

# Synthesis and Assignment of Absolute Configuration of Enantiomeric Dicyclohexylammonium 2-Oxo-2-thioxo-1,3,2-oxathiaphospholanes

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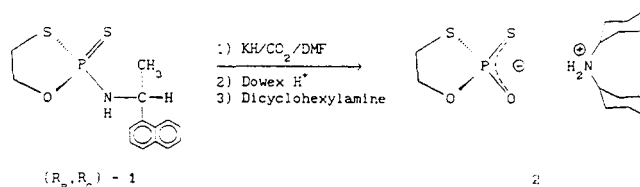
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## ABSTRACT

The title compound **2** has been synthesized and its structure has been determined by X-ray analysis. The following crystal data were found: monoclinic,  $P2_1$ ,  $a = 9.936(4)$ ,  $b = 18.009(3)$ ,  $c = 10.418(3)$  Å, and  $\beta = 107.22(3)^\circ$ . Two molecules of the compound (two oxathiaphospholane anions and two dicyclohexylammonium cations) are present in the independent part of the unit cell. The absolute configuration at the phosphorus atom is established as  $R_p$ . The ionic character of **2** is discussed. In the crystal lattice of **2**, a hydrogen-bonding system occurs.

## INTRODUCTION

Within the frame of our studies on the  $P$ -stereocontrolled synthesis of oligo(nucleoside phosphorothioate)s [1], we have recently shown that DBU-assisted methanolysis of  $[R_p, R_c]$ -2-[1-( $\alpha$ -naphthyl)ethylamino]-2-thiono-1,3,2-oxathiaphospholane (**1**) proceeds through a regio- and stereo-selective 1,3,2-oxathiaphospholane ring-opening

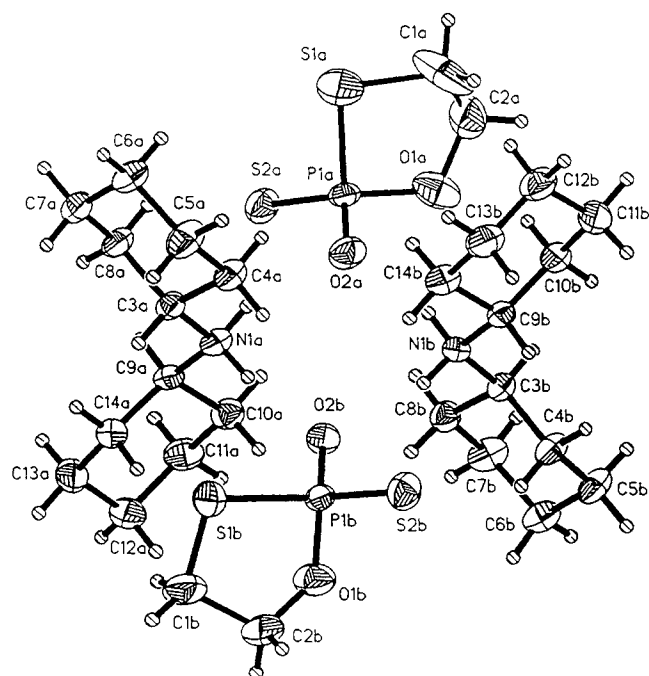


SCHEME 1

process, with net retention of configuration at phosphorus [2].

In light of our earlier studies on  $PN \rightarrow PX$  conversion [3], it was of interest to perform the synthesis of enantiomeric forms of 2-oxo-2-thioxo-1,3,2-oxathiaphospholane (**2**) via stereoretentive  $PN \rightarrow PO$  conversion of **1**  $\rightarrow$  **2**, with preservation of the labile 1,3,2-oxathiaphospholane ring system (Scheme 1). As pointed out by Inch and Hall [4], compounds **2** consisting of the  $P$ -chiral analogues of cyclic ethylene phosphate, the molecule that played the basic role in the evaluation of the pseudorotation theory of organophosphates [5], have not been so far obtained in optically active forms. We have found that metallation of DMF solutions of diastereoisomerically pure **1** with potassium hydride, followed by treatment with dry  $CO_2$ , resulted in formation of potassium 2-oxo-2-thioxo-1,3,2-oxathiaphospholane ( $K^+$ , **2**). The potassium salt was converted into the dicyclohexylammon-

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**FIGURE 1** Thermal ellipsoidal view of two independent molecules in the asymmetric part of the unit cell of compound **2** with atom numbering.

ium salt **2**, and, as such, crystallized from ethanol; starting from  $[R_p, S_c]$  -**1**, enantiomer  $[R_p]$  -**2**,  $[\alpha]_D = -16.1^\circ$  (c 1.03; EtOH), mp  $190^\circ\text{C}$  was obtained.

Analogously, homochiral  $[S_p, S_c]$  -**1** was converted into the dextrorotatory dicyclohexylam-

**TABLE 1** Bond Lengths and Valence Angles of 1,3,2-Oxathiaphospholane Ring and Its Environment; Comparison With Literature Data [1, 9, 10]

	Compound <b>2</b>		$[\eta]^a$ (Slow 1)	$[\eta]^b$
	Molecule A	Molecule B		
P-S1	2.081(3)	2.122(4)	2.094(2)	2.080(2)
P-O1	1.701(8)	1.613(6)	1.634(4)	1.632(4)
S1-C1	1.795(17)	1.805(11)	1.859(7)	1.773(8)
O1-C2	1.424(14)	1.420(14)	1.444(8)	1.436(7)
C1-C2	1.427(18)	1.545(15)	1.51(1)	1.55(1)
P-S2	1.952(3)	1.953(4)	1.924(2)	—
P-O2	1.497(7)	1.502(7)	—	—
S1-P-S2	109.7(1)	112.0(2)	115.4(1)	—
S1-P-O1	98.5(3)	96.3(3)	96.9(2)	92.8(2)
S1-P-O2	111.0(3)	110.0(3)	—	—
S2-P-O1	113.6(3)	113.4(3)	116.5(2)	—
S2-P-O2	115.3(3)	115.0(3)	—	—
O1-P-O2	107.5(4)	108.5(4)	—	—
P-S1-C1	91.3(5)	93.2(4)	93.2(2)	—
P-O1-C2	112.4(7)	114.9(6)	114.4(4)	—
S1-C1-C2	111.4(11)	105.9(8)	105.7(4)	—
O1-C2-C1	114.4(11)	108.7(9)	108.9(5)	—

<sup>a</sup> $[R_p, R_c]$ -2-[1-( $\alpha$ -naphthyl)ethylamino]-2-thiono-1,3,2-oxathiaphospholane (**1**) [1, 10].

<sup>b</sup>2,2,5,5-Tetrakis(trifluoromethyl)-1,3,4-dioxaphospholane [9, 10].

**TABLE 2** Selected Torsional Angles ( $^\circ$ ) in **2**

Angle	Molecule A	Molecule B
P1-S1-C1-C2	27.5(10)	26.2(7)
P1-O1-C2-C1	30.4(13)	48.8(10)
S1-P1-O1-C2	-8.4(7)	-25.3(7)
S1-C1-C2-O1	-39.9(14)	-47.2(10)
S2-P1-S1-C1	-129.0(5)	-121.1(4)
S2-P1-O1-C2	107.5(7)	92.0(7)
O1-P1-S1-C1	-10.1(6)	-2.6(5)
O2-P1-S1-C1	102.5(6)	109.8(5)
O2-P1-O1-C2	-123.7(7)	-138.9(7)
N1-C3-C4-C5	-178.4(7)	179.5(6)
N1-C3-C8-C7	-179.2(6)	179.3(6)
N1-C9-C10-C11	177.0(6)	175.1(6)
N1-C9-C14-C13	-174.5(7)	-178.7(6)
C3-N1-C9-C10	-176.7(6)	56.6(8)
C3-N1-C9-C14	-54.8(9)	179.1(6)
C3-C4-C5-C6	-57.2(9)	-57.6(9)
C3-C8-C7-C6	57.6(9)	55.4(9)
C4-C3-N1-C9	179.1(6)	58.3(8)
C4-C3-C8-C7	-58.6(8)	-59.0(8)
C4-C5-C6-C7	55.7(10)	56.3(10)
C5-C4-C3-C8	58.6(9)	59.0(8)
C5-C6-C7-C8	-56.1(9)	-54.8(9)
C8-C3-N1-C9	-58.7(8)	-179.0(6)
C9-C10-C11-C12	-57.7(9)	-53.6(10)
C9-C14-C13-C12	55.0(9)	56.7(10)
C10-C9-C14-C13	-55.1(9)	-57.1(9)
C10-C11-C12-C13	57.4(10)	55.0(11)
C11-C10-C9-C14	55.6(9)	55.9(9)
C11-C12-C13-C14	-55.5(10)	-56.2(10)

monium salt of 2-oxo-2-thioxo-1,3,2-oxathiaphospholane ( $[S_p]$  -**2**);  $[\alpha]_D = +15.6^\circ$  (c 0.45; EtOH).

The enantiomeric purity (in both cases  $>97\%$ ) was confirmed on the basis of  $^{31}\text{P}$  NMR spectra of diastereoisomeric salts of **2** with levorotatory 1- $\alpha$ -naphthylethylamine.

Although the assignment of absolute configuration of enantiomers of dicyclohexylammonium-**2** was predictable on the basis of the known absolute configuration of starting **1** [1] and the stereoretentive mode of  $\text{PN} \rightarrow \text{PO}$  conversion, the crystals of dicyclohexylammonium  $[R_p]$  -**2** (Figure 1) were grown and analyzed by X-ray crystallography.

## RESULTS AND DISCUSSION

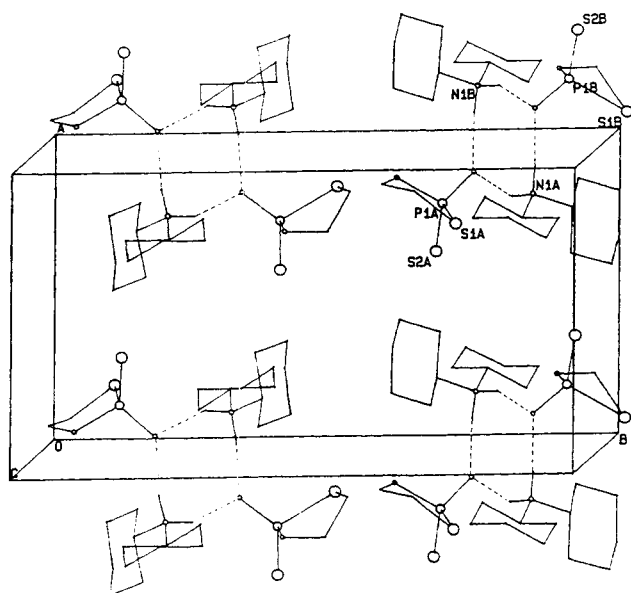
The crystals of compound **2** suitable for X-ray analysis were obtained with difficulty. Additionally, the progressive decomposition of their internal structure was observed during X-ray exposure at room temperature. Structural decomposition was noticed during three independent rentgenographical experiments, including the different time of exposure of crystals received from the different crystallization experiments. Most probably, this decomposition of crystal structure has resulted from

**TABLE 3** Asymmetry Parameters of Oxathiaphospholane and Cyclohexyl Rings in **2**

	Molecule A	Molecule B		Molecule A	Molecule B
$\Delta C_s^{(P1)}$	43.0(9)	56.6(9)	$\Delta C_2^{(P1-O1)}$	55.6(9)	63.4(9)
$\Delta C_s^{(O1)}$	38.6(9)	38.9(9)	$\Delta C_2^{(O1-C2)}$	34.7(9)	25.6(9)
$\Delta C_s^{(C2)}$	15.1(9)	1.3(9)	$\Delta C_2^{(C2-C1)}$	2.4(9)	22.6(9)
$\Delta C_s^{(C1)}$	16.8(9)	35.9(9)	$\Delta C_2^{(C1-S1)}$	34.6(9)	61.2(9)
$\Delta C_s^{(S1)}$	36.3(9)	53.9(9)	$\Delta C_2^{(S1-P1)}$	55.8(9)	77.0(9)
$\Delta C_s^{(C3)}$	0.3(5)	1.5(5)	$\Delta C_2^{(C3-C4)}$	1.7(5)	1.2(5)
$\Delta C_s^{(C4)}$	2.0(5)	1.8(5)	$\Delta C_2^{(C4-C5)}$	2.7(5)	3.5(5)
$\Delta C_s^{(C5)}$	1.8(5)	3.3(5)	$\Delta C_2^{(C5-C6)}$	1.1(5)	3.2(5)
$\Delta C_s^{(C9)}$	1.9(5)	2.0(5)	$\Delta C_2^{(C9-C10)}$	2.5(5)	2.8(5)
$\Delta C_s^{(C10)}$	1.8(5)	1.8(5)	$\Delta C_2^{(C10-C11)}$	1.3(5)	0.9(5)
$\Delta C_s^{(C11)}$	0.2(5)	0.9(5)	$\Delta C_2^{(C11-C12)}$	1.6(5)	1.9(5)

**TABLE 4** Important Hydrogen Bonds in **2**

$X-H \cdots Y$	$X-H$ (Å)	$H \cdots Y$ (Å)	$X \cdots Y$ (Å)	$X-H \cdots Y$ (°)	Symmetry
N1A-H1NA $\cdots$ O2A	0.90(2)	2.01(2)	2.83(2)	150.6(15)	$1 - X, Y - 0.5, 1 - Z$
N1B-H2NB $\cdots$ O2B	0.90(2)	1.96(2)	2.80(2)	154.8(15)	$-X, Y + 0.5, 1 - Z$
N1A-H2NA $\cdots$ O2B	0.90(2)	1.87(2)	2.76(2)	171.5(15)	—
N1B-H1NB $\cdots$ O2A	0.90(2)	1.89(2)	2.77(2)	166.0(15)	$X - 1, Y, Z$

**FIGURE 2** The unit cell of compound **2**. The molecules from the neighbor unit cells are drawn to show the hydrogen-bonding system between ions in the asymmetric part of the unit cell.

significant differences in bond lengths and valence angles in two independent molecules located in the asymmetric part of the unit cell and is also reflected in the relatively high value of the final  $R$  factor ( $R = 0.0677$ ) during structure refinement. Consequently, some discrepancies in bond lengths and valence angles appeared in two independent molecules consisting of the asymmetric part of an unit cell. For that reason, the final X-ray experiment was performed at a temperature of  $-100^\circ\text{C}$  on a single crystal placed into a capillary tube made from Lindeman glass.

Two independent molecules, with different geometry, form the asymmetric part of the unit cell of **2**. Figure 1 presents the thermal ellipsoidal view of both molecules with the atom numbering. The absolute configuration at the phosphorus atom was established in both molecules as  $R_p$  on the basis of the statistic Hamilton test [6] and by calculation of the  $\eta$  parameter [7,8]. The obtained value of  $\mathcal{R}_{\text{ratio}}$  was 1.019 for  $N = 3272$ , which gives  $\alpha \leq 10^{-9}$ ; the value of the  $\eta$  parameter was 0.645(96), and, respectively,  $\eta_{(-)} = -0.615(96)$  for the structure with inverted signs of  $f''$  values. These values indicate that the most probable configuration is  $R_p$ , and the  $S_p$  configuration should most likely be rejected.

The comparison of bond lengths and valence angles of the 1,3,2-oxathiaphospholane ring and its environment in both independent molecules of **2** with those from the literature [10] (Table 1) strongly

**TABLE 5** Crystal Data and Experimental Details

Molecular formula	C <sub>14</sub> H <sub>28</sub> NO <sub>2</sub> PS <sub>2</sub>
F(000)	364
Space group	P2 <sub>1</sub>
a(Å)	9.936(4)
b(Å)	18.009(3)
c(Å)	10.418(3)
β(°)	107.22(3)
V(Å <sup>3</sup> )	1781(15)
Z	4
μ(cm <sup>-1</sup> )	35.44
D <sub>c</sub> (g/cm <sup>3</sup> )	1.259(2)
Crystal dimensions (mm)	0.25, 0.3, 0.5
Maximum 2θ(°)	150
Radiation, λ(Å)	CuK <sub>α</sub> , 1.54178
Scan mode	ω/2θ
Scan width (°)	0.80 + 0.14 tan θ
hkl ranges	h = 0 12 k = 0 22 l = -13 13
No. of reflections collected:	
unique	3718
with I ≥ 3σ(I)	3633
DECAY correction factors:	
min	1.00003
max	1.04235
av	1.02088
EAC correction factors:	
min	0.7421
max	0.9995
av	0.9145
No. of parameters refined	361
Largest difference peak (eÅ <sup>-3</sup> )	0.708
Largest difference hole (eÅ <sup>-3</sup> )	-0.843
R	0.0677
R <sub>w</sub>	0.0719
Weighting scheme	w = 1/[σ <sup>2</sup> (F) + 0.001F <sup>2</sup> ]

indicates some imperfections of the crystalline forms of **2**.

Both P=S bonds (in two independent molecules A and B), with P–S distances 1.952(3) and 1.953(4) Å, respectively, are slightly longer than a typical “double” P=S bond (1.94 Å) and significantly shorter than the respective “single” bond (with length of the range of 2.08–2.14 Å). Respectively, lengths of the exocyclic P–O bonds of molecule A (1.497(7) Å) and molecule B (1.502(7) Å) are significantly shorter than that of the single P–O bond (typical value 1.582 Å) but longer than that of the double P=O bond (typical value 1.478 Å) [10]. This phenomenon, explained in terms of the resonance effect, is common for structures of organophosphorothioate diesters and also for those incorporated in a heterocyclic six-membered ring system [11,12] (there is no available reference regarding a five-membered ring system [10]).

The relative P–O and P–S bond lengths are

**TABLE 6** Atomic Coordinates (×10<sup>4</sup>) and Equivalent Isotropic Displacement Coefficients (Å<sup>2</sup> × 10<sup>3</sup>) of Nonhydrogen Atoms

Atom	x	y	z	U (eq)
P1A	7714(2)	4403	856(2)	27.9(4)
S1A	6774(3)	4478(2)	-1210(3)	64.5(8)
S2A	6261(2)	4366(2)	1771(2)	42.1(4)
O1A	8577(8)	3584(4)	893(7)	54(2)
O2A	8803(6)	4996(4)	1336(7)	41(2)
C1A	7808(19)	3715(8)	-1503(13)	90(5)
C2A	8195(12)	3223(6)	-380(13)	63(3)
N1A	1754(7)	1204(4)	7155(7)	29(1)
C3A	2331(7)	1825(4)	8117(7)	27(2)
C4A	1519(8)	1836(5)	9169(8)	33(2)
C5A	2056(9)	2482(6)	10151(9)	45(2)
C6A	3653(8)	2424(5)	10839(9)	39(2)
C7A	4432(8)	2381(5)	9776(8)	37(2)
C8A	3917(8)	1743(5)	8801(8)	34(2)
C9A	2385(8)	1094(4)	6012(7)	28(2)
C10A	1575(8)	468(5)	5140(8)	34(2)
C11A	2112(9)	356(5)	3920(8)	40(2)
C12A	1989(10)	1059(6)	3086(8)	43(2)
C13A	2807(10)	1689(5)	3978(8)	41(2)
C14A	2307(8)	1805(5)	5216(8)	34(2)
P1B	-2162(2)	1921(1)	5783(2)	27.5(4)
S1B	-1042(3)	2934(2)	5895(2)	42.0(4)
S2B	-3668(2)	1997(2)	6629(3)	43.4(4)
O1B	-2729(7)	1882(4)	4165(6)	47(2)
O2B	-1149(6)	1292(4)	6279(6)	36(1)
C1B	-1449(11)	3010(7)	4093(11)	60(2)
C2B	-2840(11)	2579(7)	3505(9)	49(3)
N1B	1709(7)	5124(4)	2179(6)	27(1)
C3B	2311(7)	4498(4)	3162(7)	28(1)
C4B	3897(8)	4612(5)	3812(8)	36(2)
C5B	4453(9)	3957(5)	4820(9)	41(2)
C6B	3678(9)	3919(5)	5868(9)	42(2)
C7B	2071(8)	3849(5)	5203(9)	39(2)
C8B	1518(8)	4478(5)	4194(7)	34(2)
C9B	2338(7)	5239(4)	1031(7)	27(1)
C10B	2238(8)	4540(5)	214(7)	35(2)
C11B	2755(10)	4681(6)	-1007(8)	47(2)
C12B	1990(10)	5340(6)	-1841(9)	46(2)
C13B	2101(9)	6024(6)	-1018(9)	44(2)
C14B	1536(9)	5886(5)	195(8)	36(2)
H1NA	1892(20)	782(20)	7640(20)	80*
H2NA	818(20)	1269(20)	6813(20)	80*
H1NB	786(20)	5031(20)	1801(20)	80*
H2NB	1777(20)	5549(20)	2647(20)	80*

Equivalent isotropic *U* is defined as one-third of the trace of the orthogonalized *U<sub>i</sub>* tensor. Starred atoms were refined with fixed isotropic thermal parameters.

discussed in the literature for several reasons. Several investigators [13,14] pose the question of charge localization within anionic phosphorothioate O,O-diester, arguing that the charge must be localized at the sulfur atom. The charge localization within anions of phosphorothioates becomes of special interest and importance, particularly with regard to interactions of complementary oligonucleotides bearing one or more internucleotide phosphoro-

TABLE 7 Bond Lengths (Å) in **2**

	Molecule A	Molecule B		Molecule A	Molecule B
P1–S1	2.081(3)	2.122(4)	C4–C5	1.537(13)	1.567(12)
P1–S2	1.952(3)	1.953(4)	C5–C6	1.539(11)	1.512(15)
P1–O1	1.701(8)	1.613(6)	C6–C7	1.529(14)	1.546(11)
P1–O2	1.497(7)	1.502(7)	C7–C8	1.519(12)	1.532(12)
S1–C1	1.795(17)	1.805(11)	C9–C10	1.520(11)	1.506(11)
O1–C2	1.424(14)	1.420(14)	C9–C14	1.515(11)	1.530(11)
C1–C2	1.427(18)	1.545(15)	C10–C11	1.530(13)	1.527(13)
N1–C3	1.498(10)	1.521(9)	C11–C12	1.520(13)	1.533(14)
N1–C9	1.514(12)	1.519(11)	C12–C13	1.538(13)	1.486(15)
C3–C4	1.541(12)	1.534(10)	C13–C14	1.527(13)	1.547(14)
C3–C8	1.532(10)	1.510(12)	—	—	—

TABLE 8 Bond Angles (°) in **2**

	Molecule A	Molecule B		Molecule A	Molecule B
S1–P1–S2	109.7(1)	112.0(2)	C3–C4–C5	109.4(7)	107.9(7)
S1–P1–O1	98.5(3)	96.3(3)	C4–C5–C6	111.4(8)	111.3(7)
S1–P1–O2	111.0(3)	110.0(3)	C5–C6–C7	109.8(7)	111.1(7)
S2–P1–O1	113.6(3)	113.4(3)	C6–C7–C8	112.3(7)	111.1(7)
S2–P1–O2	115.3(3)	115.0(3)	C3–C8–C7	109.6(7)	110.5(7)
O1–P1–O2	107.5(4)	108.5(4)	N1–C9–C10	107.3(6)	110.9(6)
P1–S1–C1	91.3(5)	93.2(4)	N1–C9–C14	110.7(6)	106.6(6)
P1–O1–C2	112.4(7)	114.9(6)	C10–C9–C14	111.6(7)	112.3(6)
S1–C1–C2	111.4(11)	105.9(8)	C9–C10–C11	109.9(7)	110.5(7)
O1–C2–C1	114.4(11)	108.7(9)	C10–C11–C12	112.1(7)	111.6(8)
C3–N1–C9	117.3(6)	117.4(6)	C11–C12–C13	109.3(8)	112.0(8)
N1–C3–C4	107.9(6)	110.2(6)	C12–C13–C14	111.4(7)	110.8(8)
N1–C3–C8	112.1(6)	108.2(6)	C9–C14–C13	111.7(7)	109.5(7)
C4–C3–C8	110.7(6)	111.9(6)	—	—	—

thioate junctions [15]. Assuming the ideal B conformation for oligonucleotides forming the double helix, the phosphorothioate with the  $R_p$  configuration possesses its sulfur atom directed “inward” of double helix, but the sulfur of the phosphorothioate with the  $S_p$  configuration is directed “outward”—perpendicular to the axis of the double helix [16].

Similarly, several studies on interactions between oligonucleotides and proteins, like endonucleases, were performed with oligonucleotides containing phosphorothioates of defined absolute configuration [17,18]. It could be shown that phosphates play the role of contact points with proteins *via* hydrogen-bonding between amidic hydrogens of the protein and the double P=O bond and “salt-links” between the positively charged amino acid functions and the ionized P–O bonds of phosphates [19,20].

Although compound **2** possesses, due to the presence of a phosphorothioate in a five-membered ring system, different structural features than a phosphorothioate in acyclic systems, our X-ray data of compound **2** may indicate that, in the solid

state, the negative charge is rather located at the oxygen. The distances between exocyclic O2, S2 atoms and nitrogen N1 of the dicyclohexylammonium cation in molecules A and B of **2** are N1A–O2A: 2.834(10) Å (symmetry 1 – X, Y – 0.5, 1 – Z); N1A–O2B: 2.761(9) Å; N1B–O2A: 2.768(9) Å (X – 1, Y, Z); N1B–O2B: 2.802 Å(11) (–X, 0.5 + Y, 1 – Z); S2A–N1A: 3.846(7) Å (1 – X, 0.5 + Y, 1 – Z); and S2B–N1B: 3.909(6) Å (–X, 0.5 + Y, 1 – Z); distances S2A–N1B and S2B–N1A are greater than 4.80 Å.

The conformation of two independent 1,3,2-oxathiaphospholane molecules of **2** is significantly different. The five-membered ring A adopts the half-chair conformation, with asymmetry parameters  $\Delta C_2^{C2-C1} = 2.4(9)$  and  $\Delta C_5^{C2} = 15.1(9)$ , but that of ring B forms an almost ideal envelope, with asymmetry parameters  $\Delta C_5^{C2} = 1.3(9)$  and  $\Delta C_2^{C2-C1} = 22.6(9)$  (atom C2 opens the envelope). The torsional angles and asymmetry parameters, describing the 1,3,2-oxathiaphospholane ring conformation and its environment, are presented in Tables 2 and 3.

The conformation and self-arrangement of the two independent molecules in the asymmetric part

**TABLE 9** Anisotropic Displacement Coefficients ( $\text{\AA}^2 \times 10^3$ )

Atom	$U_{11}$	$U_{22}$	$U_{33}$	$U_{12}$	$U_{13}$	$U_{23}$
P1A	27(1)	29(1)	23(1)	1(1)	0(1)	-1(1)
S1A	70(2)	86(2)	34(1)	9(2)	10(1)	-2(2)
S2A	32(1)	54(1)	41(1)	2(1)	12(1)	3(1)
O1A	71(5)	60(5)	38(4)	-20(4)	27(3)	-6(3)
O2A	29(3)	40(4)	48(4)	-7(3)	4(3)	-6(3)
C1A	161(15)	67(9)	47(7)	-12(10)	40(8)	-24(7)
C2A	52(6)	41(6)	92(9)	-2(5)	13(6)	-26(6)
P1B	25(1)	26(1)	27(1)	0(1)	1(1)	1(1)
S1B	44(1)	37(1)	43(1)	-9(1)	10(1)	1(1)
S2B	32(1)	49(1)	51(1)	-2(1)	15(1)	2(1)
O1B	55(4)	42(4)	35(3)	0(3)	1(3)	-2(3)
O2B	31(3)	29(3)	44(3)	7(3)	7(3)	9(3)
C1B	52(6)	53(6)	56(6)	-1(5)	-11(5)	20(6)
C2B	50(6)	62(7)	28(5)	-4(5)	-1(4)	-5(5)
N1A	24(3)	33(4)	26(3)	0(3)	3(3)	-3(3)
N1B	27(3)	29(4)	22(3)	1(3)	4(3)	-3(3)
C3A	24(3)	25(4)	30(4)	-2(3)	3(3)	-2(3)
C4A	27(4)	39(5)	31(4)	-2(3)	7(3)	-7(4)
C5A	34(4)	54(6)	44(5)	-6(4)	9(4)	-17(4)
C6A	33(4)	43(5)	34(4)	-3(4)	0(4)	-10(4)
C7A	29(4)	43(5)	35(4)	-6(4)	3(3)	-3(4)
C8A	24(4)	47(5)	29(4)	-3(3)	3(3)	-5(4)
C9A	23(4)	33(4)	24(4)	1(3)	2(3)	2(3)
C10A	34(4)	32(4)	33(4)	-1(3)	7(3)	-2(3)
C11A	42(5)	43(5)	31(4)	4(4)	7(4)	-6(4)
C12A	47(5)	54(6)	26(4)	-3(4)	9(4)	2(4)
C13A	46(5)	48(5)	29(4)	-12(4)	12(4)	-3(4)
C14A	32(4)	37(5)	31(4)	0(3)	6(3)	4(4)
C3B	26(3)	29(4)	27(3)	3(3)	5(3)	2(3)
C4B	24(3)	45(5)	35(4)	3(3)	4(3)	7(4)
C5B	30(4)	50(5)	39(5)	9(4)	2(3)	12(4)
C6B	35(4)	47(5)	36(4)	2(4)	0(4)	6(4)
C7B	35(4)	42(5)	38(4)	-9(4)	7(4)	10(4)
C8B	28(4)	43(5)	31(4)	2(4)	10(3)	2(4)
C9B	21(3)	33(4)	26(3)	-1(3)	5(3)	-3(3)
C10B	34(4)	35(5)	31(4)	7(4)	4(3)	1(4)
C11B	48(5)	62(6)	29(4)	13(5)	10(4)	-1(4)
C12B	39(5)	63(6)	32(4)	10(4)	4(4)	8(4)
C13B	36(5)	57(6)	36(4)	-1(4)	6(4)	2(4)
C14B	34(4)	41(5)	31(4)	-2(4)	5(3)	3(4)

The form of the anisotropic displacement parameter is  $\exp[-2\pi^2(h^2a^2U_{11} + k^2b^2U_{22} + l^2c^2U_{33} + 2hkaU_{12} + 2hlaU_{13} + 2klbU_{23})]$ , where  $a$ ,  $b$ , and  $c$  are reciprocal lattice constants.

of the unit cell are characterized also by interesting least-squares planes. The different conformation of two oxathiaphospholane rings (A, B) of **2** is proved by deviations of C1 and C2 atoms from the least-squares plane passing through P1, S1, C1, O1 atoms. The respective distances in molecule A (half-chair) are 0.253(14) Å (C1) and -0.268(8) Å (C2), but in molecule B (envelope), they are, respectively, -0.050(9) Å (C1) and 0.586(9) Å (C2).

Table 4 shows the intra- and intermolecular hydrogen-bonding system that occurs in the crystal lattice of **2**, the asymmetric part of the unit cell of which contains two pairs of oxathiaphospholane

and dicyclohexylammonium ions. These hydrogen bonds are depicted in Figure 2, which shows the pattern of molecular packing in the unit cell.

## EXPERIMENTAL

Crystals of **2**, suitable for X-ray measurements, were obtained by crystallization from ethanol by vapor diffusion of ethyl acetate.  $\text{C}_{14}\text{H}_{28}\text{NO}_2\text{PS}_2$  crystallizes in the monoclinic system, space group  $P2_1$ , with the following unit-cell parameters:  $a = 9.936(4)$  Å,  $b = 18.009(3)$  Å,  $c = 10.418(3)$  Å,  $\beta = 107.22(3)^\circ$ . Crystal data and experimental details are given in Table 5.

Intensity data were collected at a low temperature ( $-100^\circ\text{C}$ ) using a CAD4 diffractometer with graphite monochromatized radiation. Lattice constants were refined by least-squares fit of 25 reflections in the  $\theta$  range of  $20.2$ – $29.6^\circ$ . The decline in intensities of three standard reflections (3, -7, 1; 3, -5, 2; 3, 7, 1) was 8.0% during 60.5 hours of exposure. Intensity data were corrected by use of the DECAY program [21] (Table 5). Absorption correction was applied (EAC program) [21,22]. The structure of **2** was solved by direct methods (SHELXS-86 program) [23,24] and refined by full-matrix least-squares using  $F^2$ s (SHELXTL system) [25]. Hydrogen atoms were placed geometrically at idealized positions (except hydrogens connected to nitrogen, found in a difference Fourier map) and set as riding, with fixed isotropic thermal parameters. Anisotropic thermal parameters were refined for all nonhydrogen atoms. Tables 6, 7, 8, and 9, respectively, present the atomic coordinates, bond lengths and angles, and temperature factors for all nonhydrogen atoms of the asymmetric part of the unit cell.

Scattering factors were taken from the International Tables for X-ray Crystallography [26]. Values of  $F_{\text{obs}}/F_{\text{calcd}}$  and the full crystallographic data are deposited at the Cambridge Crystallographic Data Centre [27].

## Synthesis and Preparation of **2**

To a stirred solution of  $[R_p, R_c]\text{-2-[1-(}\alpha\text{-naphthyl)ethyl-amino]-2-thiono-1,3,2-oxathiaphospholane (1)}$  (0.11 g; 0.4 mmol) in dry DMF (3 mL), KH (0.08 g; 0.4 mmol, 20% dispersion in mineral oil) was added in one portion and with bubbling through the solution of gaseous  $\text{CO}_2$ , carefully dried over  $\text{P}_2\text{O}_5$ . The introduction of  $\text{CO}_2$  was continued for 12 hours at ambient temperature. An excess of unreacted KH was filtered off, the filtrate concentrated to dryness, dissolved in water, and washed with chloroform. The water layer was placed on a Dowex- $\text{H}^+$  column, and the eluate was neutralized with freshly distilled dicyclohexylamine. Water was evaporated and a solid residue was crystallized from

ethanol. Yield: 0.078 g (64.5%); mp 190–192°C,  $[\alpha]_D = -16.1^\circ$  (c 1.03; EtOH),  $^{31}\text{P}$  NMR,  $\delta = 87.3$  ppm ( $\text{D}_2\text{O}$ ), MS-FAB 155 amu.

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