Synthesis, Oxidation and Dehydrogenation of Cyclic *N*,*O*- and *N*,*S*-Acetals. II [1]. Transformation of *N*,*S*-Acetals: 3-Acylbenzothiazolines and -thiazolidines

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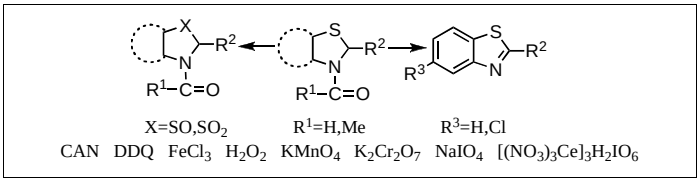
Received July 1, 2005



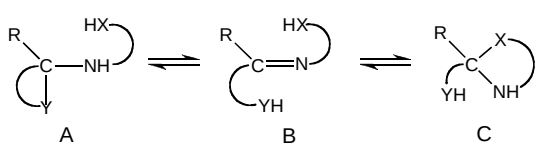
The dehydrogenations with iron(III) chloride, potassium permanganate, and for the first time, CAN, tris-[trinitrato-cerium(IV)]-paraperiodate (TTNCPP), and (diacetoxyiodo)benzene (IBDA) are investigated. Hydrogen peroxide, sodium periodate, potassium permanganate, and ammonium cerium(IV) nitrate (CAN) oxidation of chiral benzothiazolines, *O*- and *O*,*N*-acylated derivatives of the condensates of D-galactose with 2-aminothiophenols or L-cysteine, are also reported.

J. Heterocyclic Chem., **43**, 1141 (2006).

In the introduction of part I of this series, transformation of *N*,*S*-acetals: 3-acyl-1,3,4-thiadiazolines and the importance of ring-chain tautomerism (see Scheme 1) during the oxidation and dehydrogenation of cyclic *N*,*O*- and *N*,*S*-acetals has been concisely discussed [1]. As an extension of our studies on the cyclic *N*,*S*-acetals 1,3,4-thiadiazolines, we decided to investigate the reactions of their 4-C-analogues, benzothiazolines (**1**,**3**) and thiazolidines (**7**), formerly prepared by us [29,32-34], with various similar oxidants and dehydrogenating agents of diverse mechanisms of action. These derivatives are, partially or fully saturated cyclic *N*,*S*-acetals chirally substituted at C-2.

Benzothiazolines, particularly the 2-arylsubstituted derivatives, undergo dehydrogenation quite readily, *e.g.* upon treatment with benzoyl peroxide/dichloromethane [2], iron(III) chloride [3], 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) [4], and other organic H-acceptors [5], or oxygen [4] to give benzothiazoles. However, when treated with hydrogen peroxide/methanol 2-substituted benzothiazolines transform [2] into 2-methyleneaminophenyl disulfides as a result of a ring-chain tautomerism (**B** ⇌ **C**, Scheme 1) [2,5,6]. The benzothiazoline skeleton (form **C**, Scheme 1) can be stabilized by acylation at position 3, nevertheless, the nature of the acyl group (*e.g.* formyl, acetyl, propionyl) may have an influence on the biological activity [4d]. Benzothiazolines without N-acyl group and containing accessible nucleophilic groups (*e.g.* condensates of 2-aminothiophenol with aldoses, type **1a**,**b**) are especially unstable in protic solvents and their oxidation by air result in 2-aminophenyl disulfides and aldoses [7] as a consequence of a **C**→**B**→**A** transformation (see Scheme 1).

Scheme 1



During the second half of the last century, stimulated mainly by the penam→cephem ring-expansion transformations of β–lactam antibiotics [8] containing cyclic *N*,*S*-acetal moieties, the chemistry of sulfoxides [9] has been very intensively elaborated. Although the hydrogen peroxide oxidation has been used for the transformation of 3-acylthiazolidines into both the corresponding sulfoxides and sulfones [10], the reactions are time-consuming and often not chemoselective. For the preparation of thiazolidine or benzothiazoline 1,1-dioxides potassium permanganate oxidation of the 3-acyl sulfide analogues has been successfully applied [11]. Related 3-arylbenzothiazoline 1,1-dioxides, and not the corresponding sulfoxides, have been obtained by condensing 2-arylaminobenzenesulfinic acids with aldehydes or ketones [12].

As the regioselective partial dehydrogenation of thiazolidines has not been well elaborated yet [13], the unsaturation of thiazolines is generally performed in the course of heterocyclization [14]. The aromatization of thiazol(id)ines, with the concomitant rearrangement [14a], has been achieved by dehydrogenation with (alkaline) potassium hexacyanoferrate(III) [24a,15], mercury(II) acetate [15b], quinones (1,4-benzoquinone [14c,f], phenanthrenequinone [14c], tetrachloro-1,4-benzoquinone (chloranil) [14c,f], DDQ [13b,14f]), hydrogen peroxide [14a], iron(III) chloride [14a], potassium dichromate

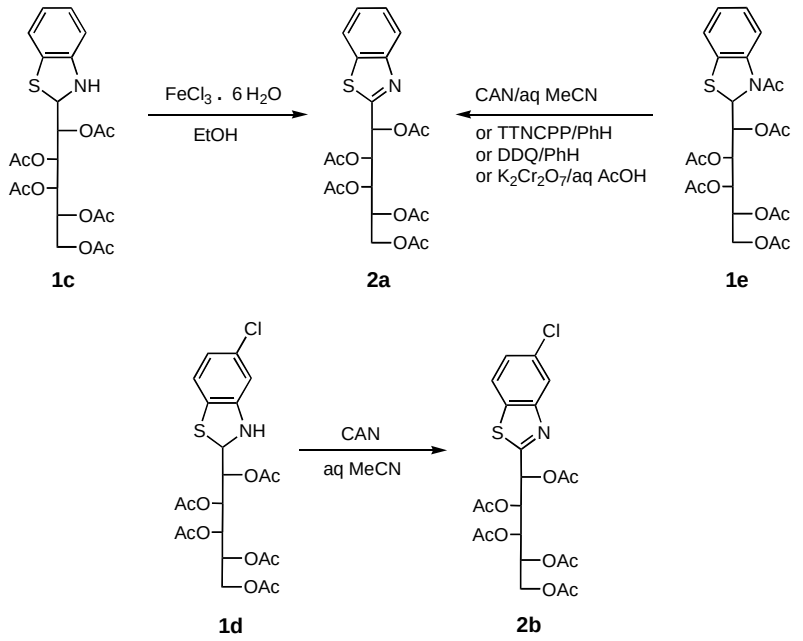
[14a], sulphur [14a,b], manganese(IV) oxide [13b,c,16], or nickel(II) peroxide [13b,17].

Results and Discussion.

The reaction of 2-monosubstituted 3-acyl-1,3,4-thiadiazolines with potassium permanganate or CAN has been found to afford thiadiazoles [1]. We observed that treatment of the analog benzothiazoline lactam **3** with CAN led to the formation of benzothiazol-2-ylbenzoic acid derivative **5** as well as the benzothiazoline sulfoxide **4** (Scheme 4). Periodic acid oxidation of **3** gave also sulfoxide **4** in similar yield.

2-(Pentaacetoxy)pentylbenzothiazolines **1c**,**d** are more stable than their polyhydroxy analogues **1a**,**b** and they could be dehydrogenated to benzothiazoles **2a**,**b** by treatment with iron(III) chloride or more favourably with CAN (Scheme 2). Treatment of **1d** with potassium permanganate afforded dehydrogenation to **2b** in a poor yield (see Table 1). However, it oxidized the 3-acetyl readily dehydrogenated to benzothiazole **2a** by treatment with potassium dichromate/aq. acetic acid, or preferably with DDQ, CAN or tris[trinitrato-cerium(IV)] paraperiodate (TTNCPP, see Scheme 2 and Table 1). The one-electron acceptor CAN readily dehydrogenated benzothiazoline **1e** to **2a** in excellent yield (see Table 1). However, under similar conditions, sulfoxide **1f** and sulfone **1g**, with electron deficient sulfur, completely resisted any transformation. Moreover, treatment of analog compounds with (diacetoxyiodo)benzene in methanol at room temperature for 36 h dehydrogenated the S–CHR–NAc acetal 5-acetamido-3-acetyl-2-(4-chlorophenyl)-1,3,4-thiadiazoline in 93% yield [1]. Due to the lack of a relatively basic reaction centre (NH), only *ca*. 75% of 3-acetyl-2-(D-*galacto*-pentaacetoxypentyl)benzothiazoline (**1e**) was dehydrogenated to **2a** when boiled for 8 days. Treatment of (+)-2-[D-*galacto*-(pentaacetoxy)pentyl]-3-acetylbenzothiazoline 1-oxide ((+)**1f**) with acetic anhydride afforded (see Scheme 3 and Experimental) the corresponding

Scheme 2



derivative **1e** to the corresponding 1,1-dioxide **1g** (see Scheme 3 and Experimental). Both dehydrogenating and oxidizing feature of potassium permanganate has been also observed in its reaction with chiral 4,5-dihydro-1,3-thiazoles. Under phase-transfer conditions, 2-thiazolines are dehydrogenated to thiazoles when treated with potassium permanganate. However, in the presence of 1 equiv. benzoic acid, they are oxidized to 2-thiazoline 1,1-dioxides [35]. The 3-acetylbenzothiazoline **1e** was also benzothiazole (**2a**) identical with that obtained by CAN, TTNCPP, DDQ, and potassium dichromate dehydrogenations of the sulfide analog (+)**1e** or by iron(III) chloride dehydrogenation of the benzothiazoline analog unacetylated at position 3 ((±)**1c**, see Scheme 2 and Table 1). Under similar conditions, 3-acetyl-2-phenyl-benzothiazoline 1-oxide is known to give 2-phenyl-benzothiazole as the major product (along with the disproportion products benzothiazoline and 1,1-dioxide) [36b]. However, 2-

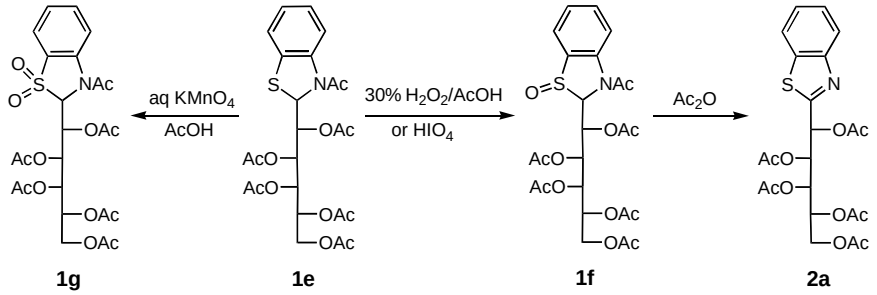
Table 1

Dehydrogenation of 2-(D-*galacto*-Pentaacetoxypentyl)benzothiazolines **1c-e**

Substrate (mmol)	Agent (mmol)	Solvents (mL)	Reaction temp. (°) (time, h)	Workup [a]	Product	Yield [b] (%)	Mp (°) (solvent)	Lit. mp (°) (solvent)
(±)**1c** [c] (2)	$FeCl_3$.6 H_2O [d] (2.88)	EtOH (40)	23 (46)	B, F	**2a** [e]	33	134 (EtOH/H_2O)	133-135 (EtOH) [f]
(–)**1d** [g] (0.25)	CAN (0.51)	MeCN (3) H_2O (0.4)	23 (0.5+0.1) [h]	B, D	**2b** [e]	48	156 (EtOH/hexane)	149 (EtOH) [f]
(–)**1d** [g] (0.5)	$KMnO_4$ (3.65)	AcOH (5) H_2O (8)	< 20 (1.5+2) [h]	E, B, D	**2b** [e]	13	155 (EtOH/hexane)	149 (EtOH) [f]
(+)**1e** [i], [l] (0.5)	CAN (0.95)	MeCN (3) H_2O (0.5)	23 (0.25+0.5) [h]	B, D	**2a** [e]	76	134 (50% 2-PrOH)	133-135 (EtOH) [f]
(+)**1e** [i] (0.25)	TTNCPP [j] (0.5)	PhH (5)	65 (3)	A, G	**2a** [e]	92	134 (50% 2-PrOH)	133-135 (EtOH) [f]
(+)**1e** [i] (5)	DDQ (6)	PhH (25)	bp (24)	B, D, H	**2a** [e]	83	133-134 (50% 2-PrOH)	133-135 (EtOH) [f]
(+)**1e** [i] (0.5)	$K_2Cr_2O_7$ (0.81)	AcOH (5) H_2O (0.6)	23 (89)	B, D, H	**2a** [e]	38 [k]	133-134 (50% 2-PrOH)	133-135 (EtOH) [f]

[a] For general operations of processing the reaction mixtures see Experimental. [b] For the pure product, without workup of the mother liquors. [c] Ref. 29. [d] To a solution of iron(III) chloride hexahydrate in commercial anhydrous ethanol was added **1c**. [e] Identical (mp, tlc, ir) with an authentic compound. [f] Ref. 30. [g] Mp 171-172° (from commercial anhydrous ethanol), $[\alpha]_D^{23}$ = –13.0 (*c* = 1 in chloroform), –93.5 (*c* = 1 in pyridine); ref. 29, mp 162° (from ethanol), $[\alpha]_D^{23}$ = –93.9 (*c* = 0.52 in pyridine). [h] Input + additional. [i] Mp 147° (from ethanol), $[\alpha]_D^{23}$ = +193 (*c* = 1 in chloroform); ref. 29, mp 131-132° (from ethanol), $[\alpha]_D^{23}$ = +72.1 (*c* = 0.43 in pyridine). [j] Tris[trinitratocerium(IV)] paraperiodate, $[(NO_3)_3Ce]_3H_2IO_6$; ref. 31. [k] In addition, 50% unreacted (+)**1e** was isolated. [l] In contrast with this, under similar conditions, sulfoxide **1g** resisted any transformation.

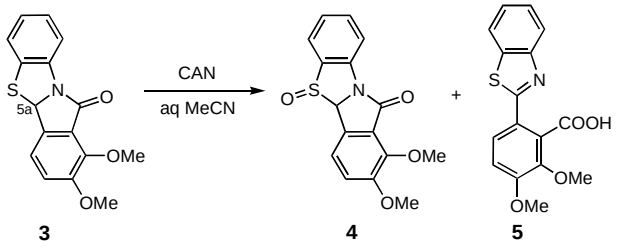
Scheme 3



methyl and 2,2-disubstituted or spiro analogs transform into 1,4-benzothiazine derivatives in a ring-expansion reaction [36a,b,37a]. Dehydrogenation of 2-substituted benzothiazoline, containing no acyl group at position 3, with 4-toluenesulfonic acid in hot ethanol is also known *via* heterolysis of the C(2)–C bond [3d]. The transformations **1**→**2** and **3**→**5** (Scheme 2-4) could be easily followed by the pmr and ir spectra due to the disappearance of S–C*H*R–N and the amide O=C–C*H*$_3$ signals and the amide band, respectively.

The reactions of some oxidizing agents with the cyclic *N*,*S*-acetals 1,3,4-thiadiazolines and benzothiazolines, show essential differences. Treatment of 3-acetyl-5-methylthiophenyl-1,3,4-thiadiazoline with 3-chloroperbenzoic acid has been reported to transform the *exo*cyclic and then the *endo*cyclic sulfur into sulfoxides [18a], or with potassium permanganate successively into the corresponding disulfone and methylsulfonylthiadiazole [18], respectively. Moreover, upon treatment with triethylamine, the disulfoxides have been transformed to 5-methylsulfinyl-2-phenyl-1,3,4-thiadiazole. In addition, 3-acyl-5-acylamino-2-phenyl-1,3,4-thiadiazoline 1-oxides, prepared with 3-chloroperbenzoic acid [19] or – in poor yields – with potassium permanganate [19a] oxidation of the corresponding sulfides, have been reported to undergo dehydrogenation by treatment with a base (pyridine or triethylamine) to give thiadiazoles [19]. Thermolysis of analog 1-oxides and 1-oxides with tertiary 5-acylamino group yields 1,3,4-oxadiazoles and 1,3,4-thiadiazoles, respectively [19]. Whereas potassium permanganate

Scheme 4



Oxidation of 3-acetylthiazolidines (**7b**,**d**,**g**,**j**), the chiral benzothiazoline (+)**1e** as well as compound **6a** [11b], by hydrogen peroxide or preferably by potassium permanganate afforded the 1,1-dioxides **7c**,**f**,**i**,**l** and **1g**. Autoxidation of *N*-chloroacetylbenzothiazoline is known to yield the corresponding 1-oxide [36b]. The preparation of similar sulfoxides with 3-chloroperbenzoic acid or sodium periodate oxidants is much more advantageous [36a]. Periodate oxidation, known to convert sulfides to

Table 2

Preparation and Properties of Thiazolidine 1-Oxides **7e**, **h**, **k** and 1,1-Dioxides **7c**, **f**, **i**, **l**

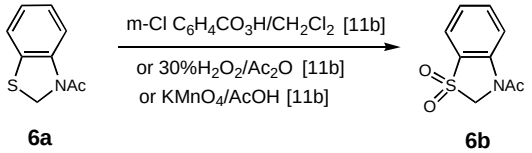
Substrate		Agent	Solvents [a]	Reaction	Workup [b]	Product	Yield [c]	Mp (°)	$[\alpha]_D^{23}$
(mmol)	$[\alpha]_D^{23}$ in $CHCl_3$ $c = 1$	(mmol)	(mL)	temp. (°) (time, h)			(%)	(solvent)	in $CHCl_3$ $c = 1$
7b [d] (0.4)	–20.3	H_2O_2 (13.2)	AcOH (4)	75 (3)	B, D	**7c**	78	170 (EtOAc/hexane)	–30.5
7d [d] (0.5)	–4.7	$NaIO_4$ (2)	2-PrOH (10) H_2O (8)	bp (3)	B, D	**7e**	62	137 (EtOAc/hexane)	+10
7d [d] (0.46)		H_2O_2 (8.8)	AcOH (4)	100 (4.5)	B, D	**7f**	67	140 (EtOAc/hexane)	–14.5
7d [d] (0.5)		$KMnO_4$ (3.75)	AcOH (10) H_2O (7)	20 (1.5)	E, B, D	**7f**	84	140 (EtOAc/hexane)	
7g [e] (0.5)	–6	$NaIO_4$ (2)	2-PrOH (10) H_2O (8)	bp (4)	B, D	**7h**	80	136 (EtOH/hexane) [f]	+12
7g [e] (1)		H_2O_2 (22)	AcOH (5)	75 (2)	B, C	**7i**	73	148 [g] (PhH/hexane)	–20.0 [e]
7g [e] (0.5)		$KMnO_4$ (3.75)	AcOH (10) H_2O (7)	23 (1)	E, B, D	**7i**	88	152 (PhH/hexane)	
7j [d] (1)	+4	$NaIO_4$ (4)	H_2O (16)	100 (3)	D [h]	**7k**	87	170 (EtOAc/hexane)	+21
7j [d] (0.5)		$KMnO_4$ (3.75)	AcOH (10) H_2O (7)	23 (0.75)	E, B, D	**7l** [i]	91	166 (EtOAc/hexane)	+7

[a] Organic solvents for the substrate, water for the oxidant. [b] For general operations of processing the reaction mixture see Experimental. [c] For the pure product, without workup of the mother liquors. [d] Ref. 32. [e] Ref. 33. [f] Anhydrous. [g] Ref. 33, mp 140-143° (from benzene with addition of petroleum ether). [h] Previously the cooled reaction mixture (a solution) was extracted with chloroform and then processed according to G. [i] An identical product was obtained from sulfone **7f** as follows: a mixture of **7f** (0.5 mmol), acetic anhydride (26.5 mmol), 4-dimethylaminopyridine (0.05 mmol), and triethylamine (1 mmol) was kept at 42° for 16 h, and then concentrated. A chloroform solution of the residue was washed with 1 N hydrochloric acid, aq. sodium hydrogencarbonate, and water, dried (magnesium sulfate) and then concentrated. Crystallization of the residue from ethyl acetate with addition of hexane afforded **7l**, mp 167-168°, in 74% yield.

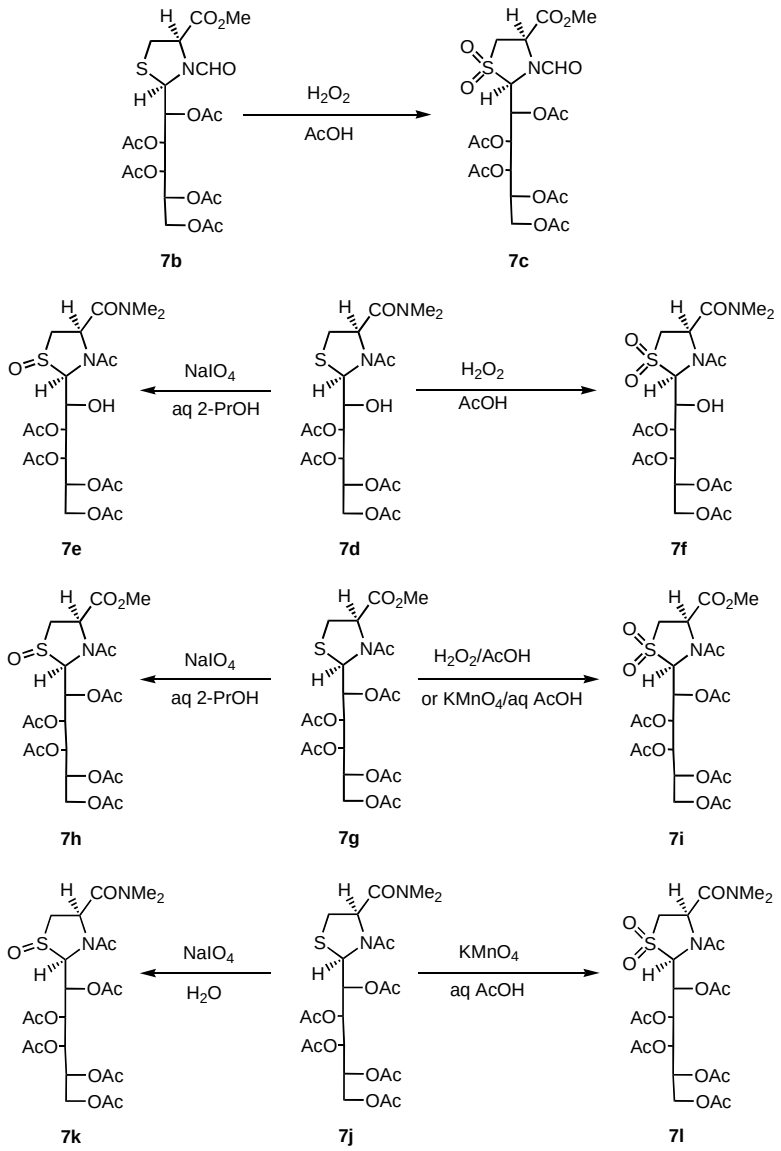
oxidation of 3-acylthiazolidines **7** (see also Table 2) and -benzothiazolines (*e.g.* **1e** or **6a**) affords the corresponding 1,1-dioxides (*e.g.* **1g**, see Experimental; or **6b**, Scheme 5) [11b], that of the 2-substituted 3-acetyl-1,3,4-thiadiazolines has been reported to give heteroaromatic thiadiazoles, *i.e.* dehydrogenation products [20]. Accordingly, a quantumchemical study of the isoelectronic furan, pyrrole, thiophene, thiazole heterocycles, as well as thiadiazoles and their mostly hypothetical sulfur-hypervalent derivatives has revealed that the thiadiazoles are aromatic compounds, with larger aromatic character than pyrrole, thiophene and furan. In contrast, the 1,3,4-thiadiazole 1-oxide or 1,1-dioxide derivatives would have a nonaromatic or antiaromatic character [21].

sulfoxides with high chemoselectivity [38], was applied to the stereoselective transformation of the chiral 3-acetylbenzothiazoline **1e** and 3-acylthiazolidines **7d**,**g**,**j** resulting the corresponding 1-oxides **1f** and **7e**,**h**,**k** (see Schemes 3, 6, Table 2 and Experimental). The stereoselective formation of sulfoxides is probably controlled by

Scheme 5



Scheme 6



steric effects of the *N*-Ac group and the C-1 and C-2 OAc groups of the chiral 2-(polyacetoxy)alkyl side chain. Upon oxidation, the C-2 chirality of these cyclic *N*,*S*-acetals was not effected, since the C-2 benzothiazoline and thiazolidine epimers would be highly laevorotatory [for (2*R*)-3-acetyl-2-[D-*galacto*-(pentaacetoxy)pentyl]-4-thiazolidinecarboxylic acid (the COOH analog of **7g**), $[\alpha]_D^{23}$ = –19.7 (*c* = 1 in chloroform) [33], for the (2*S*) diastereomer, $[\alpha]_D^{23}$ = –117.7 (*c* = 1 in chloroform) [32]]. Specific optical rotations of the sulfoxides (+)**1f** and (2*R*)-**7e**,**h**,**k** reflect the formation of a new asymmetric center (S=O) and changes in the polarity, polarizability of the cyclic *N*,*S*-acetal moiety. Configuration of the pyramidal sulfoxide moiety is stable under the conditions of the synthesis due to the back donation of an electron pair of the oxygen into a *d* orbital of the sulfur ("back bonding") [39]. Racemization at the sulfoxide moiety was observed under more vigorous conditions, at about 200°C, for acyclic benzyl and 50°C for allyl sulfoxides in the presence of strong Brönsted or Lewis acids in acetic anhydride through oxygen exchange reactions [39].

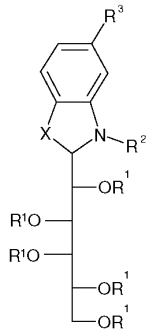
Non-stereospecific and non-stereoselective oxidation of *racemic* open-chain or cyclic sulfides may lead to the formation of *C*–epimeric sulfoxides, cyclic diastereomers preponderant with *trans* sulfoxide moiety [36a,37] (however, without any "C-2 epimerization"). Oxidative syntheses of cyclic sulfoxides have been also

Table 3
Analytical Data of Thiazolidine 1-Oxides and 1,1-Dioxides

Compound	Formula (mol. mass)	Analysis (%) Calcd./Found			
		C	H	N	S
7c	$C_{21}H_{29}NO_{15}S$	44.44	5.15	2.47	5.65
	(567.5)	44.58	5.19	2.44	5.70
7e	$C_{21}H_{32}N_2O_{12}S$	47.01	6.01	5.22	5.98
	(536.6)	47.12	6.10	5.20	5.88
7f	$C_{21}H_{32}N_2O_{13}S$	45.64	5.84	5.07	5.80
	(552.6)	45.76	5.89	5.17	5.88
7h	$C_{22}H_{31}NO_{14}S$	46.72	5.53	2.48	5.67
	(565.5)	46.84	5.60	2.44	5.58
7k	$C_{23}H_{34}N_2O_{13}S$	47.74	5.92	4.84	5.54
	(578.6)	47.86	5.98	4.89	5.47
7l	$C_{23}H_{34}N_2O_{14}S$	46.46	5.76	4.71	5.39
	(594.6)	46.28	5.79	4.86	5.40

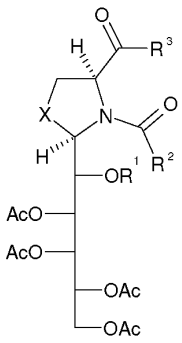
Table 4
IR Spectral Data of Sulfoxides **1f**, **7e**,**h**,**k** and Sulfones **1g**, **7c**,**f**,**l**

Compound	IR (KBr) ν (cm^{-1})
1f	1750, 1690, 1640, 1584, 1463, 1430, 1374, 1350, 1220, 1145, 1042, 960
1g	1750, 1698, 1691, 1645, 1592, 1467, 1431, 1374, 1323, 1250, 1220, 1153, 1121, 1036, 954
7c	1758, 1745, 1700, 1432, 1370, 1336, 1280, 1219, 1160, 1116, 1049, 1034, 970, 956
7e	3259, 2936, 1748, 1648, 1503, 1406, 1379, 1222, 1169, 1051, 959
7f	3281, 2983, 2939, 1750, 1650, 1430, 1392, 1371, 1330, 1257, 1212, 1143, 1121, 1042, 952
7h	2954, 2936, 1751, 1678, 1438, 1372, 1348, 1301, 1230, 1061, 1038, 956
7k	2959, 2935, 1754, 1674, 1668, 1500, 1426, 1373, 1353, 1220, 1141, 1128, 1042, 957
7l	2953, 2935, 1752, 1674, 1500, 1425, 1373, 1350, 1257, 1221, 1141, 1127, 1079, 1040, 956



1

	X	R^1	R^2	R^3
1a	S	H	H	H
1b	S	H	H	Cl
1c	S	Ac	H	H
1d	S	Ac	H	Cl
1e	S	Ac	Ac	H
1f	SO	Ac	Ac	H
1g	SO_2	Ac	Ac	H



7

	R^1	R^2	R^3	X
7a	Ac	H	OH	S
7b	Ac	H	OMe	S
7c	Ac	H	OMe	SO_2
7d	H	Me	NMe_2	S
7e	H	Me	NMe_2	SO
7f	H	Me	NMe_2	SO_2
7g	Ac	Me	OMe	S
7h	Ac	Me	OMe	SO
7i	Ac	Me	OMe	SO_2
7j	Ac	Me	NMe_2	S
7k	Ac	Me	NMe_2	SO
7l	Ac	Me	NMe_2	SO_2

reported without observing configurational isomerization [36]. Stereoselective pyrolytic cyclization of a thiosulfinate into a 2,2-disubstituted 3-acetylthiazolidine 1-oxide, with *cis* sulfoxide moiety in relation to the more bulky substituent at C-2, and into 3- acetyl-4-thiazoline has been reported [40]. The configuration of the sulfoxide group may have an effect on the conformation of the cyclic substituents [41]. Sulfoxide configuration of 1-benzothiopyrans was reported to exert an influence on the conformation of the heterocycle [42]. On the other hand, when a given ring conformation is preferred, two diastereomeric sulfoxides could have been isolated [43]. Recently, vibrational cd (vcd) [42] and "sulfoximine method" nmr investigations [44]

have been reported for configurational analysis of (benzo)sulfoxides.

CAN-mediated transformations of *N*,*O* or *S*-containing related compounds of various types described here are known [22]. Treatment with ceric salts transforms thiophenols and aromatic nitriles into 2-arylbenzothiazoles [23], sulfides into sulfoxides [24]. Treatment of 7-phenylimino-1,4-thiazepine-3-ones or 1,4-thiazepine-3,7-diones with equimolar amount of CAN has been reported to give 4-oxothiazolidine-2-acetic acid derivatives *via* ring contraction [25]. CAN, with the ability to effect selective one-electron oxidation of a susceptible heteroatom, transforms cephalosporins *via* subsequent formation of a sulfur-stabilized carbocation into 2-alkoxycephalosporins with intact cephem skeleton [26] or in a lower yield, with ring-contraction and subsequent cleavage of the lactam ring, into thiazole derivatives [27]. The intramolecular proximity of the highly electrophilic quinonoid dication moiety, generated by CAN from a 4-methoxyphenyl *N*-protecting group, has been found to effect ring cleavage of 2-substituted 3-acetylthiazolidine (at the C(2)–S bond) [28a,b] but not that of the analogous 3-acetyloxazolidine derivative (at C(2)–O) [28b]. Quite recently, *exo*cyclic C(2)–C bond fragmentation of radical cations generated by photochemical one-electron oxidation of cyclic *N*,*S*-acetals 2,2-disubstituted 3-methylbenzothiazolines to afford 2-substituted 3-methylbenzothiazolium derivatives has been accurately examined [28c]. 2,2-Disubstituted benzothiazolines with free NH group are well known to transform into 2-substituted benzothiazoles *via* C(2)–C bond cleavage [4a,28d-f].

In conclusion, we found that in the reaction between a wide variety of oxidants and cyclic *N*,*S*-acetals, the reaction route (oxidation/dehydrogenation) depends on the degree of (un)saturation and on the potential of the heterocyclic substrate for a ring-chain tautomerism as well as on the presence of an acyl group (instead of a hydrogen) at position 3. With a chiral (polyacetoxy)pentyl group at position 2 chirally substituted benzothiazolines and thiazolidine-4-carboxylic acid derivatives transform into the corresponding 1-oxides with a good chemo- and stereoselectivity.

EXPERIMENTAL

Melting points (uncorrected): Kofler block. Solutions were concentrated under reduced pressure in a rotary evaporator (<50°, bath). Tlc: Kieselgel 60 F_{254} (Merck, Alurolle). Ir (potassium bromide disks): Unicam SP-200G, Perkin-Elmer 16 PC-FT and Perkin-Elmer 283 B spectrophotometers. 200 MHz pmr: Bruker WP 200 SY instrument. Optical rotations: Schmidt-Haensch visual polarimeter (1 dm path length).

General Procedures (*cf.* Tables 1 and 2).

Ammonium Cerium(IV) Nitrate (CAN) Dehydrogenation.

To a stirred suspension/solution of the powdered substrate in acetonitrile were added powdered ammonium cerium(IV) nitrate in small portions (the proper time intervals being indicated by the change of color) and water in 3-4 portions. For reaction conditions and processing the reaction mixtures see the indications in Table 1 and the General Operations of Processing.

Tris[trinitratocerium(IV)] Paraperiodate (TTNCPP) Dehydrogenation.

A mixture of the substrate, solvent and the finely powdered oxidant was stirred as stated in Table 1. The inorganic solid was filtered off in the cold and the filtrate concentrated. The residue was crystallized.

2,3-Dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) Dehydrogenation.

A solution of the quinone and the substrate in benzene was boiled as stated in Table 1. For processing the reaction mixture see the indications in Table 1 and the General Operations of Processing.

Potassium Dichromate Dehydrogenation.

To a solution of the substrate in acetic acid was added the finely powdered oxidant with stirring. During the first two hours of reaction, water (2x0.3 mL) was added to form a homogeneous solution. For processing the reaction mixture see the indications in Table 1 and General Operations of Processing.

Potassium Permanganate Dehydrogenation/Oxidation.

To a stirred and cooled suspension of the finely powdered substrate in 99% acetic acid were added finely powdered potassium permanganate in small portions and water in 3-4 portions. For processing the reaction mixtures see the indications in Tables 1 and 2 and the General Operations of Processing.

Hydrogen Peroxide Oxidation.

To a solution or suspension of the finely powdered substrate in 99% acetic acid was added 30% hydrogen peroxide with stirring. The mixture was allowed to react as stated in Table 2. For processing the reaction mixtures see the indications in Table 2 and the General Operations of Processing.

Sodium Periodate Oxidation.

To a hot solution of the oxidant in water were added the substrate and 2-propanol (for the transformation **7j→7k** the presence of 2-propanol was superfluous). The mixture was allowed to react and then processed as stated in Table 2 and the General Operations of Processing.

General Operations of Processing the Reaction Mixtures: (see Tables 1 and 2).

(A) The product was filtered in the cold. (B) The reaction mixture was concentrated. (C) The cold residue was triturated with ice/water. (D) A solution of the product in chloroform was washed with aq. sodium hydrogencarbonate and water, dried (magnesium sulfate), and then concentrated. (E) Under ice/water cooling, to the stirred reaction mixture was added 30% hydrogen peroxide in small portions until discoloration was complete. (F) A solution of the product in chloroform was washed with aq. ammonium thiocyanate and water, dried (magnesium sulfate), and then concentrated. (G) The filtrate was concentrated. (H) The residue was separated by cc [silica gel 60; chloroform/acetone (95:5)].

(+)-2-(D-*galacto*-Pentaacetoxypentyl)-3-acetylbenzothiazoline 1-Oxide ((+)**1f**).

Procedure A.

A mixture of (+)-benzothiazoline (+)**1e** [1.079 g, 2 mmol, mp 147° (from ethanol), $[\alpha]_D^{23}$ = +193 (*c* = 1 in chloroform); [29]: mp 131-132° (from ethanol, $[\alpha]_D^{23}$ = +72.1 (*c* = 0.43 in pyridine)], periodic acid (1.711 g, 8 mmol), water (32 mL), and 2-propanol (10 mL) was boiled for 2.5 h, then cooled and diluted with water (~150 mL) to give crude (0.970 g, 87%) or recrystallized (+)**1f** (0.777 g, 70%), mp 170° (from ethyl acetate), $[\alpha]_D^{23}$ = +161 (*c* = 1 in chloroform).

Anal. Calcd. for $C_{24}H_{29}NO_{12}S$: C, 51.88; H, 5.26; N, 2.52; S, 5.77. Found: C, 51.92; H, 5.28; N, 2.58; S, 5.75. The product when crystallized from ethanol forms an ethanol solvate, mp 108°, tlc [chloroform/acetone (9:1) or ethyl acetate/methanol (9:1)] identical with the product melting at 170°.

Procedure B.

To (+)-benzothiazoline (+)**1e** (1.079 g, 2 mmol) in acetic acid (10 mL) was added 30% hydrogen peroxide (1.4 mL). The solution was kept at 40° for 18 h, then concentrated. The residue was triturated with water to give crude (1.032 g, 93%) or recrystallized (+)**1f** (0.586 g, 53%), mp 170° (from ethyl acetate), tlc identical with the sulfoxide obtained in A.

(+)-2-(D-*galacto*-Pentaacetoxypentyl)-3-acetylbenzothiazoline 1,1-Dioxide (+)**1g**.

To a solution of (+)-benzothiazoline (+)**1e** [1.079 g, 2 mmol, mp 147° (from ethanol), $[\alpha]_D^{23}$ = +193 (*c* = 1 in chloroform)] in 96% acetic acid (30 mL) was gradually added a solution of potassium permanganate (2.370 g, 15 mmol) in water (30 mL) at room temperature with stirring and occasional cooling. The reaction mixture was kept at room temperature for 1.5 h and then 30% hydrogen peroxide was added dropwise to decompose unreacted potassium permanganate. The colorless solution was concentrated and the residue triturated with water. A solution of the crude product in chloroform was washed with aq. sodium hydrogencarbonate and water, dried (magnesium sulfate), treated with charcoal, and then concentrated. The residue was crystallized from anhydrous ethanol and dried at 61°/0.1 Torr over phosphorus(V) oxide to give pure (+)**1g** (0.839 g, 73%), mp 92-94°, $[\alpha]_D^{23}$ = +23.8 (*c* = 1 in chloroform).

Anal. Calcd. for $C_{24}H_{29}NO_{13}S$: C, 50.43; H, 5.11; N, 2.45; S, 5.61. Found: C, 50.62; H, 5.14; N, 2.64; S, 5.40.

Transformation of Benzothiazoline 1-Oxide (+)**1f** into Benzothiazole **2a**.

A mixture of (+)**1f** (0.556 g, 1 mmol) and acetic anhydride (5 mL, 53 mmol) was kept at 125-128° (bath) for 3 h and then concentrated. A solution of the residue in benzene was treated with fuller's earth and charcoal and concentrated to give syrupy crude [0.271 g, 55%; tlc benzene/ethyl acetate (1:1) almost homogeneous] or crystalline benzothiazole **2a** (0.140 g, 28%), mp 132.5° (from anhydrous ethanol/hexane), identical (mp, tlc, ir) with an authentic [30] compound.

8,9-Dimethoxyisoindolo[1,2-*b*][1,3]benzothiazol-10(5a*H*)-one 5-Oxide (**4**) and 6-(2-Benzothiazolyl)-2,3-dimethoxybenzoic Acid (**5**).

Procedure A.

To a stirred suspension of finely powdered benzothiazoline lactam **3** [34] (1.497 g, 5 mmol) in acetonitrile (85 mL) were added water (5 mL) and ammonium cerium(IV) nitrate (CAN, 2.619 g, 4.777 mmol) in small portions, until the dissolution of the substrate was complete during 3.5 h, and then further 2.943 g (5.368 mmol) during 1 h. The mixture was stirred for 15 min, and then concentrated. A solution of the residue in chloroform was washed with water, dried (magnesium sulfate), and concentrated. Separation of the residue by cc [Silica-Woelm 100-200 μm; chloroform/ethyl acetate (95:5)] afforded **4** (0.159 g, 10%), mp 219° (from ethyl acetate); ir (potassium bromide): 1726, 1696, 1684, 1680, 1592, 1038 cm^{-1}; pmr (200 MHz, deuteriochloroform): δ 3.96 and 4.12 (2 s , each 3 H, 2 MeO), 5.92 (s, 1 H, 5a-H), 7.28-7.49 (m, 3 H, H-Ar; 7.26 = $CHCl_3$), 7.68-7.80 (m, 2 H, H-Ar), 7.94-7.98 (d shaped m, 1 H, 4-H-Ar).

Anal. Calcd. for $C_{16}H_{13}NO_4S$: C, 60.94; H, 4.15; N, 4.44; S, 10.17. Found: C, 60.33; H, 4.16; N, 4.38; S, 10.15. The second eluate of the cc was concentrated. The residue was triturated with some diethyl ether and hexane was added to give the amorphous acid **5** (0.378 g, 24%), an isomer of sulfoxide **4**; ir (potassium bromide): 1768, 1716, 1680, 1654, 1648, 1582, 1496, 1372 cm^{-1}; pmr (200 MHz, deuteriochloroform): δ 3.99 and 4.17 (2 s, each 3 H, 2 MeO), 7.16-7.24 (m, 2 H), 7.33-7.43 (m, 2 H), and 7.62-7.70 (m, 2 H; altogether 6 H, H-Ar).

Anal. Calcd. for $C_{16}H_{13}NO_4S$: C, 60.94; H, 4.15; N, 4.44; S, 10.17. Found: C, 61.12; H, 4.13; N, 4.15; S, 10.18.

Procedure B.

A mixture of **3** [34] (0.1497 g, 0.5 mmol), sodium periodate (0.321 g, 1.5 mmol), 2-propanol (5 mL), and water (5 mL) was boiled with stirring for 3 h and then concentrated. The residue was triturated with cold water to leave undissolved crude (0.0268 g, 17%) or recrystallized **4** (0.015 g, 9.5%), mp 215° (from ethyl acetate). The product was identical (mp, tlc, pmr) with compound **4** obtained in A by CAN oxidation.

2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-formylthiazolidine-4(*R*)-carboxylic Acid (**7a**).

Procedure A.

A mixture of 85% formic acid (1 mL, 22.1 mmol) and acetic anhydride (2 mL, 21.2 mmol), prepared at room temperature, was added in small portions under 20 min to a solution of 2(*R*)-(D-*galacto*-pentaacetoxypentyl)thiazolidine-4(*R*)-carboxylic acid [33] (0.500 g, 1.013 mmol) in anhydrous pyridine (2.5 mL, 31 mmol) with ice/salt cooling. The reaction mixture was cooled for an additional 2 h, then poured into ice-water and extracted with chloroform. The chloroform solution was washed with aq. potassium hydrogensulfate and water, dried (sodium sulfate) and concentrated. The residue was crystallized from ethyl acetate with addition of hexane to give the title compound **7a** (0.369 g, 70%), mp 174.5-175°, $[\alpha]_D^{23}$ = –13 (*c* = 1 in chloroform); ir (potassium bromide): 1740-1750 (OAc), 1670 (NCHO) cm^{-1}.

Anal. Calcd. for $C_{20}H_{27}NO_{13}S$: C, 46.06; H, 5.22; N, 2.69; S, 6.15. Found: C, 46.12; H, 5.28; N, 2.65; S, 6.11.

Procedure B.

A solution of 2(*R*)-(D-*galacto*-pentaacetoxypentyl)thiazolidine-4(*R*)-carboxylic acid [33] (1.000 g, 2.026 mmol) in 98-100% formic acid (10 mL, Merck) was warmed on a steam bath for 1 h and then concentrated. A chloroform solution of the

residue was treated with charcoal and concentrated. The residue was crystallized from ethyl acetate (2.5 mL) with addition of hexane (3 mL) to give **7a** (0.389 g, 37%), mp 147.5°, $[\alpha]_D^{23} = -14$ (*c* = 1 in chloroform).

Names of Substrates and Products Listed in Tables 1-4.

2-(D-g*alacto*-Pentaacetoxypentyl)benzothiazoline (**1c**); 2-(D-*galacto*-Pentaacetoxypentyl)-5-chlorobenzothiazoline (**1d**); 2-(D-*galacto*-Pentaacetoxypentyl)-3-acetylbenzothiazoline (**1e**); 2-(D-*galacto*-Pentaacetoxypentyl)-3-acetylbenzothiazoline 1-oxide (**1f**); 2-(D-*galacto*-Pentaacetoxypentyl)-3-acetylbenzothiazoline 1,1-dioxide (**1g**); 2-(D-*galacto*-Pentaacetoxypentyl)-benzothiazole (**2a**); 2-(D-*galacto*-Pentaacetoxypentyl)-5-chlorobenzothiazole (**2b**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-formylthiazolidine-4(*R*)-carboxylic acid methyl ester (**7b**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-formylthiazolidine-4(*R*)-carboxylic acid methyl ester 1,1-dioxide (**7c**); 2(*R*)-(D-*galacto*-2,3,4,5-Tetraacetoxy-1-hydroxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid dimethylamide (**7d**); 2(*R*)-(D-*galacto*-2,3,4,5-Tetraacetoxy-1-hydroxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid dimethylamide 1-oxide (**7e**); 2(*R*)-(D-*galacto*-2,3,4,5-Tetraacetoxy-1-hydroxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid dimethylamide 1,1-dioxide (**7f**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid methyl ester (**7g**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid methyl ester 1-oxide (**7h**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid methyl ester 1,1-dioxide (**7i**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid dimethylamide (**7j**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid dimethylamide 1-oxide (**7k**); 2(*R*)-(D-*galacto*-Pentaacetoxypentyl)-3-acetylthiazolidine-4(*R*)-carboxylic acid dimethylamide 1,1-dioxide (**7l**).

Acknowledgements.

The author thanks Mrs. Katalin Tréfás for the microanalyses and recording the ir spectra, Mme. Sára Balla and Mrs. Éva Józsa for recording the nmr spectra. Grants from the Hungarian Scientific Research Fund (OTKA T025016 and T037201) for this work are also gratefully acknowledged.

REFERENCES AND NOTES

[1] Part I: L. Somogyi, *Heterocycles*, **63**, 2243 (2004).

[2] F. J. Goetz, *J. Heterocycl. Chem.*, **4**, 80 (1967).

[3a] H. P. Lankelma and P. X. Sharnoff, *J. Am. Chem. Soc.*, **53**, 2654 (1931); [b] W. S. Emerson and T. M. Patrick, Jr., *J. Org. Chem.*, **14**, 790 (1949); [c] T. Suzuki, H. Miyamatsu, S. Ueno, M. Shimizu and J. Wada, *Yakugaku Zasshi*, **94**, 891 (1974); *Chem. Abstr.*, **81**, 136037x (1974); [d] T. Ogawa, K. Tomisawa and K. Sota, *Chem. Pharm. Bull.*, **36**, 1957 (1988).

[4a] J. L. Corbin and D. E. Work, *Can. J. Chem.*, **52**, 1054 (1974); [b] T. Itoh, K. Nagata, M. Miyazaki and A. Oshawa, *Heterocycles*, **52**, 1037 (2000); [c] X.-F. He, C. M. Vogels, A. Decken and S. A. Westcott, *Can. J. Chem.*, **81**, 861 (2003); [d] K. Yamamoto, M. Fujita, K. Tabashi, Y. Kawashima, E. Kato, M. Oya, T. Iso and J.-i. Iwao, *J. Med. Chem.*, **31**, 919 (1988); [e] Q. Chen and M. Chen, *Phosphorus, Sulfur Silicon Relat. Elem.*, **68**, 205 (1992); [f] T. Itoh, K. Nagata, H. Ishikawa and A. Ohsawa, *Heterocycles*, **62**, 197 (2004).

[5a] S. Tagami, C. Tabuchi, K. Morimoto and D. Shiho, *Yakugaku Zasshi*, **94**, 929 (1974); *Chem. Abstr.*, **82**, 43264z (1975); [b] A. Ben-Alloum, S. Bakkas and M. Soufiaoui, *Tetrahedron Lett.*, **38**, 6395 (1997).

[6a] F. J. Goetz, *J. Heterocycl. Chem.*, **5**, 501 (1968); [b] F. J. Goetz, *J. Heterocycl. Chem.*, **5**, 509 (1968); [c] L. F. Capitán-Vallvey and P. Espinosa, *Polyhedron*, **2**, 1147 (1983); [d] F. Fülöp, J. Mattinen and K. Pihlaja, *Tetrahedron*, **46**, 6545 (1990).

[7] L. Sattler, F. W. Zerban, G. L. Clark and Chia-Chen Chu, *J. Am. Chem. Soc.*, **73**, 5908 (1951).

[8] P. G. Sammes, *Chem. Rev.*, **76**, 113 (1976).

[9a] T. Durst, in Comprehensive Organic Chemistry, The Synthesis and Reactions of Organic Compounds, D. Barton and W. D. Ollis, eds, Vol **3**, D. N. Jones, ed, Pergamon Press, Oxford, 1979, pp 121-156 and 157-170; [b] S. Uemura, in Comprehensive Organic Synthesis, B. M. Trost and I. Fleming, eds, Vol **7**, S. V. Ley, ed, Pergamon Press, Oxford, 1993, pp 757-787; [c] E. G. Mata, *Phosphorus, Sulfur Silicon Relat. Elem.*, **117**, 231 (1996); [d] C. M. Rayner, *Contemp. Org. Synth.*, **3**, 499 (1996); [e] I. A. Abu-Yousef and D. N. Harpp, *Sulfur Rep.*, **20**, 1 (1997); [f] W. S. Jenks, D. D. Gregory, Y. Guo, W. Lee and T. Tetzlaff, *Mol. Supramol. Photochem.*, **1** (Organic Photochemistry), Marcel Dekker, Inc., 1997, pp 1-56; [g] J. Nakayama and Y. Sugihara, *Sulfur Rep.*, **19**, 349 (1997); [h] H. B. Kagan and P. Diter, *Organosulfur Chem.*, **2**, 1 (1998); [i] E. Juaristi and M. Ordonez, *Organosulfur Chem.*, **2**, 63 (1998); [j] S. M. Allin, S. J. Shuttleworth and P. C. Bulman Page, *Organosulfur Chem.*, **2**, 97 (1998); [k] A. D. Westwell and C. M. Rayner, *Organosulfur Chem.*, **2**, 157 (1998); [l] C. P. Baird and C. M. Rayner, *J. Chem. Soc., Perkin Trans. I*, 1973 (1998); [m] D. J. Procter, *J. Chem. Soc., Perkin Trans. I*, 641 (1999), 835 (2000), 335 (2001); [n] H. B. Kagan, Catal. Asymmetric Synth., 2nd Ed, I. Ojima, ed, Wiley-VCH, New York, N. Y., 1999 (Pub. 2000), pp 327-356; *Chem. Abstr.*, **134**, 340123q (2001).

[10] S. Ratner and H. T. Clarke, *J. Am. Chem. Soc.*, **59**, 200 (1937).

[11a] J. C. Sheehan and J. J. Ryan, *J. Am. Chem. Soc.*, **73**, 4367 (1951); [b] L. Somogyi, *Z. Naturforsch.*, **37B**, 838 (1982).

[12] W. J. Evans and S. Smiles, *J. Chem. Soc.*, 1263 (1935).

[13a] S. Boehler, K. Wagner and K. H. Baessler, *Infusionstherapie*, **16**, 82 (1989); *Chem. Abstr.*, **111**, 131357e (1989); [b] M. Groarke, M. A. McKervey, H. Moncrieff and M. Nieuwenhuyzen, *Tetrahedron Lett.*, **41**, 1279 (2000); [c] X. Fernandez, R. Fellous, L. Lizzani-Cuvelier, M. Loiseau and E. Duñach, *Tetrahedron Lett.*, **42**, 1519 (2001).

[14a] F. Asinger, M. Thiel and L. Schroeder, *Justus Liebigs Ann. Chem.*, **610**, 49 (1957); [b] F. Asinger, H. Diem and A. Sin-Gun, *Justus Liebigs Ann. Chem.*, **643**, 186 (1961); [c] M. A. Barton, G. W. Kenner and R. C. Sheppard, *J. Chem. Soc. C*, 1061 (1966); [d] J. Walker, *J. Chem. Soc. C*, 1522 (1968); [e] M. Matsui, Y. Yamada, M. Takahashi and N. Seki (Godo Shusei Co., Ltd.), Japan. 73 08, 100, 12 (Mar. 1973); *Chem. Abstr.*, **79**, 92205c (1973); [f] P. Dubs and M. Pesaro, *Synthesis*, 294 (1974); [g] T. H. Kim, J. K. Min and G.-J. Lee, *Tetrahedron Lett.*, **40**, 8201 (1999); corrigendum, **42**, 2413 (2001); [h] T. K. Ritter and C.-H. Wong, *Tetrahedron Lett.*, **42**, 615 (2001); [i] T. I. El-Emary, R. A. Ahmed and E. A. Bakhite, *J. Chin. Chem. Soc. Taipei*, **48**, 921 (2001); *Chem. Abstr.*, **136**, 279294u (2002); [j] I. Abrunhosa, M. Gulea, J. Levillain and S. Masson, *Tetrahedron: Asymmetry*, **12**, 2851 (2001); [k] S. G. Mahler, G. L. Serra, D. Antonow and E. Manta, *Tetrahedron Lett.*, **42**, 8143 (2001); [l] P. Molina, A. Tarraga and D. Curiel, *Synlett*, 435 (2002); [m] B. Liu, R. Davis, B. Joshi and D. W. Reynolds, *J. Org. Chem.*, **67**, 4595 (2002); [n] M. J. Miller and J. Hu (University of Notre Dame du Lac, USA) U. S. US 6, 403, 623 (11 Jun. 2002); *Chem. Abstr.*, **137**, 20368b (2002); [o] M. Tiecco, L. Testaferri, C. Santi, C. Tomassini, F. Marini, L. Bagnoli and A. Temperini, *Tetrahedron: Asymmetry*, **13**, 429 (2002).

[15a] E. H. White, F. McCapra, G. F. Field and W. D. McElroy, *J. Am. Chem. Soc.*, **83**, 2402 (1961); [b] N. A. Fuller and J. Walker, *J. Chem. Soc. C*, 1526 (1968).

[16a] M. Iwakawa, Y. Kobayashi, S. Ikuta and J. Yoshimura, *Chem. Lett.*, 1975 (1982); [b] Y. Hamada, M. Shibata, T. Sugiura, S.

Kato and T. Shioiri, *J. Org. Chem.*, **52**, 1252 (1987); [c] S. Mensching and M. Kalesse, *J. Prakt. Chem./Chem.-Ztg.*, **339**, 96 (1997); [d] M. Dzurilla, P. Kutschy, J. Zaletova, M. Ruzinsky and V. Kovacik, *Molecules*, **6**, 716 (2001); *Chem. Abstr.*, **136**, 118610d (2002); [e] X. Fernandez and E. Duñach, *Tetrahedron: Asymmetry*, **12**, 1279 (2001).

[17a] D. K. Minster, U. Jordis, D. L. Evans and S. M. Hecht, *J. Org. Chem.*, **43**, 1624 (1978); [b] D. L. Evans, D. K. Minster, U. Jordis, S. M. Hecht, A. L. Mazzu Jr. and A. I. Meyers, *J. Org. Chem.*, **44**, 497 (1979).

[18a] S. Kubota, K. Toyooka, M. Shibuya and Z. Taira, *J. Chem. Soc., Perkin Trans. I*, 1357 (1986); [b] S. Kubota, K. Toyooka, J. Ikeda, N. Yamamoto and M. Shibuya, *J. Chem. Soc., Perkin Trans. I*, 967 (1983).

[19a] S. Kubota, K. Toyooka, N. Yamamoto, M. Shibuya and M. Kido, *J. Chem. Soc., Chem. Commun.*, 901 (1982); [b] S. Kubota, K. Toyooka, N. Yamamoto, T. Kasai and M. Shibuya, *Heterocycles*, **24**, 21 (1986).

[20] S. Kubota, Y. Ueda, K. Fujikane, K. Toyooka and M. Shibuya, *J. Org. Chem.*, **45**, 1473 (1980).

[21a] R. Zahradnik and J. Koutecky, *Collect. Czech. Chem. Commun.*, **26**, 156 (1961); [b] P. Friedman and K. F. Ferris, *J. Mol. Struct. Theochem*, **418**, 119 (1997); [c] D. Glossman-Mitnik, *THEOCHEM*, **549**, 285 (2001).

[22] J. R. Hwu and K.-Y. King, *Curr. Sci.*, **81**, 1043 (2001), and references cited therein.

[23] R. H. Tale, *Org. Letters*, **4**, 1641 (2002).

[24a] D. P. Riley and P. E. Correa, *J. Chem. Soc., Chem. Commun.*, 1097 (1986); [b] D. P. Riley, M. R. Smith and P. E. Correa, *J. Am. Chem. Soc.*, **110**, 177 (1988); [c] M. H. Ali, D. R. Leach and C. E. Schmitz, *Synth. Commun.*, **28**, 2969 (1998).

[25] B. Zaleska and Cież, *Synlett*, 1831 (2000).

[26] D. C. Humber and S. M. Roberts, *Synth. Commun.*, **15**, 681 (1985).

[27] R. A. Fletton, D. C. Humber, S. M. Roberts and J. L. Wright, *Spec. Publ. – R. Soc. Chem. (Recent Adv. Chem. β-Lactam Antibiot.)*, **52**, 342 (1985); *Chem. Abstr.*, **107**, 39474k (1987).

[28a] F. Bertha, J. Feller, M. Kajtár-Peredy, G. M. Keserü, K. Lempert, L. Párkányi and J. Tamás, *Tetrahedron*, **49**, 7803 (1993); [b] A. Sápi, F. Bertha, J. Feller, M. Kajtár-Peredy, G. M. Keserü and K. Lempert, *Tetrahedron*, **52**, 771 (1996); [c] D. Shukla, G. Liu, J. P. Dinnocenzo and S. Farid, *Can. J. Chem.*, **81**, 744 (2003); [d] R. C. Elderfield and E. C. McClenachan, *J. Am. Chem. Soc.*, **82**, 1982 (1960); [e] G. Trapani, A. Latrofa, A. Reho and G. Liso, *J. Heterocycl. Chem.*, **26**, 721 (1989); [f] M. Sako, R. Totani, T. Niwa, K. Hirota and Y. Maki, *J. Chem. Soc., Perkin Trans. I*, 915 (1990).

[29] R. Bognár, Z. Kolodynska, L. Somogyi, Z. Györgydeák, L. Szilágyi and É. N. Nemes, *Acta. Chim. Acad. Sci. Hung.*, **62**, 65 (1969).

[30] R. Bognár, I. Farkas, L. Szilágyi, M. Menyhárt, É. N. Nemes and I. F. Szabó, *Acta Chim. Acad. Sci. Hung.*, **62**, 179 (1969).

[31] H. Firouzabadi, N. Iranpoor, G. Hajipoor and J. Toofan, *Synth. Commun.*, **14**, 1033 (1984).

[32] R. Bognár, Z, Györgydeák, L. Szilágyi and L. Somogyi, *Justus Liebigs Ann. Chem.*, 1637 (1975).

[33] R. Bognár, L. Somogyi and Z. Györgydeák, *Justus Liebigs Ann. Chem.*, **738**, 68 (1970).

[34] L. Somogyi, *Liebigs Ann. Chem.*, 657 (1985).

[35a] R. A. Aitken, D. P. Armstrong, R. H. B. Galt and S. T. E. Mesher, *J. Chem. Soc., Perkin Trans. I*, 935 (1997); [b] R. A. Aitken, S. T. E. Mesher, F. C. Ross and B. M. Ryan, *Synthesis*, 787 (1997).

[36a] M. Hori, T. Kataoka, H. Shimizu and Y. Imai, *Heterocycles*, **10**, 17 (1978); [b] M. Hori, T. Kataoka, H. Shimizu and Y. Imai, *Chem. Pharm. Bull.*, **27**, 1982 (1979); [c] T. Takata, K. Ishibashi and W. Ando, *Tetrahedron Lett.*, **26**, 4609 (1985); [d] T. Akasaka, A. Sakurai and W. Ando, *J. Am. Chem. Soc.*, **113**, 2696 (1991).

[37a] F. Chioccara, L. Oliva and G. Prota, *Synthesis*, 744 (1978); [b] H. D. Mah and W. S. Lee, *J. Heterocycl. Chem.*, **26**, 1447 (1989); [c] W. S. Lee, K. D. Nam, H.-G. Hahn and H. D. Mah, *J. Heterocycl. Chem.*, **30**, 1105 (1993); [d] H.-G. Hahn, K. D. Nam and H. D. Mah, *J. Heterocycl. Chem.*, **36**, 271 (1999); [e] S. Raghavan, S. R. Reddy, K. A. Tony, Ch. N. Kumar, A. K. Varma and A. Nangia, *J. Org. Chem.*, **67**, 5838 (2002).

[38] N. J. Leonard and C. R. Johnson, *J. Org. Chem.*, **27**, 282 (1962).

[39] S. Oae, in Organic Chemistry of Sulfur, S. Oae, ed, Plenum Press, New York and London, 1977, pp 383-471.

[40] H. Mah, K. D. Nam and H.-G. Hahn, *Heterocycles*, **45**, 1999 (1997).

[41] D. Crich, J. Mataka, L. N. Zakharov, A. L. Rheingold and D. J. Wink, *J. Am. Chem. Soc.*, **124**, 6028 (2002).

[42a] F. J. Devlin, P. J. Stephens, P. Scafato, S. Superchi and C. Rosini, *Tetrahedron: Asymmetry*, **12**, 1551 (2001); [b] F. J. Devlin, P. J. Stephens, P. Scafato, S. Superchi and C. Rosini, *Chirality*, **14**, 400 (2002); *Chem. Abstr.*, **137**, 179094f (2002).

[43] A. C. Bényei and L. Somogyi, *Phosphorus, Sulfur and Silicon*, **143**, 191 (1998).

[44] T. Kusumi, *Kagaku to Seibutsu*, **39**, 569 (2001); *Chem. Abstr.*, **135**, 238694k (2001).