3. G. K. Musorin and S. V. Amosova, USSR Inventor's Certificate No. 1,337,388; Byul. Izobr., No. 34 (1987).
4. M. Karplus, J. Am. Chem. Soc., 85, 2870 (1963).
5. B. A. Trofimov, S. V. Amosova, G. K. Musorin, V. V. Nosyreva, and M. L. Al'pert, USSR Inventor's Certificate No. 1,114,675; Byul. Izobr., No. 35 (1984).
6. E. M. Arnett and L. E. Smith, J. Am. Chem. Soc., 85, 2870 (1977).

SYNTHESIS, STRUCTURE, AND PROPERTIES OF 2-THIO-4-IMINO-5-SPIROCYCLOHEXANEHYDANTOINS

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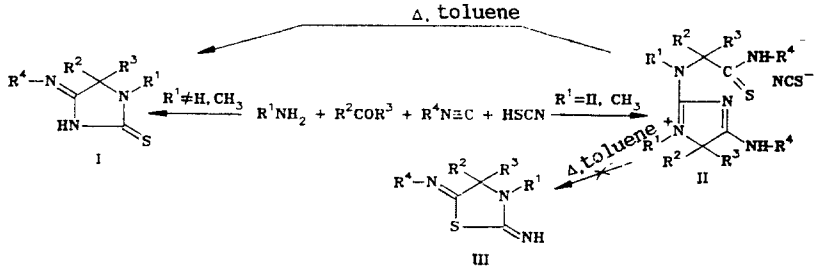
The imidazolium salt, obtained by the multicomponent condensation of benzyl isonitrile, methylamine, cyclohexanone, and thiocyanic acid, undergoes thermal recyclization to 1-methyl-2-thio-4-imino-5-spirocyclohexanehydantoin. The stereochemical and structural features and properties of the 2-thiohydantoins are analyzed on the basis of the data of x-ray structural analysis and geometrical modeling.

It was shown [1] that the multicomponent condensation with the participation of ammonia or methylamine does not lead to the corresponding hydantoins (I), expected according to the Ugi reaction [2, 3], but is accompanied by the formation of the imidazolium salts (II). When they were boiled in toluene or benzene, the product, to which the thiazolidinimine structure (III) was assigned [1] on the basis of spectral data, was obtained. However, it was shown as a result of the x-ray structural investigation performed that the product of the thermal recyclization (IIa) has the thiohydantoin structure (Ia) (Tables 1-3).



Ia, b $R^1=CH_3$; I c $R^1=CH_2Ph$; Ia–c $R^2+R^3=(CH_2)_5$; Ia, c $R^4=CH_2Ph$; Ib $R^4=4\text{-}CH_3C_6H_4$

The five-membered heterocycle of the molecule of (Ia) (Fig. 1) and the S, $N_{(3)}$, $C_{(4)}$, and $C_{(16)}$ atoms lie in one plane with the accuracy of ±0.02 Å. The strong p-π* conjugation appears as the following features: the significant [up to 1.331(3) Å (Table 1)] contraction of the $N_{(2)}$-$C_{(1)}$ bond, which is characteristic of the thioamide fragment [1, 4], the delocalization of the electron density of the amidine grouping – $N_{(1)}$-$C_{(2)}$ 1.318(3) Å and $N_{(3)}$-$C_{(2)}$ 1.324(3) Å, the fact that the $N_{(1)}$-$C_{(1)}$ bond length of 1.376(3) Å is intermediate between that of N_{sp^3}-C_{sp^2} 1.45 Å (without the p-π* conjugation) [5] and N_{sp^2}-C_{sp^2} 1.33 Å (with p-π* conjugation), and the increase of the C=S bond length 1.681(3) Å by 0.01-0.03 Å by comparison with thioamides [1, 4].

It should be noted that hydrogen was not found at the $N_{(1)}$ atom in spite of the reliable localization of the hydrogen atoms, even at the periphery of the molecule. It can be proposed as an explanation of this result, as well as the equality of the $N_{(1)}$-$C_{(2)}$ and $N_{(3)}$-$C_{(2)}$ bonds, that the indicated hydrogen atom participates in the tautomeric equilibrium, since this is characteristic of amidines [6, 7]. The anti-orientation of the unshared electron pair of $N_{(3)}$

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TABLE 1. Bond Lengths d (Å) in the Molecule of (Ia)

Bond	d	Bond	d
S—$C_{(1)}$	1,681(3)	$C_{(4)}$—$C_{(5)}$	1,505(4)
$N_{(1)}$—$C_{(1)}$	1,376(3)	$C_{(5)}$—$C_{(6)}$	1,321(5)
$N_{(1)}$—$C_{(2)}$	1,318(3)	$C_{(5)}$—$C_{(10)}$	1,374(6)
$N_{(2)}$—$C_{(1)}$	1,331(3)	$C_{(6)}$—$C_{(7)}$	1,362(7)
$N_{(2)}$—$C_{(3)}$	1,472(3)	$C_{(7)}$—$C_{(8)}$	1,357(9)
$N_{(2)}$—$C_{(16)}$	1,469(5)	$C_{(8)}$—$C_{(9)}$	1,388(10)
$N_{(3)}$—$C_{(2)}$	1,324(3)	$C_{(9)}$—$C_{(10)}$	1,405(9)
$N_{(3)}$—$C_{(4)}$	1,458(4)	$C_{(11)}$—$C_{(12)}$	1,545(5)
$C_{(2)}$—$C_{(3)}$	1,526(3)	$C_{(12)}$—$C_{(13)}$	1,519(7)
$C_{(3)}$—$C_{(11)}$	1,515(4)	$C_{(13)}$—$C_{(14)}$	1,516(6)
$C_{(3)}$—$C_{(15)}$	1,539(4)	$C_{(14)}$—$C_{(15)}$	1,514(5)

TABLE 2. Bond Angles ω (deg) in the Molecule of (Ia)

Angle	ω
$C_{(1)}N_{(1)}C_{(2)}$	107,1(2)
$C_{(1)}N_{(2)}C_{(3)}$	11,5(2)
$C_{(1)}N_{(2)}C_{(16)}$	124,7(3)
$C_{(3)}N_{(2)}C_{(16)}$	123,7(3)
$C_{(2)}N_{(3)}C_{(4)}$	121,0(2)
$N_{(1)}C_{(1)}S$	122,8(2)
$N_{(2)}C_{(1)}S$	125,9(2)
$N_{(1)}C_{(1)}N_{(2)}$	111,3(2)
$N_{(1)}C_{(2)}N_{(3)}$	122,6(2)
$N_{(3)}C_{(2)}C_{(3)}$	124,5(2)
$N_{(1)}C_{(2)}C_{(3)}$	113,0(2)
$N_{(2)}C_{(3)}C_{(2)}$	97,1(2)
$N_{(2)}C_{(3)}C_{(11)}$	109,8(3)
$N_{(2)}C_{(3)}C_{(15)}$	110,6(2)
$C_{(2)}C_{(3)}C_{(11)}$	114,5(2)
$C_{(2)}C_{(3)}C_{(15)}$	112,6(3)
$C_{(11)}C_{(3)}C_{(15)}$	111,4(3)
$N_{(3)}C_{(4)}C_{(5)}$	114,6(3)
$C_{(4)}C_{(5)}C_{(6)}$	120,3(3)
$C_{(4)}C_{(5)}C_{(10)}$	122,5(4)
$C_{(6)}C_{(5)}C_{(10)}$	117,3(4)
$C_{(5)}C_{(6)}C_{(7)}$	122,6(4)
$C_{(6)}C_{(7)}C_{(8)}$	120,4(5)
$C_{(7)}C_{(8)}C_{(9)}$	119,3(6)
$C_{(8)}C_{(9)}C_{(10)}$	119,5(6)
$C_{(9)}C_{(10)}C_{(5)}$	120,8(5)
$C_{(3)}C_{(11)}C_{(12)}$	113,5(3)
$C_{(11)}C_{(12)}C_{(13)}$	111,4(4)
$C_{(12)}C_{(13)}C_{(14)}$	111,5(4)
$C_{(13)}C_{(14)}C_{(15)}$	112,1(4)
$C_{(3)}C_{(15)}C_{(14)}$	113,5(3)

TABLE 3. Atomic Coordinates ($\times 10^4$) in the Molecule of (Ia)

Atom	x	y	z
S	2547(1)	4043(0)	517(1)
$N_{(1)}$	1914(1)	4962(1)	2087(2)
$N_{(2)}$	2711(1)	5474(1)	822(3)
$N_{(3)}$	1489(1)	5946(1)	3180(2)
$C_{(1)}$	2397(2)	4857(2)	1150(3)
$C_{(2)}$	1904(1)	5660(1)	2322(3)
$C_{(3)}$	2425(2)	6090(1)	1523(3)
$C_{(4)}$	1017(2)	5494(2)	3924(3)
$C_{(5)}$	1359(2)	5207(2)	5072(3)
$C_{(6)}$	1005(2)	4696(2)	577(5)
$C_{(7)}$	1285(3)	4429(3)	6830(5)
$C_{(8)}$	1935(4)	4663(3)	7245(5)
$C_{(9)}$	2314(4)	5176(4)	6577(7)
$C_{(10)}$	2029(3)	5427(3)	5467(6)
$C_{(11)}$	2064(2)	6622(2)	666(4)
$C_{(12)}$	1837(3)	7333(2)	1296(5)
$C_{(13)}$	2464(3)	7674(2)	1982(5)
$C_{(14)}$	2799(2)	7148(2)	7879(4)
$C_{(15)}$	3031(2)	6452(2)	2267(4)
$H_{(41)}$	883(19)	4996(19)	3410(38)
$H_{(42)}$	618(20)	5804(20)	4138(37)
$H_{(6)}$	463(36)	4599(37)	5469(87)
$H_{(7)}$	1041(25)	4163(26)	7440(47)
$H_{(8)}$	2156(29)	4494(28)	7967(59)
$H_{(9)}$	2822(30)	5395(28)	7149(55)
$H_{(10)}$	2301(27)	5885(26)	5089(50)
$H_{(111)}$	1634(23)	6412(22)	277(44)
$H_{(112)}$	2432(23)	6714(24)	−27(42)
$H_{(121)}$	1549(21)	7620(21)	696(40)
$H_{(122)}$	1416(26)	7235(25)	2001(50)
$H_{(131)}$	2295(27)	8152(28)	2415(52)
$H_{(132)}$	2768(33)	7847(31)	1266(61)
$H_{(141)}$	3275(21)	7277(22)	3293(41)
$H_{(142)}$	2416(18)	7028(18)	3585(34)
$H_{(151)}$	3341(27)	6523(25)	1787(49)
$H_{(152)}$	3203(22)	6024(22)	2914(43)
$H_{(161)}$	3354(24)	5114(23)	−562(49)
$H_{(162)}$	3502(26)	5924(28)	−209(52)

and the hydrogen atom at the $N_{(1)}$ atom requires that the H^+ should come out of the σ-plane of the amidine grouping in the transfer. Even the densely packed molecular crystals are not an obstacle to such a transfer since the real volume of the H^+ is very small [8].

The bond lengths of the amidine group which we determined in the plane system of the hydantoin (Ia) are close to those previously determined [9] for N-pivaloylpivalamidine.

The cyclohexane fragment has the chair conformation with the angles of bending of 44.3° at the $C_{(11)}\ldots C_{(15)}$ line and 49.4° at the $C_{(12)}\ldots C_{(14)}$ line. The small compression of the cyclohexane near the spiro position [the $C_{(3)}C_{(15)}C_{(14)}$ and $C_{(3)}C_{(11)}C_{(12)}$ angles increase to 113.5(3)° (Table 2)] and the anti-orientation of the benzyl and cyclohexyl groups are caused by the tendency to lower the repulsion of the $N_{(3)}\ldots H_{(142)}$ and $N_{(3)}\ldots H_{(122)}$ atoms. The real $N_{(3)}\ldots H_{(122)}$ and $N_{(3)}\ldots H_{(142)}$ distances of 2.71 and 2.87 Å are in approximate agreement with

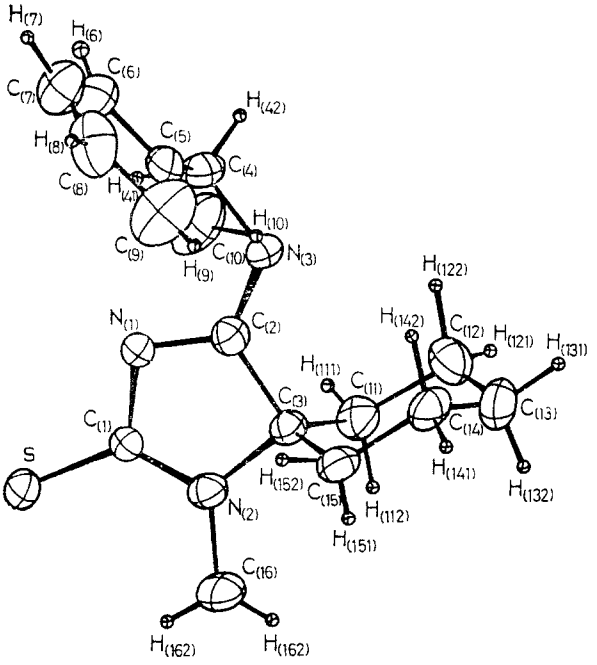


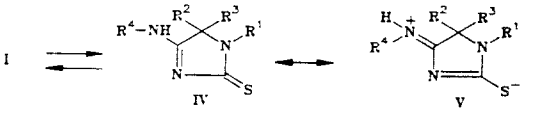
Fig. 1. The structure of 1-methyl-2-thio-4-benzylimino-5-spiro-cyclohexanehydantoin (Ia).

the total van der Waals radii of the N and H atoms [10], i.e., the deformations considered above actually lower the strain energy of the molecule of (Ia). For the same reason, the anti-orientation of the benzyl and cyclohexyl groups is realized in (Ia); there are very short $C_{(4)}H_2...H_{(142)}$, $H_{(122)}$ contacts in the syn-orientation.

The methylamino group has a larger volume than the imine group; this leads to the disposition of the former in the equatorial position of the cyclohexane, which is energetically more favorable than the axial. It may be assumed that the conversion of the cyclohexane has a low probability of occurrence in the solution, and the same thermodynamically more stable conformer is realized in the liquid phase as also exists in the crystal.

The unusual orientation of the phenyl group, which shields the $C_{(4)}$-$N_{(3)}$ bond [the torsion angle $N_{(3)}C_{(4)}C_{(5)}C_{(10)}$ is 9.0°], should be noted. The repulsion of the $N_{(3)}...C_{(10)}$ atoms is thereby partly compensated by the increase of the $N_{(3)}C_{(4)}C_{(5)}$ angle to 114.6(3)°, leading to the $N_{(3)}...C_{(10)}$ distance of 2.86 Å. The reasons for the anomaly are unclear; the significant role of the energy of the crystal field of compound (Ia) is not excluded.

The results of the x-ray structural investigation indicate that the hydantoins (Ia, b), which were previously unobtainable by the Ugi reaction, may also be obtained utilizing isonitriles, but as a result of the thermal decomposition of the salt (II). As already noted, the results of the x-ray structural investigations indicate the possibility of the tautomerism of the iminothiohydantoins (I). The NMR spectra of the compounds of this series confirm the existence of their amine and imine forms in the solution (Table 4). It follows from the comparative analysis of the ^{13}C NMR spectra of the compounds (I) and (VI) that only the iminothiohydantoins contain a double set of signals, whereby one of the signals of the C=S group is significantly shifted to low field (190...195 ppm). The most probable cause of such an effect, which was previously observed for analogous systems [11], is the formation of the amine form (IV) of iminothiohydantoin. The last guarantees the definite contribution of the resonance structure (V), which has raised electron density at the sulfur atom; as a result of this, there is also the shift of the signal of the thione group to low field.



It is characteristic that the hydantoin occurs preferentially in the form (IV) (~60%) in the case of $R^4 = CH_2Ph$, whereas about 30% of the hydantoin occurs in the imino form (I)

TABLE 4. NMR Spectra of the Compounds Synthesized

Compound	^{1}H NMR spectrum, ppm	^{13}C NMR spectrum, ppm
Ia	1,66 (10H, m, cyclo-C_6H_{10}); 3,01; 3,15 (3H, 2 s, N—CH_3); 4,29; 4,48 (2H, 2 s, N—CH_2); 7,03...7,14 (5H, 2 s, C_6H_5); 8,33 (NH)	193,2; 179,1 (C=S); 181,2; 158,0 (C=N); 141,1; 138,4; 137,4; 128,9; 128,4; 128,2; 126,9; 125,4 (C_6H_5); 68,8; 65,5 (C-spiro); 52,6; 45,5 (CH$_2$—Ph); 31,4; 31,3 (N—CH_3); 28,1...19,9 (cyclo-C_6H_{10})
Ib	1,73 (10H, m, cyclo-C_6H_{10}); 2,25 (3H, s, Ar—CH_3); 3,04 (3H, s, N—CH_3); 6,81 (4H, q, p-C_6H_4); 7,62 (NH, br. s)	193,1; 179,2 (C=S); 179,8; 157,8 (C=N); 145,6; 138,4; 136,5; 133,2; 131,4; 129,7; 120,4; 119,2 (C_6H_4); 70,4; 65,6 (Cspiro); 37,7; 37,4 (N—CH_3); 31,2...19,5 (cyclo-C_6H_{10}, Ar—CH_3)
Ic	1,61 (10H, m, cyclo-C_6H_{10}); 3,60 (H m, HS as a result of the thione-thiol); 4,35; 4,53 (2H, 2 s, N—CH_2); 4,80; 4,98 (2H, 2 s, CH_2—N=C); 7,16 (10H, 2 s, C_6H_5); 8,40 (NH, br.s)	194,7; 180,5 (C=S); 181,3; 157,5 (C=N); 140,8; 138,2; 128,3; 127,9; 126,9; 126,5 (C_6H_5); 69,7; 66,7 (C-spiro); 52,5; 46,9; 45,5; 44,4 (CH$_2$—Ph); 32,5; 32,0 (N—CH_3); 24,0...19,7 (cyclo C_6H_{10})
VIa	1,76 (10H, m, cyclo-C_6H_{10}); 3,14 (3H, s, N—CH_3); 9,33 (NH, br.s)	180,4; 178,2 (C=S, C=O); 66,3; 28,9; 24,7; 21,2 ($C_{(1,2,3,4)}$); 30,8 (N—CH_3)
VIb	1,57 (10H, m, cycloC_6H_{10}); 4,89 (2H, s N—CH_2); 7,25 (5H, s, C_6H_5); 10,60 (NH, br.s)	

TABLE 5. Physicochemical Characteristics of the Compounds Synthesized

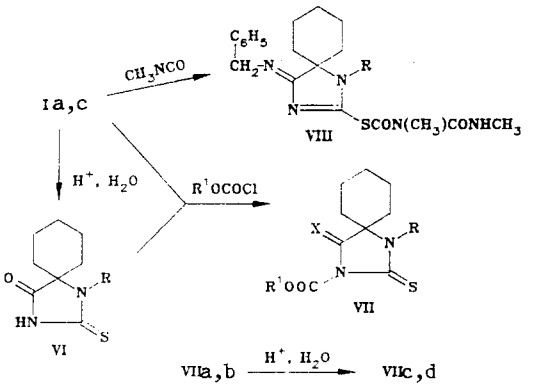
Compound	Empirical formula	mp, °C	IR spectrum, cm^{-1} (KBr)			Yield, %
			NH	C=O	C=N, C=C	
Ia	$C_{16}H_{21}N_3S$	205	3420	—	1585...1600	100
Ib	$C_{16}H_{21}N_3S$	155	3415	—	1695	70
Ic	$C_{22}H_{25}N_3S$	237	3350...3440	—	1580...1600, 1610	62
VIa	$C_9H_{14}N_2OS$	152	3430	1730	1640	50
VIb	$C_{15}H_{18}N_2OS$	130...131	3440	1765	—	53
VIIa	$C_{21}H_{29}N_3O_2S$	—	—	1760	1590, 1620, 1640	85
VIIb	$C_{27}H_{33}N_3O_2S$	—	—	1710, 1760	1610	65
VIIc	$C_{14}H_{22}N_2O_3S$	102...103	—	1740, 1790	—	96
VIId	$C_{20}H_{26}N_2O_3S$	—	—	1760, 1785	—	75
VIIIa	$C_{20}H_{27}N_5O_2S$	142	3370	1730, 1715	1650	58
VIIIb	$C_{26}H_{31}N_5O_2S$	132...133	3445	1705, 1725	1680	88

when R^4 = 4-$CH_3C_6H_4$. This effect conforms with the known fact that there is a shift of the tautomeric equilibrium in favor of the imine form when there is a decrease in the basicity of the exocyclic nitrogen atom [12].

Geometrical modeling of the optimal conformation of the R^1 group (CH_2Ph) in compound (Ic) was carried out from the data of the x-ray structural analysis of the hydantoin (Ia) (R^4 = CH_2Ph) to explain the spectral data. It was shown that the phenyl group can only occur in the anti-orientation to the cyclohexyl, since the short contacts of C(Ph)...C (cyclohexyl) 2.6 Å (minimal) otherwise lead to the increase in the energy of the molecule and the instability of the given conformation. However, high strain arises in the compound (Ic) owing to the nonvalent interactions S...H(Ph) 2.8 Å and C(1)...H(Ph) 2.4 Å even in the anti-orientation of the phenyl group to the cyclohexane ring.

According to all evidence, the indicated strain partly lowers the twisting of the heterocycle; this should lead to the decrease of the p-π* conjugation in compound (Ic). These factors, in total, favor some increase in the chemical shift of the $C_{(2)}$ atom in the NMR spectrum of the hydantoin (Ic) by comparison with (Ia). This conclusion may also accommodate the data on the reactivity of the 2-thioimidazolidin-4-ones (VIa, b). Compound (VIa) reacts slowly with chlorocarbonate esters; 1 h is required for the completion of the reaction (monitoring ib by the method of TLC). At the same time, the thiohydantoins (VIb) react rapidly (1...5 min) with chlorocarbonate esters, whereby the decomposition of the reaction product with the isolation of the initial (VIb) is observed with the increase in the duration of the reaction. (Formula, top, following page.)

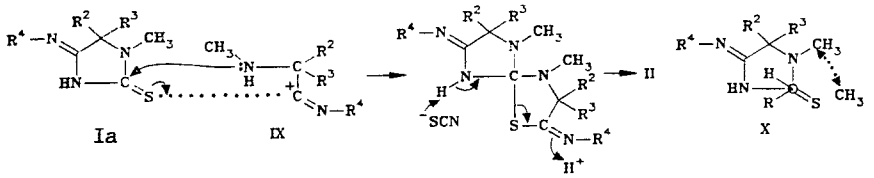
The decrease of the conjugation in the molecule of (VIb) should lead to the increase of the acidic properties of the $N_{(3)}$-H group, the increase of its capacity for partial ionization under the influence of triethylamine, and, in consequence of this, higher reactivity by com-



V) a VIIa,c,VIIIa R=CH_3; VIb, VIIb,d, VIIIb R=CH_2Ph; VIIa–d R=iso-C_4H_9; VIa,b X=NCH_2Ph; VIc,d X=O

parison with the hydantoin (VIa). It was shown somewhat unexpectedly that the thiohydantoins (Ia, c) give the disubstituted products (VIII) with excess methyl isocyanate; their structure was confirmed by the data of IR spectroscopy (Table 5) and mass spectrometry.

It should be noted that thiohydantoins of the type (Ic) are known at the present time; they were obtained by the authors [2], where $R^1 = CH_2R$ (R = CH_2, C_6H_5, n-C_3H_7), iso-Pr, and Ph. Therefore, the volume of the substituent R^1 is higher than that of the CH_3 group for all the thiohydantoins obtained by the Ugi reaction; the reaction under the Ugi conditions leads to the imidazolium salts (II) when R^1 = H or CH_3. In connection with this, there arose the proposition that the formation of the salts (II) may pass through the intermediate product of the reaction of (Ia) according to the scheme*



One of the reaction stages is thereby the formation of the intermediate (X), which will not be sterically destabilized by the repulsion of the methyl substituents of the nucleophile and the hydantoin when $R^1 = CH_3$ [when $R^1 = CH_2R$, the repulsion of the CH_2R groups should stabilize the system and lead to the decomposition of (X)]. In fact, geometric modeling showed that there are no contacts significantly less than the totals of the van der Waals radii when $R^1 = CH_3$ in the initial stage of the nucleophilic addition ($R_{N\ldots C=S}$ = 2.7 Å, the angle of attack N...C = S 90°), whereas the system is very strained [R (of the hydantoin)...H (of the nucleophilic group) 2.3 Å] for $R^1 = CH_2R$ (taking into account the cis-orientation of the R to the attacking nucleophile) and further approach is of low probability. Compound (Ia) was included in the conditions of the reaction revealed by us in order to test the proposition; however the consumption of the hydantoin was not observed with the formation of the salts (II). It cannot be excluded that the incorrect angle of attack N...C=S was taken in the initial modeling; this comprises 107.5° in conformity with the analysis of the x-ray structural data [13]. We will note that such an approach is sterically forbidden since the nonvalent distances N(Nu)...H (Ia) comprise 1.9 Å in the initial stage of the attack, i.e., 0.7 Å less than the sum of the van der Waals radii of the N and H atoms.

In conclusion, we will note the following case. In the crystal of (Ia), the molecules are disposed in pairs relative to the origin of the coordinates in the quadrants (0, X, Y–0, $\bar{X}$, $\bar{Y}$, height Z) and (0, $\bar{X}$, Y–0, X, $\bar{Y}$, height $\bar{Z}$). Cavities are thereby formed in the region of (0, $\bar{X}$, Y–0, X, $\bar{Y}$, height Z) and (0, X, Y–0, $\bar{X}$, $\bar{Y}$, height $\bar{Z}$); these are evidently occupied by disordered solvent molecules. Peaks (7...10) with the electron density approximately twice that at the corresponding hydrogen atoms of the compound (Ia) were found in the different syntheses in the indicated regions.

*The scheme of the formation of (II) via the corresponding derivative of thiazolidinimine was previously [1] proposed.

The attempt to identify the peaks was unsuccessful since the majority of them gave short mutual contacts. We propose that the nature of the disordered molecules will be shown in the low-temperature x-ray structural investigation.

EXPERIMENTAL

The IR spectra were taken on a Perkin-Elmer 457 instrument with KBr tablets and in CCl_4. The ^1H and ^{13}C NMR spectra were taken on the Bruker HX-90E (90 MHz), Varian HL-400, and Varian WM-250 (250 MHz) instruments for the solutions in $(CD_3)_2SO$, using the internal standard of TMS. The mass spectra were obtained on the LKB-2091 mass spectrometer at 70 eV.

The course of the reaction and the purity of the substances were monitored by the method of TLC on plates of Silufol UV-254 in the solvent systems of 1:3 acetone-benzene and 1:2 acetone:hexane. The structure of the compounds was confirmed by the data of the elemental analysis and by spectral data (Tables 4, 5).

The data of the elemental analyses of the compounds (I), (VI), and (VII) for C, H, N, and S correspond with the calculated values.

1-Methyl-2-thio-4-p-tolylimino-5-spirocyclohexanehydantoin (Ib). The imidazolium salt (II) (0.01 mole) is boiled in toluene for 40 min; the monitoring is by the method of TLC. The reaction product which was precipitated after cooling is filtered off.

In the analogous way, 1-methyl-2-thio-4-benzylimino-5-spirocyclohexanehydantoin (Ia) is obtained.

X-Ray Structural Investigation of (Ia). The main crystallographic data are as follows: $C_{16}H_{21}N_3S$; M = 288.93; a = b = 18.510(4), c = 10.946(4) Å; V = 3750.3 Å^3; d_{calc} = 1.22 g/cm^3; Z = 8; space group 14. The intensities of 1692 reflections with $I > 2\sigma(I)$ were measured on the DAR-UM diffractometer with the CuK_α-emission. The structure was decoded in the "manual" regime by the Rentgen-75 program [14]. The reference reflection was chosen in accordance with the rules of [15]; the reflection coordinates were chosen from the number of the strongest with the maximal TRP. In order to facilitate the decoding, two reflections of the particular type (type hk0, phase 0 or 180°) were included in the list of the reflection coordinates. The model of the structure was found from the variant with the R-evaluation 0.971; the H atoms were localized from the R-syntheses. Refinement was carried out by the method of least squares with the full-matrix approximation according to [14] taking into account the anisotropy for the S, N, and C atoms and the isotropy for the H atoms up to R = 0.063 (the R-factor for the reflections of the type hk0 comprises 0.165, and $R \leq 0.062$ in the remaining layers hkl...hk10). The difference synthesis showed peaks closely disposed to each other with the height of the electron density double that for the corresponding hydrogen atoms. The impossibility of the unambiguous identification led to the high total R-factor and the R-factor on the zero layer.

The atomic coordinates are presented in Table 3; the molecule in Fig. 1 was obtained by the ELLIDS program [16].

The geometrical modeling was carried out using the complex of the Viking programs [17].

1-Benzyl-2-thio-4-benzylimino-5-spirocyclohexanehydantoin (Ic). To the solution of 0.49 g (0.005 mole) of cyclohexanone in 10 ml of methanol are added, sequentially, 0.535 g (0.005 mole) of benzylamine, 0.485 g (0.005 mole) of potassium thiocyanate, 0.685 g (0.005 mole) of triethylamine hydrochloride dissolved in 1 ml of water, and then 0.585 g (0.005 mole) of benzyl isocyanide. The mixture is stirred at room temperature. At the end of the reaction (with chromatographic monitoring), the precipitated product is filtered off, and is washed with water and hexane. The mass spectrum* is as follows: 28 (30), 42 (12), 66 (6), 81 (11), 91 (100), 92 (12), 111 (6), 272 (20), $(M + 1)^+$ 364 (40), $(M + 2)^+$ 365 (29).

1-Methyl-2-thio-4-oxa-5-spirocyclohexanehydantoin (VIa). Compound (Ia) (0.001 mole) in 20 ml of ethanol is boiled with 1 ml of 10% HCl in the course of 1 h. At the end of the reaction, the mixture is diluted with water and cooled; the precipitated product is filtered off and washed with water.

*Here and subsequently, the peaks of the ions with the intensity greater than 5% of the maximal are presented.

4.65 ppm, which is not in accord with the proposed structure. The same compound was formed in the reaction of methylenebis-2,2'-cyclohexanone with phosphorus pentasulfide in the absence of solvent with subsequent treatment of the reaction mixture with aqueous sodium bicarbonate [3].

Compound (VIb) is obtained analogously. The mass spectrum is as follows: 30 (5), 39 (6), 41 (9), 53 (6), 54 (7), 56 (6), 65 (13), 67 (18), 77 (9), 79 (13), 81 (10), 82 (6), 91 (50), 106 (73), 107 (13), 110 (17), 148 (10), 165 (10), 183 (5), 219 (12), M^+ 274 (100), $(M + 1)^+$ 275 (18), $(M + 2)^+$ 276 (7).

1-Methyl-2-thio-3-isobutoxycarbonylamino-4-oxa-5-spiro-cyclohexanehydantoin (VIIc). To 1 mmole of the compound (VIa) in 10 ml of toluene are added 1.5 mmole of triethylamine and 1.5 mmole of isobutyl chloroformate. The mixture is maintained for 1 h at room temperature. At the end of the reaction (with chromatographic monitoring), the triethylamine hydrochloride is filtered off; the solvent is evaporated, and the oil obtained is crystallized with hexane.

Compound (VIId) is obtained analogously. In contrast to the substance (VIa), compound (VIb) reacts with alkyl chlorocarbonates in the course of 1-5 min.

1-Benzyl-2-thio-3-isobutoxycarbonylamino-4-benzylimino-5-spirocyclohexanehydantoin (VIIb). To the solution of 0.18 g (0.05 mmole) of compound (Ic) and 0.101 g (1 mmole) of triethylamine in 10 ml of toluene are added, dropwise, 0.136 g (1 mmole) of isobutyl chlorocarbonate, and the mixture is maintained for 3 h at room temperature. At the end of the reaction (with chromatographic monitoring), the triethylamine hydrochloride is filtered off, and the solvent is evaporated. The reaction product is an oil.

Compound (VIIa) is obtained analogously from compound (Ia).

1-Methyl-2-[(N-methylcarbamoyl)methylamino]carbonylthio-4-benzylimino-5-spirocyclohexanehydantoin (VIIIa). To the solution of 0.143 g (0.5 mmole) of compound (Ia) are added 1.425 g (25 mmole) of methyl isocyanate and 0.347 ml (2.5 mmole) of triethylamine. At the end of the reaction (with monitoring by the method of TLC), the solution is evaporated; the oil obtained is crystallized with hexane. The mass spectrum is as follows: 42 (18), 58 (79), 91 (78), 171 (38), 196 (31), 232 (21), 287 (100), 288 (20), M^+ 401 (53), and $(M + 1)^+$ 402 (3).

Compound (Ic) reacts analogously with methyl isocyanate with the formation of the product (VIIIb).

LITERATURE CITED

1. A. I. Polyakov, L. A. Medvedeva, O. A. D'yachenko, A. B. Zolotoi, and L. O. Atovmyan, Khim. Geterotsikl. Soedin., No. 1, 53 (1986).
2. I. Ugi, F. K. Rosendahe, and F. Bodesheim, Annalen, 666, 54 (1963).
3. I. Ugi, Isonitrile Chemistry, Acad. Press, New York (1971), p. 145.
4. D. E. Jensen, S.-O. Laweson, R. Bardi, A. M. Piazzesi, and C. Toniolo, Tetrahedron, 41, 5595 (1985).
5. N. A. Tarasenko, V. P. Avakyan, and V. V. Belik, Zh. Strukt. Khim., 19, 541 (1978).
6. K. E. Raczyns and J. Ozczapowitz, Tetrahedron, 41, 5175 (1985).
7. I. D. Cunningham and A. F. Hegarty, J. Chem. Soc., Perkin Trans. 2, No. 4, 537 (1986).
8. S. Lifson, A. I. Hagler, and P. Dauber, J. Am. Chem. Soc., 101, 5111 (1979).
9. J. Uvoslef, M. L. Fracy, and C. P. Nash, Acta Cryst., C42, 353 (1986).
10. Yu. V. Zefirov and P. M. Zorkii, Zh. Strukt. Khim., 15, 118 (1974).
11. V. V. Negrebetskii, V. I. Kal'chenko, O. V. Balitskaya, M. Yu. Kornilov, and L. N. Markovskii, Zh. Obshch. Khim., 54, 1764 (1984).
12. Yu. N. Sheinker, Dokl. Akad. Nauk SSSR, 113, 1080 (1957).
13. H. B. Burgi, J. D. Danitz, and E. Shefter, Acta Cryst., B30, 1517 (1974).
14. V. I. Andrianov, D. Sh. Safina, and B. A. Tarnopol'skii, "Rentgen-75." An Automated System of Programs for the Decoding of Crystal Structures [in Russian], Publishing House of the Institute of Chemical Physics of the Academy of Sciences of the USSR, Chernogolovka (1975), p. 82.
15. C. Giacovazzo, Acta Cryst., A30, 390 (1974).
16. A. N. Chekhlov, Kristallografiya, 26, 596 (1981).
17. Yu. A. Ustynyuk, Quantum-chemical Methods of Calculation of Molecules [in Russian], Khimiiya, Moscow (1980).