*, 860*m*, 850*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 8.65 (*d*, *J* = 0.5, H–C(4′)); 5.76 (br. *d*, *J* = 7.5, H–C(1)); 4.65 (*dd*, *J* = 1.9,

7.5, H–C(2)); 4.03 (*dd*, *J* = 6.2, 8.5, H–C(5)); 3.95 (*td*, *J* ≈ 5.8, 8.1, H–C(4)); 3.83 (*dd*, *J* = 5.4, 8.0, H'–C(5)); 3.13 (br. *dt*, *J* ≈ 1.2, 8.0; after addn. of D_2O: *dd*, *J* = 1.8, 8.1, H–C(3)); 1.98 (*d*, *J* = 8.5, exchanged with D_2O, OH–C(3)); 1.64 (*s*, Me); 1.50 (*s*, Me); 1.33 (*s*, 2 Me). ^{13}C-NMR: *Table 5*. CI-MS (NH_3): 318 (17), 317 (100, $[M + 1]^+$). Anal. calc. for $C_{13}H_{20}N_2O_5S$ (316.38): C 49.35, H 6.37, N 8.85, S 10.13; found: C 49.22, H 6.30, N 8.59, S 9.88.

Thermolysis of **21**. In an NMR tube, a soln. of **21**/**22** *ca.* 9:1 (15 mg) in $CDCl_3$ (0.6 ml) was kept at 20° and monitored by ^{1}H-NMR (integration of the signals at 5.90, 5.67, and 5.54 ppm). Half-life of **21**: 21.6 h. The complex reaction mixture contained ca. 20–25% of **27** which was not analyzed any further.

*Methyl 2,3:5,6-Di-*O*-isopropylidene-1-*C*-(methylthio)-*α*-*D*-mannofuranoside* (**26**). A soln. of **21** (100 mg, ca. 0.3 mmol) in MeOH (25 ml) was stirred for 2 d at r.t. Evaporation gave crude **26** (*ca.* 100 mg, > 95% pure by ^{1}H-NMR), which was purified by prep. HPLC (hexane/AcOEt 4:1). R_f (hexane/AcOEt 2:1) 0.39. IR ($CHCl_3$): 3000*m*, 2940*m*, 2910*w*, 2840*w*, 1385*m*, 1375*m*, 1265*m*, 1165*m*, 1150*m*, 1115*s* (sh), 1100*s*, 1075*s*, 1035*s*, 1010*m* (sh), 985*m*, 965*m*, 955*m*, 890*w*, 870*m*, 845*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 4.82 (*dd*, *J* = 3.8, 5.8, H–C(3)); 4.56 (*d*, *J* = 5.9; irrad. at 3.31: NOE (1.5%); irrad. at 2.08: NOE (1.9%); H–C(2)); 4.40 (*ddd*, *J* = 4.3, 6.2, 7.9, H–C(5)); 4.11 (*dd*, *J* = 6.2, 8.8, H–C(6)); 4.01 (*dd*, *J* = 4.3, 8.8, H'–C(6)); 3.80 (*dd*, *J* = 3.8, 7.9; irrad. at 3.31: NOE (1.7%); H–C(4)); 3.31 (*s*; irrad. at 2.08: NOE (2%), MeO); 2.08 (*s*; irrad. at 3.31: NOE (3%); MeS); 1.53 (*s*, Me); 1.45 (*s*, Me); 1.37 (*s*, Me); 1.36 (*s*, Me). CI-MS (NH_3): 305 (2, $[M - Me]^+$), 290 (17), 289 (100, $[M - MeO]^+$), 273 (22, $[M - MeS]^+$), 263 (3, $[M$ – acetone + H$]^+$).

Thermolysis of **22**. A soln. of **22** (20 mg) in high-boiling petroleum ether (40 ml) was kept at 100° for 8 h and evaporated. ^{1}H-NMR: **22** (30%), **27** (35%), and **28** [37] (35%). Half-life of **21**: *ca.* 6 h. Prep. HPLC (hexane/AcOEt 2:1) gave pure samples of **27** and **28**.

*Data of 1,2-Anhydro-3,4:6,7-di-*O*-isopropylidene-1-thio-*β*-*D*-*manno*-hept-2-ulofuranose* (= *(1S)-2,3:5,6-Di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,2'(3'H)-thiirine]*; **27**). ^{1}H-NMR (300 MHz, $CDCl_3$): 4.96 (*dd*, *J* = 3.7, 5.9, H–C(4)); 4.57 (*d*, *J* = 5.9, H–C(3)); 4.50 (*ddd*, *J* = 3.9, 6.0, 8.2, H–C(6)); 4.10 (*dd*, *J* = 6.1, 8.9, H–C(7)); 4.02 (*dd*, *J* = 3.9, 8.9, H'–C(7)); 3.79 (*dd*, *J* = 3.7, 8.2, H–C(5)); 2.63 (*d*, *J* = 1.5, H–C(1)); 2.50 (*d*, *J* = 1.5, H'–C(1)); 1.58 (*s*, Me); 1.45 (*s*, Me); 1.39 (*s*, Me); 1.38 (*s*, Me). ^{13}C-NMR: *Table 5*. EI-MS: 273 (13, $[M -$ Me$]^+$), 113 (8), 101 (38), 97 (11), 85 (14), 83 (10), 81 (11), 73 (10), 69 (12), 59 (24), 55 (10), 43 (100), 41 (22), 39 (12).

*Ethyl (Z)- and (E)-3,6-Anhydro-2-deoxy-4,5:7,8-di-*O*-isopropylidene-*D*-manno-oct-2-enonate* (**29** and **30**, resp.). A mixture of **1** (274 mg, 1 mmol) and $Rh_2(OAc)_4 2H_2O$ (22 mg, 0.1 mmol) in toluene (10 ml) was heated to 110° and treated dropwise within 1 h with a soln. of ethyl diazoacetate (1.71 g, 15 mmol) in toluene (10 ml). Evaporation and FC (75 g, hexane/*t*-BuOMe 2:1 → 1:1) of the residue gave **29** (108 mg, 33%) and **30** (85 mg, 26%).

Data of **29**: R_f (hexane/*t*-BuOMe 2:1) 0.25. IR (film): 2988*w*, 2909*w*, 1712*s*, 1665*m*, 1457*w*, 1375*m*, 1257*m*, 1194*s*, 1157*m*, 1119*m*, 1069*s*, 954*w*, 873*w*, 847*w*, 812*w*. ^{1}H-NMR (250 MHz, $CDCl_3$): 5.14 (*dd*, *J* = 1.0, 6.0, H–C(4)); 5.11 (*d*, *J* = 1.0, H–C(2)); 4.78 (*dd*, *J* = 3.5, 6.0, H–C(5)); 4.47–4.54 (*m*, H–C(7)); 4.38 (*dd*, *J* = 3.5, 8.0, H–C(6)); 4.08–4.24 (*m*, 4 H); 1.48 (*s*, Me); 1.46 (*s*, Me); 1.41 (*s*, 2 Me); 1.27 (*t*, *J* = 7.1, Me). EI-MS: 313 (35, $[M -$ Me$]^+$), 283 (9), 255 (10), 213 (48), 185 (4), 167 (11), 101 (100), 85 (16), 69 (16), 59 (17), 43 (97).

Data of **30**: R_f (hexane/*t*-BuOMe 1:1) 0.23. IR (film): 2986*w*, 2909*w*, 1713*s*, 1660*s*, 1455*w*, 1372*s*, 1338*w*, 1304*w*, 1258*m*, 1212*m*, 1158*m*, 1117*s*, 1069*s*, 977*w*, 938*w*, 844*w*. ^{1}H-NMR (250 MHz, $CDCl_3$): 5.76 (*dd*, *J* = 1.0, 6.1, H–C(4)); 5.43 (*d*, *J* = 1.0, H–C(2)); 4.86 (*dd*, *J* = 4.0, 6.0, H–C(5)); 4.44–4.51 (*m*, H–C(7)); 4.04–4.24 (*m*, 5 H); 1.46 (*s*, Me); 1.45 (*s*, Me); 1.43 (*s*, Me); 1.40 (*s*, Me); 1.27 (*t*, *J* = 7.1, Me). EI-MS: 313 (21, $[M -$ Me$]^+$), 283 (6), 255 (6), 213 (26), 167 (8), 153 (5), 139 (4), 125 (4), 111 (5), 101 (72), 85 (13), 69 (19), 43 (100).

*Ethyl 2,3-Anhydro-2-(ethoxycarbonyl)-4,5:7,8-di-*O*-isopropylidene-2-thio-β-*D*-manno-oct-3-ulofuranosonate* (= *Diethyl (1S)-2,3:5,6-Di-*O*-isopropylidenespiro[[1,4]anhydro-*D*-mannitol-1,2'(3'H)-thiirine]-3',3'-dicarboxylate*; **31**) *and Ethyl 3,6-Anhydro-2-deoxy-2-(ethoxycarbonyl)-4,5:7,8-di-*O*-isopropylidene-*D*-manno-oct-2-enonate* [35] (**32**). A mixture of **1** (274 mg, 1 mmol), ethyl diazomalonate (559 mg, 3 mmol), and $Rh_2(OAc)_4 \cdot 2H_2O$ (6 mg, 0.03 mmol) in toluene (10 ml) was heated to 80°. Once the evolution of gas had ceased (5 min), the mixture was cooled to r.t. and evaporated. FC (25 g, hexane/AcOEt 7:1 → 5:1) gave **32** (116 mg, 29%) and **31** (292 mg, 68%).

In a parallel reaction, the mixture was cooled to r.t., treated with $P(NEt_2)_3$ (181 µl, 1 mmol), and stirred for 1.5 h at 80°. Filtration (toluene) of the cold mixture through silica gel, evaporation of the filtrate, and FC (50 g, hexane/AcOEt 2:1) of the residue gave **32** (371 mg, 93%).

Data of **31**: R_f (hexane/AcOEt 5:1) 0.23. ^{1}H-NMR ($CDCl_3$): 5.37 (*d*, *J* = 5.8, H–C(4)); 4.95 (*dd*, *J* = 3.4, 5.8, H–C(5)); 4.45 (*ddd*, *J* = 3.8, 6.1, 8.4, H–C(7)); 4.29 (*q*, *J* = 7.1, CH_2); 4.26 (*q*, *J* = 7.1, CH_2); 4.06 (*dd*, *J* = 6.1, 8.9, H–C(8)); 3.90 (*dd*, *J* = 3.4, 8.4, H–C(6)); 3.86 (*dd*, *J* = 3.8, 8.9, H'–C(8)); 1.55 (*s*, Me); 1.43 (*s*, Me); 1.42 (*s*, Me); 1.36 (*s*, Me); 1.33 (*t*, *J* = 7.1, Me); 1.29 (*t*, *J* = 7.1, Me). EI-MS: 417 (4, $[M - Me]^+$), 385 (34), 355 (17), 339 (4), 285 (13), 253 (12), 239 (37), 196 (15), 187 (12), 101 (90), 97 (12), 85 (17), 69 (26), 59 (29), 55 (14), 43 (100), 29 (77).

Data of **32**. R_f (hexane/AcOEt 2:1) 0.27. M.p. 91–92° ([35]: 92–93°). IR (KBr): 2984*m*, 2894*w*, 1714*s*, 1656*s*, 1452*w*, 1380*m*, 1261*s*, 1208*s*, 1159*m*, 1111*s*, 1081*s*, 1046*s*, 1004*w*, 974*w*, 936*w*, 907*w*, 882*m*, 821*w*, 781*w*. ^{1}H-NMR ($CDCl_3$): 5.75 (*d*, *J* = 5.7, H–C(4)); 4.84 (*dd*, *J* = 3.7, 5.7, H–C(5)); 4.50 (*ddd*, *J* = 4.5, 6.0, 7.5, H–C(7)); 4.33 (*dd*, *J* = 3.7, 7.5, H–C(6)); 4.26 (*q*, *J* = 7.1, 1 H); 4.25, (*q*, *J* = 7.1, 2 H); 4.24 (*q*, *J* = 7.1, 1 H); 4.07–4.19 (*m*, 2 H–C(8)); 1.45 (*s*, Me); 1.44 (*s*, Me); 1.42 (*s*, Me); 1.39 (*s*, Me); (*s*, Me); 1.295 (*t*, *J* = 7.1, Me); 1.285 (*t*, *J* = 7.1, Me). EI-MS: 385 (30, $[M - Me]^+$), 355 (11), 339 (4), 285 (12), 253 (12), 239 (36), 196 (17), 187 (10), 101 (94), 87 (12), 69 (19), 59 (19), 43 (100), 29 (50).

*Ethyl 3,6-Anhydro-2-deoxy-2-(ethoxycarbonyl)-4,5-*O*-isopropylidene-7-*O*-trityl-*D*-*ribo*-hept-2-enonate* (**33**). A mixture of **2** (223 mg, 0.5 mmol) and $Rh_2(OAc)_4 \cdot 2H_2O$ (11 mg, 0.05 mmol) in toluene (5 ml) was treated dropwise (within 30 min) at 110° with a soln. of diethyl diazomalonate (376 mg, 2 mmol) in toluene (5 ml). The mixture was cooled to r.t., treated with $P(NEt_2)_3$ (91 µl, 0.5 mmol), stirred for 1.5 h at 80°, and cooled to 0°. Filtration (toluene) through a pad of silica gel, evaporation of the filtrate, and FC (25 g, hexane/AcOEt 5:1) gave **33** (198 mg, 69%). R_f (hexane/AcOEt 5:1) 0.27. M.p. 146°. IR (KBr): 2935*w*, 2872*w*, 1722*s*, 1630*w*, 1491*w*, 1447*w*, 1371*w*, 1290*m*, 1252*w*, 1226*m*, 1194*s*, 1153*m*, 1094*s*, 1044*w*, 1003*m*, 956*w*, 895*w*, 835*w*, 797*w*, 747*m*, 707*m*, 629*w*. ^{1}H-NMR ($CDCl_3$): 7.22–7.43 (*m*, 15 arom. H); 5.99 (*d*, *J* = 5.9, H–C(4)); 4.81 (*t*, *J* = 2.8, H–C(6)); 4.48 (*d*, *J* = 5.9, H–C(5)); 4.22–4.43 (*m*, 2 CH_2); 3.64 (*dd*, *J* = 2.8, 10.8, H–C(7)); 2.96 (*dd*, *J* = 2.8, 10.8, H'–C(7)); 1.43 (*s*, Me); 1.27–1.36 (*m*, 3 Me). Anal. calc. for $C_{34}H_{36}O_8$ (572.54): C 71.31, H 6.34; found: C 71.16, H 6.50.

X-Ray Analyses of **4**, **13**, *and* **24**. Crystals were obtained from THF/hexane (**4**), AcOEt (**13**), or petroleum ether (**24**). **4**: $C_{18}H_{28}O_5S$ (365.5); orthorhombic $P2_12_12_1$; a = 6.022 (3), b = 8.620 (3), c = 35.42 (2) Å; V = 1838.7 (14) Å^3; D_x = 1.288 Mg/m^3; Z = 4. **13**: $C_{12}H_{22}O_5$ (246.3); monoclinic $C2$; a = 8.767 (3), b = 7.607 (3), c = 19.812 (8) Å, β = 99.12 (3)°; V = 1304.6 (9) Å^3; D_x = 1.254 Mg/m^3; Z = 4. **24**: $C_{13}H_{20}N_2O_5S$ (316.4); orthorhombic $P2_12_12_1$; a = 5.501 (3), b = 14.351 (6), c = 19.709 (13) Å; V = 1556.0 (15) Å^3; D_x = 1.350 Mg/m^3; Z = 4. Intensities were measured in the ω-scan mode on a *Nicolet-R3m* diffractometer (graphite-monochromator, MoK_α, λ = 0.71069 Å) at 183 (**4**, **24**) or 163 K (**24**), $2\Theta_{(max)}$ = 56°, variable scan speed of 1.0 to 15.0°/min in ω (**4**, **24**) or of 1.70 to 19.53°/min in ω (**13**). Of the 2607 (**4**), 1775 (**13**), or 2210 (**24**) total collected reflections and 2574 (**4**), 1690 (**13**), or 2184 (**24**) independent reflections, 1375 (**4**), 1320 (**13**), or 1095 (**24**) were observed ($F > 5.0\sigma(F)$). R = 0.07, R_w = 0.083 (**4**); R = 0.0709, R_w = 0.0896 (**13**); R = 0.0595, R_w = 0.0641 (**24**). The structures were solved with the direct-methods routine of SHELXS-86 [44], and the refinement was performed with *Nicolet* SHELXTL PLUS [45]. Local disorder was observed in the cyclohexane moiety of **13**.

REFERENCES

[1] M. Hürzeler, B. Bernet, A. Vasella, *Helv. Chim. Acta* **1993**, *76*, 995.

[2] P. Metzner, *Synthesis* **1980**, 1185.

[3] a) D. L. Boger, S. M. Weinreb, 'Hetero Diels-Alder, Methodology in Organic Synthesis', Academic Press, New York, 1987, pp. 120–145; b) *ibid.*, pp. 214–238.

[4] E. Schaumann, in 'The Chemistry of Double-Bonded Functional Groups, Supplement A', Ed. S. Patai, John Wiley, Chichester, 1989, Part 2, pp. 1269–1371.

[5] S. Scheithauer, R. Mayer, 'Thio- and Dithiocarboxylic Acids and Their Derivatives' in 'Topics in Sulfur Chemistry', Ed. A. Senning, Thieme-Verlag, Stuttgart, 1979, Vol. 4, pp. 295–306.

[6] S. M. Weinreb, R. R. Staib, *Tetrahedron* **1986**, *38*, 3087.

[7] E. Vedejs, T. H. Eberlein, D. J. Mazur, C. K. McClure, D. A. Perry, R. Ruggeri, E. Schwartz, J. S. Stults, D. L. Varie, R. G. Wilde, S. Wittenberger, *J. Org. Chem.* **1986**, *51*, 1556; E. Vedejs, D. A. Perry, K. N. Houk, N. G. Rondan, *J. Am. Chem. Soc.* **1983**, *105*, 6999; E. Vedejs, D. A. Perry, *ibid.* **1983**, *105*, 1683; E. Vedejs, T. H. Eberlein, D. L. Vanle, *ibid.* **1982**, *104*, 1445.

[8] K. Hartke, T. Kissel, J. Quante, G. Henssen, *Angew. Chem.* **1978**, *90*, 1016; K. Hartke, G. Henssen, T. Kissel, *Liebigs Ann. Chem.* 1980, 1665.

[9] P. Beslin, P. Metzner, *Tetrahedron Lett.* **1980**, *21*, 4657.

[10] H. Meier, in 'Houben-Weyl's Methoden der organischen Chemie', Ed. K. H. Büchel, Thieme, Stuttgart, 1985, Band E11, Teil 2, pp.1498–1508.

[11] R. Mayer, S. Scheithauer, in 'Houben-Weyl's Methoden der organischen Chemie', Ed. K. H. Büchel, Thieme, Stuttgart, 1985, Band E5, Teil 1, pp. 785–811.

[12] M. Regitz, H. Heydt, in '1,3-Dipolar Cycloaddition Chemistry', Ed. A. Padwa, John Wiley, New York, 1984, Vol. 1, pp. 470–477.

[13] A. Schönberg, E. Frese, W. Knöfel, K. Praefcke, *Chem. Ber.* **1970**, *103*, 938; A. Schönberg, B. König, E. Singer, *ibid.* **1967**, *100*, 767.

[14] R. Huisgen, W. Mack, E. Anneser, *Angew. Chem.* **1961**, *73*, 656; K. Bunge, R. Huisgen, R. Raab, H. J. Sturm, *Chem. Ber.* **1972**, *105*, 1307.

[15] K. Hartke, T. Gillmann, *Chem.-Zt.* **1986**, *110*, 338.

[16] a) A. P. Krapcho, M. P. Silvon, I. Goldberg, E. G. E. Jahngen, Jr., *J. Org. Chem.* **1974**, *39*, 860; b) A. P. Krapcho, D. R. Rao, M. P. Silvon, B. Abegaz, *ibid.* **1971**, *36*, 3885; c) T. Katada, S. Eguchi, T. Sasaki, *J. Chem. Soc., Perkin Trans. 1* **1984**, 2641; d) R. Huisgen, G. Mloston, *Tetrahedron Lett.* **1985**, *26*, 1049.

[17] G. Mloston, H. Heimgartner, *Helv. Chim. Acta* **1992**, *75*, 1825.

[18] R. Huisgen, C. Fulka, I. Kalwinsch, L. Xingya, G. Mloston, J. R. Moran, A. Pröbstl, *Bull. Soc. Chim. Belg.* **1984**, *93*, 511.

[19] K. Hartke, A. Kumar, J. Köster, G. Henssen, T. Kissel, T. Kämpchen, *Chem. Ber.* **1982**, *115*, 3096.

[20] V. A. Montero, I. T. Hernandez, J. de Pascual Teresa, J. R. Moran, R. Olabarrieta, *J. Org. Chem.* **1989**, *54*, 3664.

[21] J. M. Beiner, D. Lecadet, D. Paquer, A. Thuiller, J. Vialle, *Bull. Soc. Chim. Fr.* **1973**, 1979; J. M. Beiner, D. Lecadet, D. Paquer, A. Thuiller, *ibid.*, **1973**,1983.

[22] U. Schmidt, E. Heymann, K. Kabitzke, *Chem. Ber.* **1963**, *96*, 1478.

[23] A. Ohno, T. Koizumi, Y. Akasaki, *Bull.Chem. Soc. Jpn.* **1974**, *47*, 319.

[24] S. Takano, S. Tomita, M. Takahashi, K. Ogasawara, *Synthesis* **1987**, 1116.

[25] D. M. Vyas, G. W. Hay, *J. Chem. Soc., Perkin Trans. 1* **1975**, 180.

[26] P. Herczegh, M. Zsély, L. Szilágyi, R. Bognár, *Heterocycles* **1989**, *28*, 887; P. Herczegh, M. Zsély, R. Bognár, L. Szilágyi, *Tetrahedron Lett.* **1986**, *27*, 1509.

[27] G. Seitz, R. Mohr, W. Overheu, R. Allmann, M. Nagel, *Angew. Chem.* **1984**, *96*, 885.

[28] R. E. Ireland, D. M. Obrecht, *Helv. Chim. Acta* **1986**, *69*, 1273.

[29] H. Günther, 'NMR-Spektroskopie', Georg Thieme Verlag, Stuttgart, 1983, pp.115–118; L. M. Jackman, S. Sternhell, 'Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry', in 'International Series in Organic Chemistry', Eds. D. H. R. Barton and W. Doering, Vol. 10, 1969, pp.316–328.

[30] M. C. Grossel, *Tetrahedron Lett.* **1980**, *21*, 1075.

[31] R. Mayer, W. Broy, R. Zahradnik, *Adv. Heterocycl. Chem.* **1967**, *8*, 219.

[32] G. Casy, S. Lane, R. K. Taylor, J. *Chem. Soc., Perkin Trans. 1* **1986**, 1397.

[33] W. Ried, U. Reiher, *Chem. Ber.* **1987**, *120*, 657.

[34] R. Sustmann, W. Sicking, H. Lamy-Schelkens, L. Ghosez, *Tetrahedron Lett.* **1991**, *32*, 1401; H. Lamy-Schelkens, D. Giomi, L. Ghosez, *ibid.* **1989**, *30*, 5887; M. Rivera, H. Lamy-Schelkens, F. Sainte, K. Mbiya, L. Ghosez, *ibid.* **1988**, *29*, 4573.

[35] B. Aebischer, R. Meuwly, A. Vasella, *Helv. Chim. Acta* **1984**, *67*, 2236.

[36] a) R. Huisgen, G. Mloston, C. Fulka, *Heterocycles* **1985**, *23*, 2207; b) L. Xingya, R. Huisgen, *Tetrahedron Lett.* **1985**, *24*, 4181.

[37] R. Csuk, B. I. Glänzer, *Tetrahedron* **1991**, *47*, 1655.

[38] H. P. Braun, H. Meier, *Tetrahedron* **1975**, *31*, 637.

[39] P. Dais, A. S. Perlin, *Carbohydr. Res.* **1986**, *146*, 177.

[40] M. Hürzeler, B. Bernet, A. Vasella, *Helv. Chim. Acta* **1992**, *75*, 557.

[41] M. P. Doyle, *Acc. Chem. Res.* **1986**, *19*, 348.

[42] A. Krebs, W. Rüger, B. Ziegenhagen, M. Hebold, I. Hardtke, R. Müller, M. Schütz, M. Wietzke, M. Wilke, *Chem. Ber.* **1984**, *117*, 277.
[43] L. F. Fieser, M. Fieser, 'Reagents for Organic Synthesis', John Wiley, New York, 1967, Vol. 1, p. 191.
[44] G. M. Sheldrick, 'SHELXS-86, A Program for the Solution of Crystal Structures from Diffraction Data', University of Göttingen, Germany.
[45] G. M. Sheldrick, 'SHELXTL Plus, an Integrated System for Solving, Refining and Displaying Crystal Structures from Diffraction Data, Version 3.0', University of Göttingen, Germany.