Stereochemistry of 1,3-diheterocyclanes
4.* Molecular and crystal structures of monosubstituted five-membered cyclic sulfites

A. A. Bredikhin, A. T. Gubaidullin, D. B. Krivolapov, Z. A. Bredikhina, and I. A. Litvinov*

A. E. Arbuzov Institute of Organic and Physical Chemistry, Kazan Research Center of the Russian Academy of Sciences, 8 ul. Akad. Arbuzova, 420088 Kazan, Russian Federation.
Fax: +7 (843 2) 75 2253. E-mail: baa@iopc.kcn.ru

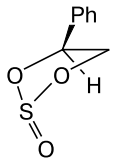
Racemic and enantiopure *cis*- and *trans*-4-(1-naphthyloxy)methyl-2-oxo-1,3,2-dioxathiolanes were studied by X-ray diffraction. The factors responsible for their crystal packings were revealed. The conformation of the exocyclic fragment varies from synclinal to antiperiplanar depending on both the local (*cis*—*trans* isomerism of the molecule) and external (homochiral/heterochiral environment) stereochemical factors. Data on the structures of five-membered sulfites in crystals were generalized. It was concluded that the heterocycle has considerable conformational flexibility.

Key words: cyclic sulfites, 1,3,2-dioxathiolanes, chirality, X-ray diffraction analysis, conformational analysis, crystal packing.

Cyclic sulfites are widely used in modern organic chemistry. The chemistry and numerous synthetic applications of these compounds have been summarized in sufficient detail in the reviews.[2,3] However, the three-dimensional structures of cyclic sulfites, particularly, of five-membered sulfites, are poorly studied. Although the conformations of 1,3,2-dioxathiolanes were formally discussed in the review[2] and monographs,[4,5] the data are either scarce and/or are based on the results obtained by indirect structural methods, where numerous (not always justified) assumptions are used.

Direct structural analysis of cyclic sulfites by electron diffraction presents difficulty[5] because these molecules are relatively compact and contain many nearly equal interatomic distances, resulting in a strong correlation between the geometric and vibrational parameters. Taking into account this fact, the conclusion about the planar five-membered ring in the ethylenesulfite (2-oxo-1,3,2-dioxathiolane) molecule, which has been drawn in the early electron diffraction study,[6] seems to be not rigorous.

Many structural aspects of 1,3,2-dioxathiolanes could be elucidated by X-ray diffraction analysis. However, the simplest molecules of this class remained virtually unstudied by this direct method. In the Cambridge Structural Database,[7] data on unsubstituted dioxathiolane are lacking. Only one *trans*-monosubstituted five-membered cyclic sulfite and one *cis*-monosubstituted sulfite, *viz.*, (2*S*,4*S*)-2-oxo-4-phenyl-1,3,2-dioxathiolane (**1**)[8] and (2*S*,4*S*)-2-oxo-4-[(1*R*)-1-chloro-1-phenylmethyl]-1,3,2-dioxathiolane (**2**), respectively,[9] were described.



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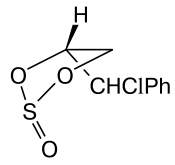

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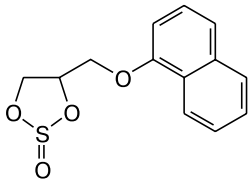
The generalization needs further extension of this series. Besides, chiral (like all monosubstituted dioxathiolanes) compounds **1** and **2** were studied only in enantiomerically pure form, *i.e.*, it was impossible to compare the structural characteristics of the molecules in crystals of racemic and enantiopure samples.

In the present study, particular attention has been given to stereoisomeric 4-(1-naphthyloxymethyl)-2-oxo-1,3,2-dioxathiolanes (**3**), which have been used earlier (as a mixture of diastereomers) for the synthesis of the drug propranolol.[10—12]



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Samples of individual diastereomers *cis*- and *trans*-**3** were prepared and studied by X-ray diffraction both in the

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racemic and scalemic forms. It was found that there are two independent molecules per asymmetric unit in the crystal structure of *rac*-**3** (both *cis* and *trans*). Consequently, we had data on the structures of six molecules of monosubstituted five-membered cyclic sulfites. In addition, we refined the experimental X-ray diffraction characteristics of the crystal structure of **2** obtained in our earlier study[9] with the use of the SHELX-97 program package. The improved structural parameters of this nonracemic sulfite and the published data for molecule **1** together with the new information are discussed below.

Experimental

The optical rotation was measured on a Perkin—Elmer 341 polarimeter.

(2*RS*,4*R*)-4-(1-Naphthyloxy)methyl-2-oxo-1,3,2-dioxathiolanes ((2*RS*,4*R*)-3). A mixture of diastereomeric (2*R*,4*R*)- and (2*S*,4*R*)-4-(1-naphthyloxy)methyl-2-oxo-1,3,2-dioxathiolanes ((2*RS*,4*R*)-**3**) was prepared from (*S*)-glycidol, $SOCl_2$, and α-naphthol.[12] Column chromatography (silica gel, μ 40/100, 200×20 mm column, heptane—CH_2Cl_2 as the eluent) of this mixture (0.68 g) afforded (2*S*,4*R*)-**3** (*scal-cis*-**3**) in a yield of 0.19 g, R_f 0.43 (CH_2Cl_2), m.p. 97—99 °C, $[\alpha]_D^{20}$ −1.2 (*c* 1.56, CH_2Cl_2) (*cf.* lit. data[12]: m.p. 97—99 °C, $[\alpha]_D^{20}$ −0.5 (*c* 0.43, CH_2Cl_2)) and (2*R*,4*R*)-**3** (*scal-trans*-**3**) in a yield of 0.22 g, R_f 0.32 (CH_2Cl_2), m.p. 68—69 °C, $[\alpha]_D^{20}$ +24.4 (*c* 0.93, CH_2Cl_2) (*cf.* lit. data[12]: $[\alpha]_D^{20}$ +24.2 (*c* 0.46, CH_2Cl_2)). Analogously, the reaction with the use of racemic glycidol produced racemic dioxathiolanes (2*RS*,4*SR*)-**3** (*rac-cis*-**3**), m.p. 88—89 °C, and (2*RS*,4*RS*)-**3** (*rac-trans*-**3**), m.p. 72—73 °C. The spectroscopic characteristics of the resulting sulfites are completely identical to those described earlier.[12]

X-ray diffraction study of compounds 3 was carried out on an automated four-circle Enraf-Nonius CAD-4 diffractometer at 20 °C (Mo-Kα radiation for *scal-cis*-**3** and Cu-Kα radiation for three other samples, ω/2θ-scanning technique, variable θ-scan rate was 1—16.4 deg min^{-1}). The intensities of check reflections showed no decrease in the course of X-ray data collection, and no absorption correction was applied. The structures were solved by direct methods using the SIR program[13] and refined first isotropically and then anisotropically with the use of the SHELX-97 program package.[14] The coordinates of the hydrogen atoms were calculated based on the stereochemical criteria and refined using a riding model. All calculations were carried out with the use of the MolEN [15] and WinGX programs.·[16] Intermolecular contacts, including hydrogen bonds in the crystal structures, were analyzed with the use of the PLATON program.[17] The absolute configurations of the molecules in the crystals of *scal-trans*-**3** and *scal-cis*-**3** were determined by Flack's method.[18] The crystal structures of *rac-trans*-**3** and *rac-cis*-**3** contain two independent molecules (A and B) adopting different configurations per asymmetric unit. The unit cell parameters, details of X-ray data collection, and results of structure refinement are given in Table 1.

X-ray diffraction data for compounds *scal-trans*-**3**, *scal-cis*-**3**, *rac-trans*-**3**, and *rac-cis*-**3** were deposited with the Cambridge Structural Database (refcodes CCDC 296478, 296479, 296480, and 296481, respectively).

Results and Discussion

Conformation of the dioxathiolane ring

The overall views of the molecular structures of compounds **3** in the crystalline phase are shown in Fig. 1. Hereinafter, the prefixes *cis* and *trans* are used instead of the rigorous but not always clear Cahn—Ingold—Prelog *R*/*S* nomenclature to denote the relative configurations of the S(2) and C(4) atoms, the macroscopic character of the sample being indicated by the additional prefixes *rac* and *scal* (racemic and scalemic, respectively). It is more convenient to compare the structural information in series of compounds when considering the heterocycle in the same orientation. For this purpose, Tables 2 and 3 give data for the molecules with the *R* configuration of the sulfur atom. In racemic samples, these molecules exist in reality. If the present or cited[8,9] studies dealt with scalemic samples represented by another enantiomer, the tables list the experimental characteristics of the scalar structural parameters (bond lengths and bond angles) for the enantiomer under study, whereas the vector characteristics (torsion angles) in the tables retain the original magnitudes but have the opposite sign.

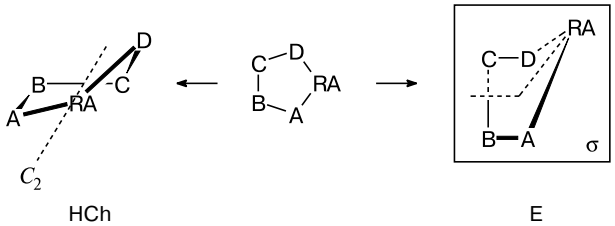
Table 2 lists principal structural characteristics of the dioxathiolane fragment in all eight molecules under study. The last column gives the averaged (after discarding the largest and smallest values) bond lengths and bond angles in the heterocycle. On the whole, the bond lengths and bonds angles in the individual molecules differ only slightly (within experimental errors) from the average values. Hence, the average geometry of monosubstituted five-membered cyclic sulfites can be considered. The average parameters describe the structure characterized by high pyramidality of the fragment adjacent to the sulfur atom, which is typical of three-coordinate derivatives.[5] The sum of the average bond angles about the S(2) atom is only 309.7°. The average O(1)—S(2)—O(3) bond angle (92.9°) is close to the right angle. The presence of the substituent leads to a substantial difference in the O(1)—S(2), O(3)—S(2) and O(1)—C(5), O(3)—C(4) bond lengths, which are symmetrical in the unsubstituted ring. The presence of the substituent also influences, although to a lesser degree, the analogous pairs of the O(1)—S(2)—O(2) and O(2)—S(2)—O(3), C(5)—O(1)—S(2) and S(2)—O(3)—C(4), O(3)—C(4)—C(5) and C(4)—C(5)—O(1) bond angles.

The conformations of the heterocycle in sulfites **1—3** are completely described by the endocyclic torsion angles τ given in Table 2. However, the conformations of the five-membered rings are commonly analyzed at the qualitative level in terms of the limiting structures, such as a half-chair (HCh) and an envelope (E). In the case of cyclopentane, these structures (more exactly, families of 10 degenerate HCh and 5 degenerate E) are clearly dis-

Table 1. Crystallographic parameters of compounds *scal-trans*-**3**, *scal-cis*-**3**, *rac-trans*-**3**, and *rac-cis*-**3** and details of X-ray diffraction study

Parameter	*scal-trans*-**3**	*scal-cis*-**3**	*rac-trans*-**3**	*rac-cis*-**3**
Color, shape	Colorless, prismatic			
Molecular formula	$C_{13}H_{12}O_4S$	$C_{13}H_{12}O_4S$	$C_{13}H_{12}O_4S$	$C_{13}H_{12}O_4S$
Molecular weight	264.29	264.29	264.29	264.29
Crystal system	Orthorhombic	Orthorhombic	Triclinic	Triclinic
Space group	$P2_12_12_1$	$P2_12_12_1$	$P\bar{1}$	$P\bar{1}$
Unit cell parameters[3]				
a/Å	9.462(7)	5.422(6)	7.061(2)	6.431(6)
b/Å	5.344(3)	11.029(1)	8.253(6)	9.56(1)
c/Å	25.03(2)	20.693(2)	21.615(5)	20.06(2)
α/deg	—	—	97.40(4)	85.75(8)
β/deg	—	—	91.38(2)	82.68(8)
γ/deg	—	—	97.87(3)	90.00(9)
V/Å^3	1265.6(2)	1237.4(1)	1236.2(1)	1219.0(2)
Z	4	4	4	4
K	65.3	67.3	67.5	68.8
ρ_{calc}/g cm^{-3}	1.38	1.42	1.42	1.44
μ/cm^{-1}	23.3	2.6	23.8	24.2
F(000)	552	552	552	552
Radiation (λ/Å)	Cu-Kα (1.54184)	Mo-Kα (0.71073)	Cu-Kα (1.54184)	Cu-Kα (1.54184)
θ Scan range	$3.53 \le \theta \le 56.96$	$2.70 \le \theta \le 26.3$	$5.46 \le \theta \le 57.2$	$3.16 \le \theta \le 74.33$
Scan angle	$0.53 + 0.36 \cdot tg\theta$	$0.68 + 0.4 \cdot tg\theta$	$0.53 + 0.36 \cdot tg\theta$	$0.53 + 0.36 \cdot tg\theta$
Standard reflections	Two check reflections distributed in orientation and three check reflections distributed in intensity after each 200 reflections			
Ranges of measured indices	$-9 \le h \le 7$ $-4 \le k \le 5$ $-27 \le l \le 24$	$0 \le h \le 6$ $0 \le k \le 13$ $-25 \le l \le 0$	$-7 \le h \le 6$ $0 \le k \le 8$ $-23 \le l \le 23$	$-6 \le h \le 6$ $-10 \le k \le 9$ $-19 \le l \le 19$
Number of measured reflections	2572	1506	3272	5406
Number of observed reflections with $I > 2\sigma(I)$	852	876	2492	768
Flack's parameter	0.15(6)	0.2(2)	—	—
Final R factors				
R	0.079	0.040	0.049	0.072
R_w	0.17	0.084	0.130	0.131
GOOF	1.067	1.007	1.043	0.901
Δ/σ	0.002	0.000	0.001	0.000
Number of parameters in refinement	164	163	325	302
Number of independent reflections	1251	1456	2952	2515

tinguished by the symmetry and belong to the point groups $\boldsymbol{C}_2$ (HCh) and $\boldsymbol{C}_s$ (E). It should be noted that the symmetry element, *viz.*, the axis C_2 or the plane σ, in each limiting conformer passes through the only atom thus differentiating it from all other atoms. Let us call this atom the reference atom (RA).



HCh E

A loss of the strict symmetry leads to removal of degeneration in the HCh and E families. However, the explicit indication of the reference atom, through which the symmetry element passes in the prototype molecule (cyclopentate) adopting an analogous conformation, would suffice to unambiguously determine which particular half-chair or envelope exists. A lowering of the symmetry makes it difficult to assign the conformers to a particular prototype (family). In the ideal half-chair, two torsion angles, in which the reference atom is terminal, *viz.*, τ(RA—A—B—C) and τ(RA—D—C—B), are equal both in the magnitude and sign. Let us assume that the half-chair conformation is such in which there are two angles identical in sign and different by less than 5°. Analo-

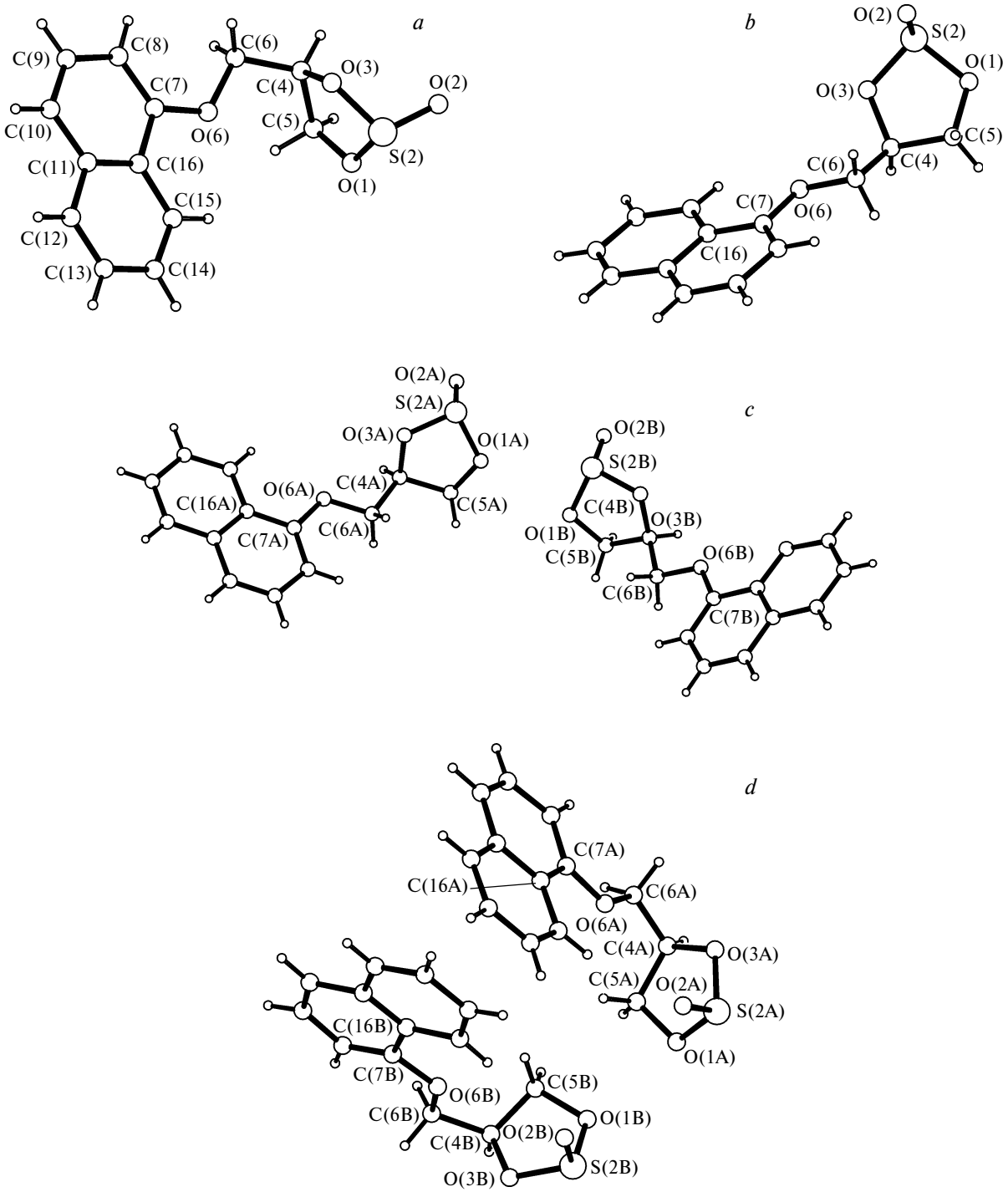


Fig. 1. Geometry of molecules **3** in the crystals: *a*, *scal-trans*-**3**; *b*, *scal-cis*-**3**; *c*, *rac-trans*-**3**; *d*, *rac-cis*-**3**.

gously, the envelope conformation is such in which the torsion angle formed by four successive atoms, excluding the reference atom, *i.e.*,. τ(A—B—C—D), is smaller than 5° in magnitude (in the ideal envelope, this angle is equal to zero). In this case, the reference atom and the symbol of the family, HCh or E, would suffice to identify a particular conformation (correct to the signs of the torsion angles). For example, as can be seen from Table 2, there are no zero torsion angles in the dioxathiolane fragment of molecule *scal-trans*-**3**. The S(2)—O(3)—C(4)—C(5) and C(5)—O(1)—S(2)—O(3) torsion angles have the same sign and differ in magnitude by ~3°. This conformation can be assigned to half-chairs with the C(5) reference atom and is denoted (C(5))-HCh.

Table 2. Selected geometric parameters of the 1,3,2-dioxathiolane ring in compounds **3**

Parameter	*scal-trans*-**1***	*scal-cis*-**2**	*scal-trans*-**3**	*scal-cis*-**3**	*rac-trans*-**3A**	*rac-trans*-**3B**	*rac-cis*-**3A**	*rac-cis*-**3B**	I**
Bond					Bond length/Å				
S(2)=O(2)	1.431	1.442(4)	1.386(7)	1.416(3)	1.425(3)	1.426(3)	1.48(1)	1.48(1)	1.436
O(1)—S(2)	1.634	1.609(4)	1.513(9)	1.600(4)	1.598(3)	1.606(3)	1.575(9)	1.628(8)	1.595
S(2)—O(3)	1.600	1.593(4)	1.539(7)	1.601(3)	1.595(3)	1.585(3)	1.607(8)	1.609(8)	1.597
O(3)—C(4)	1.472	1.452(5)	1.47(1)	1.450(4)	1.446(4)	1.462(4)	1.46(1)	1.50(1)	1.463
C(4)—C(5)	1.510	1.490(6)	1.50(1)	1.510(6)	1.512(5)	1.512(5)	1.48(2)	1.48(2)	1.502
C(5)—O(1)	1.407	1.433(5)	1.36(1)	1.426(5)	1.426(4)	1.382(5)	1.47(1)	1.41(1)	1.409
Bond angle					φ/deg				
O(1)—S(2)—O(2)	105.5	106.7(3)	113.1(6)	109.7(2)	109.9(2)	108.7(2)	110.4(6)	108.8(6)	109.2
O(2)—S(2)—O(3)	109.8	105.8(2)	109.6(4)	106.8(2)	107.4(2)	108.0(2)	106.8(6)	107.1(6)	107.6
O(1)—S(2)—O(3)	93.6	92.7(2)	92.4(4)	93.8(2)	92.6(1)	92.7(1)	92.7(5)	92.9(5)	92.9
S(2)—O(3)—C(4)	111.2	112.5(3)	112.6(6)	114.1(2)	114.4(2)	113.2(2)	113.8(8)	112.5(7)	113.1
O(3)—C(4)—C(5)	103.2	106.4(4)	103.7(7)	104.6(3)	105.2(3)	104.3(3)	106(1)	105.0(9)	104.6
C(4)—C(5)—O(1)	107.8	106.2(4)	104.7(7)	105.8(4)	105.5(3)	108.3(3)	103(1)	106(1)	106.0
C(5)—O(1)—S(2)	113.7	110.5(3)	118.8(8)	110.4(2)	111.7(2)	113.9(2)	112.2(8)	110.3(8)	112.2
Torsion angle					τ/deg				
O(1)—S(2)—O(3)—C(4)	−27.1	−27.6(5)	−26.9(7)	−13.9(3)	−20.4(2)	−26.1(2)	−13.4(9)	−16.6(9)	
S(2)—O(3)—C(4)—C(5)	34.3	13.1(6)	22.1(8)	−4.8(4)	4.4(2)	19.3(2)	−7(1)	−2(2)	
O(3)—C(4)—C(5)—O(1)	−25.4	11.1(7)	−5.1(9)	24.3(4)	16.5(2)	−1.1(3)	25(2)	24(2)	
C(4)—C(5)—O(1)—S(2)	8.4	−31.0(7)	−14(1)	−35.9(4)	−32.3(2)	−17.3(2)	− 40(1)	−38(1)	
C(5)—O(1)—S(2)—O(3)	10.6	34.6(5)	25.2(8)	29.8(3)	31.4(2)	25.6(2)	30.6(9)	32.5(9)	

* The geometric parameters were calculated from the CSD data, the errors are not given.
** The average value.

Table 3. Selected torsion angles in the acyclic fragment in compounds **3**

Compound, molecule	Torsion angle/deg		
	C(6)—O(6)—C(7)—C(16)	C(4)—C(6)—O(6)—C(7)	C(5)—C(4)—C(6)—O(6)
scal-trans-**3**	169.6(6)	160.0(6)	50.9(9)
scal-cis-**3**	179.7(3)	−171.6(3)	177.5(3)
rac-trans-**3A**	−180.0(3)	178.0(3)	175.0(4)
rac-trans-**3B**	178.5(2)	−177.0(3)	−175.2(3)
rac-cis-**3A**	−177.2(9)	167.2(9)	−55(1)
rac-cis-**3B**	179.1(8)	−171.9(9)	49(1)

Analogously, the nearly-zero O(3)—C(4)—C(5)—O(1) torsion angle is found in molecule *rac-trans*-**3B** (see Table 2), *i.e.*, the conformation of the heterocycle can be considered as an envelope and is denoted (S(2))-E.

In order in which cyclic sulfites are listed in Table 2, the five-membered fragment adopts the following conformations: (O(1))-HCh, (C(4))-HCh, (C(5))-HCh, (O(1))-E, (O(1))-E, (S(2))-E, (O(3))-HCh, and (O(1))-E. Hence, the following conclusions can be drawn. The conformation of molecule *scal-trans*-**1** presented in the figure in the original study,[8] where it was described as a half-chair with the central sulfur atom (in the present study, it is denoted (S(2))-HCh), was incorrect. As can be seen from Table 2, the reference torsion angles in the conformation (S(2))-HCh are 34° and 8°, *i.e.*, they are too different for the confromation to be described as a half-chair. Apparently, the assignment of the conformation in the study[8] was made in accordance with the commonly accepted tendency to consider the conformational behavior of five-membered cyclic sulfites, regardless of the mode of substitution, as equilibrium between the conformers (S(2))-HCh and (S(2))-E, with one of them predominating (see the studies[2,4,5] and references therein). Evidently, the X-ray diffraction data do not allow one to assume this simplification. It should be noted that the conformation (O(1))-E, which is generally not considered, is observed in the crystalline state more often than other conformations (3 of 8 structures). On the whole, the situation does not correspond to the conformational equilibrium between two limit forms, (S(2))-HCh and (S(2))-E, but more likely statistically reflects individual steps of the pseudorotation involving all atoms of the

heterocycle. As compared to cyclopentane, three methylene units in five-membered cyclic sulfites are replaced by two oxygen atoms and the S=O group. This should be accompanied by a substantial decrease in the barriers to conformational distortion of the ring, which are low enough even in cyclopentane itself. Evidently, the fact that there are no obvious predominant conformers of the heterocycle in the crystalline phase reflects that the limit structures are energetically similar along the pseudorotation coordinate. Within the framework of methods employing the average parameters, the latter fact, along with low barriers, can lead to a model of an effectively planar ring, which was apparently reflected on the interpretation of the early electron diffraction experiment.[6]

Conformations of the acyclic fragment in naphthyloxymethyl-substituted dioxathiolanes

The conformations of the acyclic fragment in molecules **3** is qualitatively presented in Fig. 1. The quantitative data on selected torsion angles (normalized taking into account the classification used in the study) are given in Table 3. The C(7) and C(16) atoms mentioned in this table correspond to positions 1 and 9 of the naphthalene system, and the C(6) atom belongs to the exocyclic oxymethyl group.

As can be seen from Fig. 1 and Table 3, the C(4)C(6)O(6)C(7)C(16) fragment in all molecules **3** retains the expected all-transoid conformation although the C(4)—C(6)—O(6)—C(7) dihedral angle is substantially smaller than the ideal value (180°) if the naphthoxyl fragment "overhangs" above or below the heterocycle.

The exocyclic C(5)—C(4)—C(6)—O(6) torsion angle nearest to the heterocycle appears to be the structural variable more labile and sensitive to the stereochemical factors. For one-half of molecules **3** under study, this angle is close to 180° and characterizes the expected antiperiplanar (*ap*) conformation, whereas this angle in another half of molecules is close to ±60° typical of synclinal (*sc*) conformers. Interestingly, the relative conformations of the naphthoxyl and heterocyclic fragments characterized by this angle vary under any change in the stereochemical factors. For example, the *trans* isomer in the homochiral crystals exists in the more compact *sc* conformation, whereas the *cis* isomers adopts the more extended *ap* conformation. This effect could be attributed to steric interactions between the naphthyl moiety and the oxygen atom of the S=O group in the compact *sc* conformer, which is unfavorable for the *cis* isomer. However, the inverse conformational preference is observed in the racemic crystals as compared to the scalemic crystals. In the racemic crystals, the *cis* isomer adopts the compact *sc* conformation, whereas the *trans* isomer exists in the extended all-antiperiplanar conformation. The position of the naphthoxyl fragment resulting from the rotation about the exocyclic C—C bond in chiral cyclic sulfites **3** can be described as follows:

Diastereomer	Sample	
	Enantiopure	Racemic
trans-**3**	*sc*	*ap*
cis-**3**	*ap*	*sc*

In our opinion, this conformational behavior is a striking example of the equal influence of both the local (*cis—trans* isomerism of the molecule) and external (homochiral/heterochiral environment) stereochemical factors on the structural characteristics of the molecule.

Crystal packing of cyclic naphthyloxymethyl-substituted dioxathiolanes

Since molecules **3** contain no proton-donor groups, the crystal packing of these compounds is determined by relatively weak C—H...O interactions, π—π interactions between the aromatic systems, and van der Waals forces. As expected, the density of the crystals of the racemic compounds is somewhat higher than that of the scalemic crystals (Wallach's rule),[19] and the density of the crystals of the *cis* isomers is higher than that of the *trans* isomers (see Table 1).

In the crystal structure of *scal-trans*-**3**, there is the intermolecular C(4)—H(4)...O(2′) hydrogen bond ([1/2 + *x*, 5/2 – *y*, –*z*], C(4)—H(4), 0.98 Å; H(4)...O(2′), 2.44 Å; C(4)...O(2′), 3.228(7) Å; C(4)—H(4)...O(2′), 137°) and the intramolecular C(5)—H(51)...O(6) hydrogen bond (C(5)—H(51), 0.97 Å; H(51)...O(6), 2.46 Å; C(5)...O(6), 2.823(7) Å; C(5)—H(51)...O(6), 102°). The intermolecular hydrogen bonds link the molecules to form infinite chains along the 0*x* axis. In the crystal structure of *scal-trans*-**3**, the aromatic fragments of the molecules are almost parallel to each other (the dihedral angle between the planes of the naphthyl fragments of the adjacent molecules is 3.4°; the shortest distance between the planes is 3.30 Å), resulting in the formation of tilted stacks of the molecules along the 0*y* axis (Fig. 2, *a*). Taken together, these interactions give rise to layered structures, in which two mutually perpendicular directions differ in the type of interactions. In the crystal stucture of *scal-trans*-**3**, only C—H...π interactions between the naphthyl fragments of the molecules are present between these layers.

As opposed to the above-described packing, the tilted stacks of the parallel naphthyl fragments are arranged along the 0*x* axis in the crystal structure of *scal-cis*-**3** (see Fig. 2, *b*) (the dihedral angle between the planes is 1.9°; the shortest distance between the planes is 3.51 Å). The intermolecular hydrogen bonds involving the H(51) and

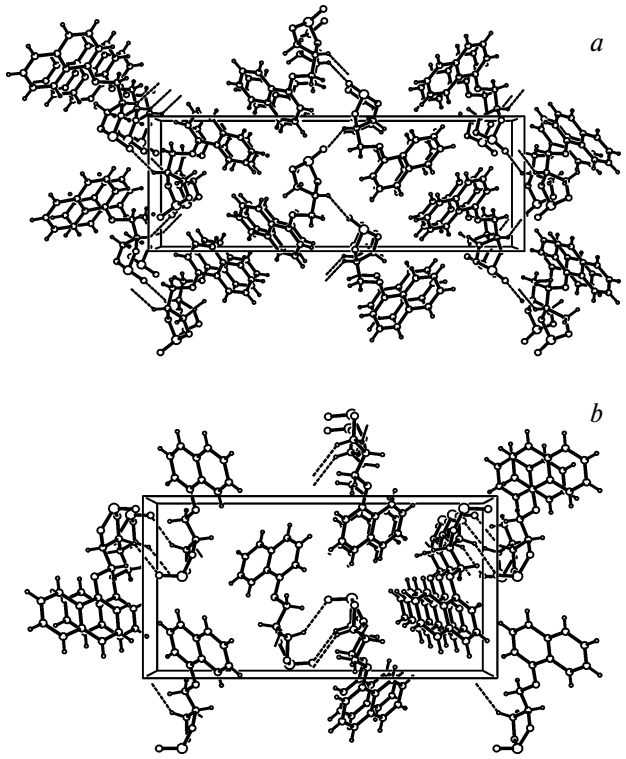


Fig. 2. Crystal packing of *scal-trans*-**3** (*a*) and *scal-cis*-**3** (*b*) projected along the 0*y* (*a*) and 0*x* (*b*) axes.

H(52) atoms, C(5)—H(51)...O(2′) ([−1/2 + *x*, −1/2 − *y*, 2 − *z*], C(5)—H(51), 0.97 Å; H(51)...O...(2′), 2.52 Å; C(5)...O(2′), 3.340(6) Å; C(5)—H(51)...O(2′), 143°) and C(5)—H(52)...O(3″) ([−1 + *x*, *y*, *z*], C(5)—H(52), 0.97 Å; H(52)...O(3″), 2.47 Å; C(5)...O(3″), 3.291(6) Å, C(5)—H(52)...O(3″), 143°), act in the same direction. This gives rise to cylindrical supramolecular structures, whose parallel hexagonal packing along the crystallographic axis 0*x* represents the crystal packing as a whole. It should be noted that C—H...π interactions between these supramolecular structures are absent.

The molecular packing in the crystal structures of the racemic compounds is characterized by the presence of homochiral layers, *i.e.*, layers consisting of the molecules with the same configuration of the chiral S(2) and C(4) atoms. For example, this layer in the crystal of *rac-trans*-**3** is formed through numerous intermolecular C—H...O interactions with the H...O distances varying in the range of 2.59—2.90 Å (Fig. 3, *a*). In the crystal, the layers composed of the molecules adopting different configurations alternate along the 0*y* direction and are linked to each other by π...π interactions between the almost parallel naphthyl fragments (the dihedral angles between the planes are 0—2.2°; the distances between the planes are 3.5—3.55 Å) and C—H...π interactions (the distances between the hydrogen atoms and the centers of gravity are 2.8—3.3 Å) (see Fig. 3, *b*).

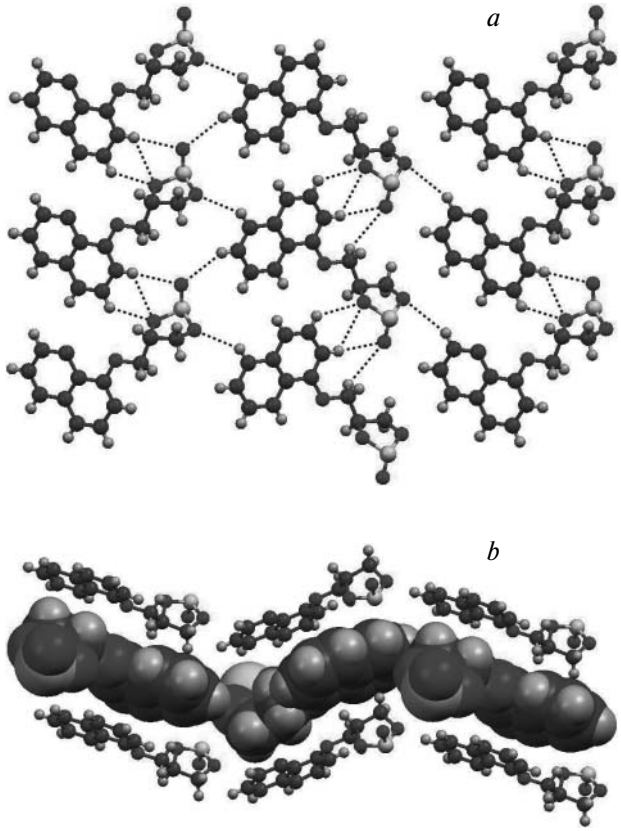


Fig. 3. (*a*) Intermolecular C—H...O interactions in the homochiral layer in the crystal of *rac-trans*-**3** (indicated by dashed lines). The projection along the 0*y* axis. (*b*) The packing of layers in the crystal of *rac-trans*-**3**. The projection along the 0*x* axis. The homochiral layer of the molecules adopting the (2*S*,4*S*) configuration is represented by van der Waals spheres.

The crystal structure of *rac-cis*-**3** also consist of alternating homochiral layers, but C—H...O and S...O interactions in the layers do not lead to hydrogen bonding between all molecules in the layer but only to the formation of ribbon-like supramolecular structures. The H(51B)...O(2B′) [*x* − 1, *y*, *z*] and H(4A)...O(2A′) [*x* − 1, *y*, *z*] intramolecular interactions give rise to chains of the independent molecules A and B (H(51B)...O(2B′), 2.53 Å; C(5B)—H(51B)...O(2B′), 139°; H(4A)...O(2A′), 2.70 Å; C(4A)—H(4A)...O(2A′), 119°). The chains are linked to each other to form ribbon-like structures *via* the S(2A)...O(1B′) interactions ([1 − *x*, 1 − *y*, −1 − *z*], S(2A)...O(1B′), 3.357(3) Å; O(1A)—S(2A)...O(1B′), 135°). The π...π contacts between the naphthyl fragments of the molecules related by the translation along the 0*x* axis act in the same direction. In the layers, the supramolecular structures are linked to each other by usual van der Waals contacts (Fig. 4, *a*). Interestingly, analogous supramolecular structures are observed in the scalemic crystals of the *cis* isomer.

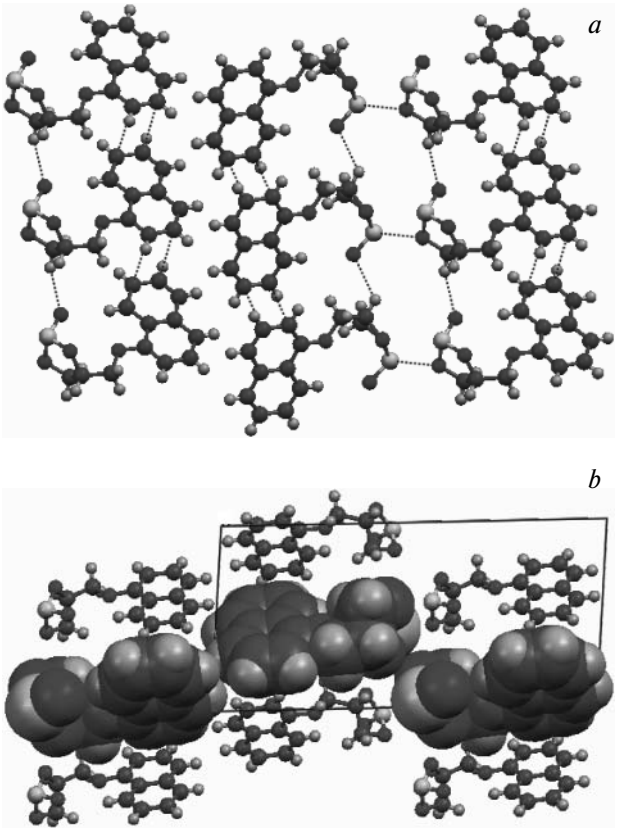


Fig. 4. (*a*) Intermolecular C—H...O, S...O, and π—π interactions in the homochiral layer in the crystal of *rac-cis*-**3** (indicated by dashed lines). The projection along the 0*y* axis. (*b*) The projection along the 0*x* axis onto the packing of the layers in the crystal. The homochiral layer of the molecules adopting the (2*R*,4*S*) configuration is represented by van der Waals spheres.

As in the above-considered crystal structure, there is alternation of homochiral layers linked to each other by numerous π...π contacts between the parallel naphthyl fragments (the dihedral angles between the planes are 0.4—0.5°, the distances are 3.32—3.36 Å; see Fig. 4, *b*).

To conclude, we studied four samples (two racemic and two enantiopure) of two isomeric compounds by X-ray diffraction and obtained quantitative data on the structures of six monosubstituted cyclic sulfites in the crystalline phase. A comparative analysis of these data and X-ray diffraction data published in the literature allowed us to determine the average structural parameters of the sulfite heterocycle and demonstrate its substantial conformational flexibility.

A comparison of the structures of the exocyclic fragment in the 4-(1-naphthyloxy)methyl-1,3,2-dioxathiolane molecules, to be more precise, the orientations of the substituents in the ethane-like fragment about the exocyclic C(4)—C(6) bond revealed the change in the preferable conformation from antiperiplanar (transoid) to synclinal (gauche) under any change in the stereochemical factors. In the racemic samples, the naphthoxyl fragment of *trans*-sulfites adopts the *ap* conformation, whereas this fragment in *cis*-sulfites has the *sc* conformation. To the contrary, the *ap* conformation is typical of the *cis* isomer of the enantiopure samples, whereas the *sc* conformation is characteristic of the *trans* isomer. This behavior of the compounds under study clearly demonstrates that it is important to take into account the influence of the character of chirality of the crystalline phase on the stereochemistry of chiral compounds.

Finally, we revealed the main supramolecular motifs, which characterize the crystal packing of naphthyloxymethyl-substituted dioxathiolanes, and found factors responsible for their formation. It was demonstrated that the crystal packing is composed of alternating infinite homochiral layers, *i.e.*, layers formed by molecules with chiral centers adopting the same configuration. It remains unclear whether this property is associated with the chemical nature of the samples or it is determined by the internal symmetry of the crystal packing.

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