

STRUCTURE
OF ORGANIC COMPOUNDS

X-ray Mapping in Heterocyclic Design:
XIV. Tricyclic Heterocycles Based
on 2-Oxo-1,2,5,6,7,8-Hexahydroquinoline-3-Carbonitrile

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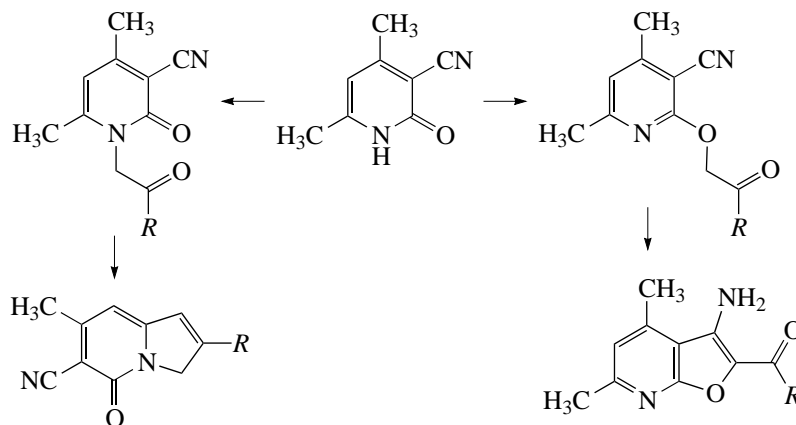
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Abstract—The structures of four compounds are studied using single-crystal X-ray diffraction: 1-[2-(4-chlorophenyl)-2-oxoethyl]-2-oxo-1,2,5,6,7,8-hexahydroquinoline-3-carbonitrile [$a = 4.908(4)$ Å, $b = 11.644(10)$ Å, $c = 13.587(2)$ Å, $\beta = 94.31(5)^\circ$, $Z = 2$, space group $P2_1$]; 2-[2-(4-chlorophenyl)-2-oxoethoxy]-5,6,7,8-tetrahydroquinoline-3-carbonitrile [$a = 7.6142(8)$ Å, $b = 14.778(2)$ Å, $c = 14.132(2)$ Å, $\beta = 100.38(1)^\circ$, $Z = 4$, space group $P2_1/c$]; 4-(aminocarbonyl)-2-(chlorophenyl)-6,7,8,9-tetrahydro[1.3]oxazolo[3,2-*a*]quinolin-3-ium perchlorate [$a = 5.589(7)$ Å, $b = 24.724(15)$ Å, $c = 13.727(5)$ Å, $\beta = 97.66(9)^\circ$, $Z = 4$, space group $P2_1/n$]; and (3-amino-5,6,7,8-tetrahydrofuro[2,3-*b*]quinolin-2-yl)-(4-chlorophenyl) methanone [$a = 7.150(2)$ Å, $b = 7.4288(10)$ Å, $c = 15.314(3)$ Å, $\alpha = 98.030(10)^\circ$, $\beta = 99.21(2)^\circ$, $\gamma = 105.34(2)^\circ$, $Z = 2$, space group $P\bar{1}$]. The structures are solved by direct methods and refined by the full-matrix least-squares procedure in the anisotropic approximation to $R = 0.0728$, 0.0439 , 0.1228 , and 0.0541 , respectively. The structure of 1-(4-chlorophenyl)-4-piperidin-1-yl-8,9-dihydro-7*H*-pyrrolo[3.2.1-*ij*]quinoline-5-carboxamide [$a = 23.9895(9)$ Å, $b = 5.1557(3)$ Å, $c = 17.0959(9)$ Å, $\beta = 106.43^\circ$, $Z = 4$, space group $P1/c$] is investigated by X-ray powder diffraction. This structure is solved using the grid search procedure and refined by the Rietveld method to $R_{wp} = 0.0773$, $R_{exp} = 0.0540$, $R_p = 0.0585$, $R_b = 0.1107$, and $\chi^2 = 1.78$. © 2004 MAIK “Nauka/Interperiodica”.

INTRODUCTION

Readily available derivatives of 6-methyl-cyanopyridones-2 are promising substances as precursors of complex condensed heterocyclic compounds. For example, it is known that the phenacylation of these

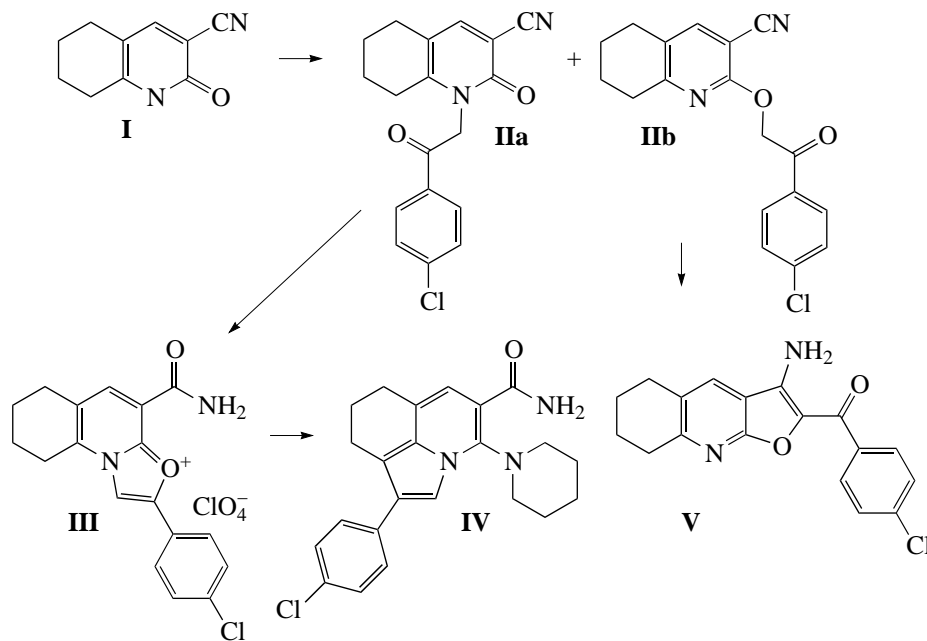
pyridones results the formation of *N* and *O* alkylation products. It should be noted that, in alkaline media, *O* isomers easily enter into cyclization reactions with the formation of furo[2,3-*b*]pyridine derivatives, whereas *N* isomers are cyclized to form 5-indolizinones [1, 2] (see Scheme 1):



Scheme 1

In the present work, we demonstrated that the possible heterocyclization reactions of 6-methyl-cyanopyridones-2 are not exhausted by the above processes. The

synthesis of the studied compounds was performed according to the following scheme:



By using compound **I** as an example, we found one more direction of the heterocyclization of *N*-phenyl derivatives of the aforementioned pyridones, namely, the transformation of *N* isomer **IIa** into compound **III**, which, in turn, can be recycled into the poorly investigated compound **IV**.

Earlier, the phenacylation of compound **I** was not described. We revealed that this reaction results in the formation of *N* and *O* isomers (in the ratio 1 : 1); in this case, it is possible to separate the mixture of isomers. As could be expected, compound **IIb** is cyclized with the formation of compound **V**.

Table 1. Physicochemical characteristics of the compounds synthesized

Compound	Melting temperature T_m , °C	$^1\text{H NMR}^*$ (DMSO- d_6)
IIa	233	8.10 and 7.69 (d, 8.3 Hz, 2H, 14-CH + 15-CH and 17-CH + 18-CH)**; 8.03 (s, 1H, 4-CH); 5.66 (s, 2H, 11-CH ₂); 2.57 (m, 4H, 6-CH ₂ + 9-CH ₂); 1.73 and 1.64 (m, 2H, 7-CH ₂ and 8-CH ₂)***
IIb	247	8.01 and 7.64 (d, 8.6 Hz, 2H, 14-CH + 15-CH and 17-CH + 18-CH)**; 7.98 (s, 1H, 4-CH); 5.97 (s, 2H, 11-CH ₂); 2.66 and 2.56 (t, 5.8 Hz and 6.0 Hz, 2H, 6-CH ₂ and 9-CH ₂)***; 1.70 (m, 4H, 7-CH ₂ + 8-CH ₂)
III	283	9.52 (s, 1H, 11-CH); 8.59 (s, 1H, 4-CH), 8.32 and 8.24 (s, 1H, 31-NH ₂); 8.12 and 7.8 (d, 8.6 Hz, 2H, 14-CH + 15-CH and 17-CH + 18-CH)**; 3.14 and 2.98 (t, 5.9 Hz and 5.6 Hz, 2H, 6-CH ₂ and 9-CH ₂)***; 2.02 and 1.86 (m, 2H, 7-CH ₂ and 8-CH ₂)***
IV	262	7.78 and 6.41 (s, 1H, 31-NH ₂); 7.66 and 7.47 (d, 8.5 Hz, 2H, 17-CH + 18-CH and 14-CH + 15-CH)**; 7.53 (s, 1H, 4-CH); 6.41 (s, 1H, 11-CH); 3.17 and 3.05 (s, 2H, 19-CH ₂ and 23-CH ₂)***; 2.96 and 2.78 (t, 2H, 5.6 Hz, 8-CH ₂ and 6-CH ₂)***; 1.95 (m, 2H, 7-CH ₂); 1.82 and 1.70 and 1.40 (m, 6H, Pip (CH ₂ -CH ₂ -CH ₂))
V	278	8.16 (s, 1H, 4-CH); 8.11 and 7.63 (d, 8.3 Hz, 2H, 14-CH + 15-CH and 17-CH + 18-CH)**; 7.56 (s, 2H, 31-NH ₂); 2.91 and 2.86 (t, 6.4 Hz and 6.1 Hz, 2H, 6-CH ₂ and 9-CH ₂)***; 1.82 (m, 4H, 7-CH ₂ + 8-CH ₂)

* The assignment of the signals is given in accordance with the atomic numbering used in X-ray diffraction analysis (Figs. 2–6).

** The reverse assignment of CH₂ groups is possible.

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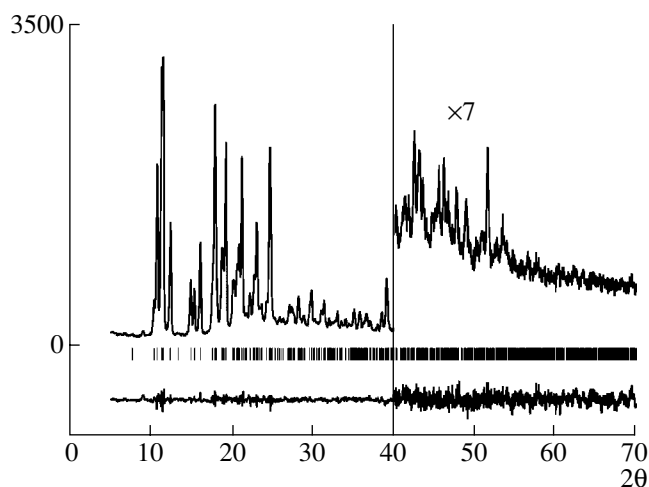


Fig. 1. Experimental and difference X-ray powder diffraction patterns (after the final Rietveld refinement) for structure **IV**.

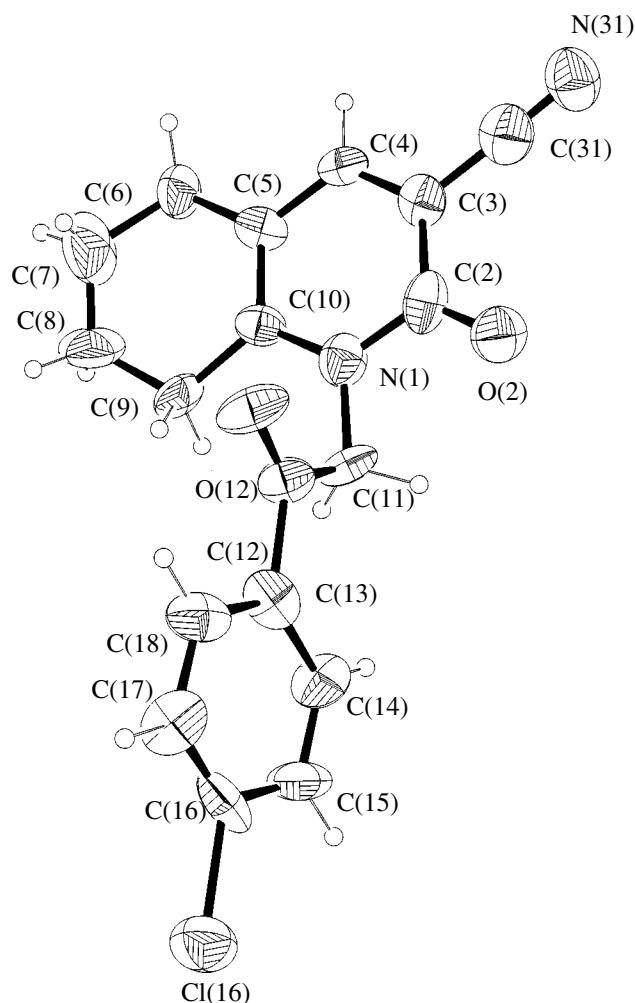


Fig. 2. Molecular structure and atomic numbering for compound **IIa**.

In this work, we did not analyze the possibility of cyclizing compound **IIa** into indolizine. It is known [3] that, under the action of acids, *N*-phenacylpyridones-2 are able to undergo cyclocondensation with the formation of bicyclic oxazolopyridinium salts. In [3], it was shown that oxazolopyridinium salts with a methyl group in the fifth position can be recycled to form 5-substituted indolizines. In the case of compound **IIa**, a similar cyclization proceeds with the formation of tricyclic compound **III**. It is worth noting that the cyclization is accompanied by the hydrolysis of the nitrile group and the formation of the amide group in the system. Compound **III** also contains the methylene group in the position appropriate for recyclization. It turned out that, under the action of the secondary amine, the tricyclic system of oxazolopyridinium undergoes previously unknown recyclization into a poorly studied tricyclic system of compound **IV**. Note that the topological feature of the observed recyclization is the transformation of a partially hydrogenated *cata*-condensed tricyclic system (in which each fusion atom is shared only by two rings) into a *peri*-condensed system (involving the atom shared by three rings).

EXPERIMENTAL

Compounds **I–V** were synthesized according to Scheme 2.

Compound 2-oxo-1,2,5,6,7,8-hexahydroquinoline-3-carbonitrile (I) was prepared using the procedure described in [4] and was investigated in our previous work [5]. The physicochemical characteristics of the compounds synthesized are presented in Table 1.

1-[2-(4-Chlorophenyl)-2-oxoethyl]-2-1,2,5,6,7,8-hexahydroquinoline-3-carbonitrile (IIa) and **2-[2-(4-chlorophenyl)-2-oxoethoxy]-5,6,7,8-tetrahydroquinoline-3-carbonitrile (IIb)**. These compounds were synthesized according to a procedure similar to that proposed in [1]. Potassium hydroxide (0.0057 mol) and ethanol (5 ml) were placed in a round-bottomed flask. Compound **I** (0.0057 mol) was added portionwise with stirring to the prepared solution. The mixture was allowed to stand in an ultrasonic bath for 40 min, and then the alcohol was evaporated with a rotary evaporator. Dimethylformamide (10 ml) and phenacyl bromide (0.0057 mol) were added to the dry residue. The mixture was allowed to stand at an elevated temperature ($T \sim 50^\circ\text{C}$) for 18 h with stirring. After completing the reaction (controlled by thin-layer chromatography indicating the absence of compound **I**), the reaction mixture was cooled and poured into water. The precipitate was filtered off and dried in air. The mixture of *N* and *O* isomers was separated using a column (sorbet, SiO_2 ; chloroform : hexane = 1 : 1). The yields of compounds **IIa** and **IIb** were equal to 43 and 47%, respectively.

4-(Aminocarbonyl)-2-(chlorophenyl)-6,7,8,9-tetrahydro[1.3]oxazolo[3,2-*a*]quinolin-3-ium perchlorate (III). Compound **III** was prepared from com-

Table 2. Crystal data, data collection, and refinement parameters for structures **IIa**, **IIb**, **III**, **IV**, and **V**

Empirical formula	C ₁₈ H ₁₅ ClN ₂ O ₂ (IIa)	C ₁₈ H ₁₅ ClN ₂ O ₂ (IIb)	C ₁₈ H ₁₆ ClN ₂ O ₂ · ClO ₄ (III)	C ₂₃ H ₂₄ ClN ₃ (IV)	C ₁₈ H ₁₅ ClN ₂ O ₂ (V)
Molecular weight	326.79	326.79	427.24	393.92	326.79
Crystal system	Monoclinic	Monoclinic	Monoclinic	Monoclinic	Triclinic
Space group	<i>P</i> 2 ₁	<i>P</i> 2 ₁ / <i>c</i>	<i>P</i> 2 ₁ / <i>n</i>	<i>P</i> 2 ₁ / <i>c</i>	<i>P</i> $\bar{1}$
<i>a</i> , Å	4.908(4)	7.6142(8)	5.589(7)	23.9895(9)	7.150(2)
<i>b</i> , Å	11.644(10)	14.778(2)	24.724(15)	5.1557(3)	7.4288(10)
<i>c</i> , Å	13.587(8)	14.132(2)	13.727(5)	17.0959(9)	15.314(3)
α , deg					98.030(10)
β , deg	94.31(5)	100.38(1)	97.66(9)	106.43(3)	99.21(2)
γ , deg					105.34(2)
<i>V</i> , Å ³	774.3(10)	1564.2(4)	1881(3)	2028.18(2)	760.0(3)
<i>Z</i>	2	4	4	4	2
ρ_{calcd} , g/cm ³	1.401	1.388	1.508	1.290	1.428
$\mu(\text{CuK}\alpha)$, cm ⁻¹	2.28	2.26	3.46	1.80	2.32
θ range, deg	3.26-54.98	4.37-69.97	3.58-49.97	1.92-35.00	2.98-69.92
Crystal size, mm	0.3 × 0.3 × 0.3	0.3 × 0.3 × 0.3	0.3 × 0.3 × 0.3	Powder	0.3 × 0.3 × 0.3
Number of reflections measured	1576	3083	2030		2900
Number of unique reflections	1433 (<i>R</i> _{int} = 0.074)	2958 (<i>R</i> _{int} = 0.028)	1936 (<i>R</i> _{int} = 0.244)		2791 (<i>R</i> _{int} = 0.079)
Number of reflections refined	209	209	254		217
<i>R</i> factor [<i>I</i> ≥ 2σ(<i>I</i>)] <i>R</i> ₁ / <i>wR</i> ₂	0.0728/0.1399	0.0439/0.1099	0.1228/0.2983		0.0541/0.1379
$\Delta\rho_{\text{max}}/\Delta\rho_{\text{min}}$, e/Å ³	0.233/−0.180	0.175/−0.256	0.776/−0.518		0.597/−0.531
<i>R</i> _{wp}				0.0773	
<i>R</i> _{exp}				0.0540	
<i>R</i> _p				0.0585	
<i>R</i> _b				0.1107	
χ^2				1.78	

compound **IIa** according to a procedure similar to that described in [3]. Compound **IIa** (1 g) was dissolved in 96% H₂SO₄ (2 ml) and left to stand for a night. 70% HClO₄ (5 ml) was added to water (50 ml), and the H₂SO₄ mixture was poured into the prepared solution. The precipitate was filtered off, washed on a filter with water, and dried. The yield of compound **III** was 98%.

1-(4-Chlorophenyl)-4-piperidin-1-yl-8,9-dihydro-7H-pyrrolo[3,2,1-*ij*]quinoline-5-carboxamide (IV). This compound was synthesized according to a procedure similar to that described in [3]. Compound **III** (0.5 g) and piperidine (5 ml) were boiled in acetonitrile (15 ml) to the formation of a yellowish green thick solution. The solution was poured into water, and the precipitate was filtered off and recrystallized from acetonitrile. The yield of compound **IV** was 87%.

Table 3. Selected bond lengths *d* (Å) in structure **IIa**

Bond	<i>d</i>	Bond	<i>d</i>
N(1)–C(2)	1.355(19)	C(6)–C(7)	1.50(2)
N(1)–C(10)	1.41(2)	C(7)–C(8)	1.36(2)
N(1)–C(11)	1.472(18)	C(8)–C(9)	1.48(2)
C(2)–O(2)	1.21(2)	C(9)–C(10)	1.479(18)
C(2)–C(3)	1.44(2)	C(11)–C(12)	1.499(18)
C(3)–C(4)	1.361(11)	C(12)–O(12)	1.168(17)
C(3)–C(31)	1.43(2)	C(12)–C(13)	1.55(2)
C(4)–C(5)	1.499(11)	Cl(16)–C(16)	1.781(17)
C(5)–C(10)	1.38(2)	C(31)–N(31)	1.13(2)
C(5)–C(6)	1.482(19)		

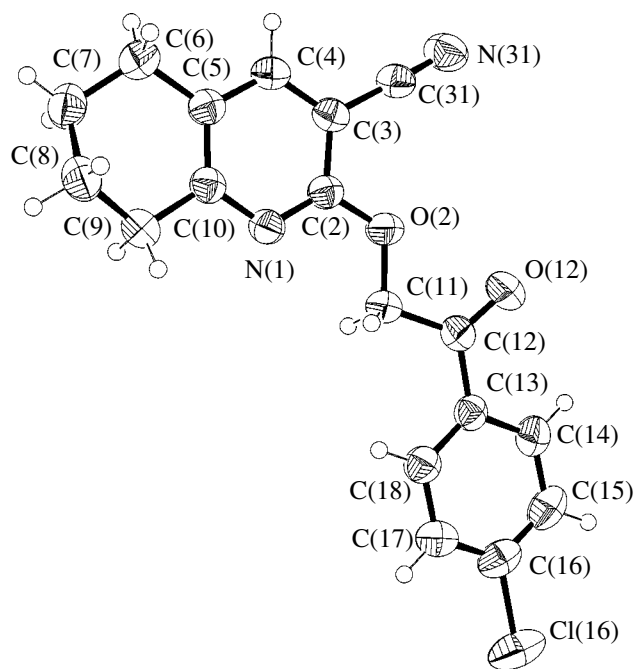


Fig. 3. Molecular structure and atomic numbering for compound **IIb**.

(3-Amino-5,6,7,8-tetrahydrofuro[2,3-*b*]quinolin-2-yl)-(4-chlorophenyl)-methanone (V). Compound **V** was prepared using a procedure similar to that proposed by Gewald [1]. Compound **IIb** was boiled in absolute methanol with a threefold excess of sodium methylate for 16 h. The precipitate was filtered off, washed on a filter with methanol, and dried. The yield of compound **V** was 68%.

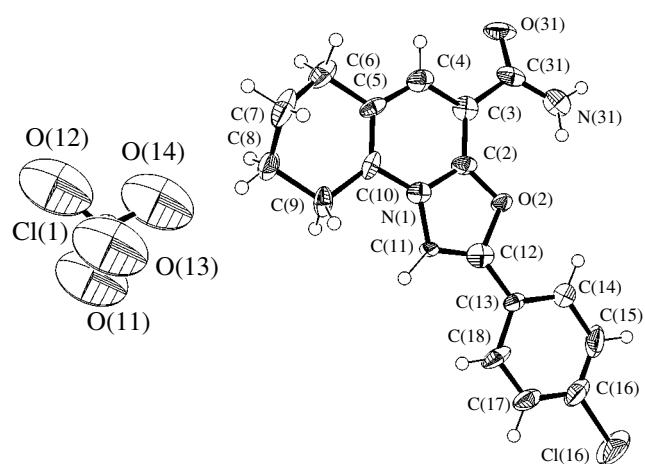


Fig. 4. Molecular structure and atomic numbering for compound **III**.

The experimental intensities of diffraction reflections for single crystals of compounds **IIa**, **IIb**, **III**, and **V** were measured on a CAD4 automated diffractometer [6] ($\text{CuK}\alpha$ radiation, graphite monochromator, ω scan mode) at room temperature. The unit cell parameters were determined and refined using 25 reflections in the θ ranges 24° – 26.5° , 30° – 35° , 21° – 25° , and 25° – 29° , respectively. No correction for absorption was introduced because of the small linear absorption coefficients of the compounds studied and the small sizes of their crystals. The primary processing of the sets of diffraction data was performed with the WinGX program package [7]. All the subsequent calculations were carried out with the SHELX97 program package [8]. The

Table 4. Selected bond angles ω (deg) in structure **IIa**

Angle	ω	Angle	ω
C(2)–N(1)–C(10)	123.7(16)	C(8)–C(7)–C(6)	121(2)
C(2)–N(1)–C(11)	114.6(16)	C(7)–C(8)–C(9)	118.8(18)
C(10)–N(1)–C(11)	121.7(15)	C(10)–C(9)–C(8)	112.5(16)
O(2)–C(2)–N(1)	122(2)	C(5)–C(10)–N(1)	118.6(14)
O(2)–C(2)–C(3)	122(2)	C(5)–C(10)–C(9)	124.5(19)
N(1)–C(2)–C(3)	115.8(18)	N(1)–C(10)–C(9)	116.8(17)
C(4)–C(3)–C(31)	118.7(19)	N(1)–C(11)–C(12)	111.0(10)
C(4)–C(3)–C(2)	122.4(16)	O(12)–C(12)–C(11)	121.8(16)
C(31)–C(3)–C(2)	118.9(19)	O(12)–C(12)–C(13)	127.3(16)
C(3)–C(4)–C(5)	119.7(16)	C(11)–C(12)–C(13)	110.9(17)
C(10)–C(5)–C(4)	119.7(17)	C(17)–C(16)–Cl(16)	122.4(16)
C(10)–C(5)–C(6)	120.3(15)	C(15)–C(16)–Cl(16)	113.6(19)
C(4)–C(5)–C(6)	120.0(17)	N(31)–C(31)–C(3)	179(3)
C(5)–C(6)–C(7)	107.6(14)		

Table 5. Selected bond lengths d (Å) in structure **IIb**

Bond	d	Bond	d
N(1)–C(2)	1.312(2)	C(5)–C(6)	1.505(3)
N(1)–C(10)	1.353(2)	C(6)–C(7)	1.514(3)
C(2)–O(2)	1.350(2)	C(7)–C(8)	1.508(3)
C(2)–C(3)	1.409(2)	C(8)–C(9)	1.524(3)
O(2)–C(11)	1.426(2)	C(9)–C(10)	1.502(3)
C(3)–C(4)	1.375(3)	C(11)–C(12)	1.499(3)
C(3)–C(31)	1.436(3)	C(12)–O(12)	1.211(2)
C(31)–N(31)	1.136(3)	C(12)–C(13)	1.488(3)
C(4)–C(5)	1.390(3)	C(16)–Cl(16)	1.739(2)
C(5)–C(10)	1.394(2)		

crystal structures were determined by direct methods. The positional and thermal parameters for all the non-hydrogen atoms were refined in the anisotropic approximation. The hydrogen atoms, except for the hydrogen atoms involved in the formation of hydrogen bonds, were located from geometric considerations and refined as riding atoms together with the corresponding carbon atoms. The thermal parameters of these hydrogen atoms were calculated from those of the carbon atoms [$U_{\text{iso}}(\text{H}) = 1.2U_{\text{eq}}(\text{C})$ for the aromatic hydrogen atoms and $U_{\text{iso}}(\text{H}) = 1.5U_{\text{eq}}(\text{C})$ for the aliphatic hydrogen atoms]. The hydrogen atoms involved in the formation of hydrogen bonds were located from electron-density difference syntheses and independently refined in the isotropic approximation.

For compound **III**, the R factor is rather large due to the low quality of crystals.

The diffraction experiments for compound **IV** (available only in the form of a finely crystalline powder) were performed on a DRON-3 automated powder diffractometer (NPO Burevestnik) (CuK_α radiation; Ge monochromator; step width, 0.02° in 2θ) at room temperature. The unit cell parameters were determined with the ITO indexing program [9]. Preliminary information on the molecular structure of compound **IV** was obtained from the NMR spectroscopic data. The initial geometrical model was constructed using semiempirical and empirical methods with the MOPAC 6.0 [10] and PCMODEL [11] programs. The structure was solved by the grid search procedure [12] based on the preassigned molecular fragments. The Rietveld full-profile refinement of the structure was carried out according to the MRJA program [13]. The pseudo-Voigt function was used as a profile function, and the background was approximated by Chebyshev fifth-degree polynomials. The thermal parameters of the non-hydrogen atoms of the molecular skeleton were averaged in the course of refinement. The hydrogen atoms were placed at calculated positions. The experimental and difference X-ray powder diffraction patterns after the final refinement are shown in Fig. 1. The tick marks indicate the calculated positions of reflections.

The main parameters of the X-ray diffraction experiments and crystal data for compounds **IIa**, **IIb**, **III**, **IV**, and **V** are summarized in Table 2. The spatial arrangement of atoms in molecules and their numbering are depicted in Figs. 2–6 obtained with the ORTEP-3 graphic program package [14, 15]. The interatomic dis-

Table 6. Selected bond angles ω (deg) in structure **IIb**

Angle	ω	Angle	ω
C(2)–N(1)–C(10)	118.20(16)	C(5)–C(6)–C(7)	112.84(17)
N(1)–C(2)–O(2)	121.31(16)	C(8)–C(7)–C(6)	110.87(18)
N(1)–C(2)–C(3)	123.41(17)	C(7)–C(8)–C(9)	111.29(18)
O(2)–C(2)–C(3)	115.28(16)	C(10)–C(9)–C(8)	113.22(17)
C(2)–O(2)–C(11)	117.73(14)	N(1)–C(10)–C(5)	123.10(17)
C(4)–C(3)–C(2)	117.49(17)	N(1)–C(10)–C(9)	115.89(16)
C(4)–C(3)–C(31)	121.24(17)	C(5)–C(10)–C(9)	121.02(17)
C(2)–C(3)–C(31)	121.25(17)	O(2)–C(11)–C(12)	107.73(15)
N(31)–C(31)–C(3)	177.7(2)	O(12)–C(12)–C(13)	120.78(18)
C(3)–C(4)–C(5)	120.65(17)	O(12)–C(12)–C(11)	120.60(18)
C(4)–C(5)–C(10)	117.12(17)	C(13)–C(12)–C(11)	118.61(16)
C(4)–C(5)–C(6)	120.19(17)	C(15)–C(16)–Cl(16)	119.27(17)
C(10)–C(5)–C(6)	122.67(17)	C(17)–C(16)–Cl(16)	119.49(18)

Table 7. Selected bond lengths d (Å) in structure **III**

Bond	d	Bond	d	Bond	d	Bond	d
N(1)–C(11)	1.390(15)	C(3)–C(4)	1.381(18)	C(5)–C(6)	1.501(18)	C(12)–C(13)	1.459(18)
N(1)–C(10)	1.367(16)	C(3)–C(31)	1.540(19)	C(6)–C(7)	1.48(2)	C(16)–C(16)	1.710(15)
N(1)–C(2)	1.371(16)	C(31)–O(31)	1.198(15)	C(7)–C(8)	1.51(2)	Cl(1)–O(14)	1.3644(14)
C(2)–O(2)	1.361(15)	C(31)–N(31)	1.330(18)	C(8)–C(9)	1.534(18)	Cl(1)–O(11)	1.3648(12)
C(2)–C(3)	1.374(18)	C(4)–C(5)	1.392(18)	C(9)–C(10)	1.464(18)	Cl(1)–O(12)	1.3650(13)
O(2)–C(12)	1.388(15)	C(5)–C(10)	1.367(18)	C(11)–C(12)	1.343(18)	Cl(1)–O(13)	1.365(2)

tances and bond angles in the structures are presented in Tables 3–12.

The crystal data for the structures studied (CIF files) have been deposited with the Cambridge Structural Database (deposits CCDC nos. 24-9841–24-9845).

RESULTS AND DISCUSSION

In structure **IIa** (Fig. 2), the O(2), C(6), C(9), C(31), and N(31) atoms lie in the plane of the six-membered heterocycle, whereas the C(7) and C(8) atoms in the cyclohexene fragment deviate from its plane by 0.58 and 0.21 Å, respectively.

The *n*-chlorobenzoyl group of the molecule is nearly perpendicular to the plane of the heterocyclic fragment of the molecule: the corresponding dihedral angle between the planes is equal to 78.76(1)°.

The C(7)–C(8) distance (Table 3) is considerably shorter than the distances between the other atoms forming the six-membered aliphatic ring due to strong anisotropy of thermal vibrations of these atoms. However, by introducing the correction for anisotropy of thermal vibrations [16], this distance (1.61 Å) can be considered to correspond to the C–C single bond between *sp*³-hybridized carbon atoms.

A comparison of the C(3)–C(4)–C(5)–C(10) fragment with a similar fragment in the 2-oxo-1,2,5,6,7,8-hexahydroquinoline-3-carbonitrile molecule [5] indicates a quasi-diene character of the fragments under

consideration and a similar structure of the bicyclic fragments of the studied compounds.

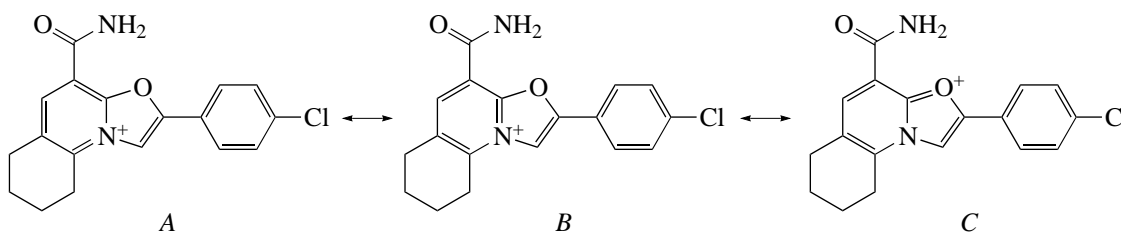
In molecule **IIb** (Fig. 3), the C(6), C(9), O(2), C(31), and N(31) atoms lie in the plane of the pyridine ring, whereas the C(7) and C(8) atoms of the cyclohexene fragment deviate from the ring plane by –0.35 and 0.39 Å, respectively.

The dihedral angle between the planes of the heterocyclic fragment and the benzoyl group of the molecule is equal to 2.75(7)°; i.e., the phenacyloxy group virtually lies in the plane of the heterocyclic fragment.

In structure **III** (Fig. 4), the C(6) and C(9) atoms lie in the plane of the oxazopyridine bicycle, and the C(7) and C(8) atoms deviate from the plane by –0.53 and 0.24 Å, respectively.

The C(31)–O(31)–N(31)H(31A)H(31B) amide group is rotated with respect to the plane of the bicycle by 18.83° and forms the intramolecular hydrogen bond with the O(2) atom. The hydrogen atoms of the amide group and the oxygen atoms of the perchlorate anion are involved in the formation of the intermolecular hydrogen bonds N(31)–H(31A)···O(12) and N(31)–H(31B)···O(13), which link molecules into chains. The parameters of the hydrogen bonds are listed in Table 13, and their spatial arrangement is shown in Fig. 7. The dihedral angle between the planes of the heterocyclic and phenyl rings is equal to 5.3(7)°.

The structure of the oxazopyridinium cation can be represented by three resonance structures (see Scheme 3):

**Scheme 3**

The bond lengths in the C(3)–C(4)–C(5)–C(10) fragment (Table 7) indicate its quasi-diene structure.

Consequently, the resonance form **A** should make the least contribution and the structure of the molecule

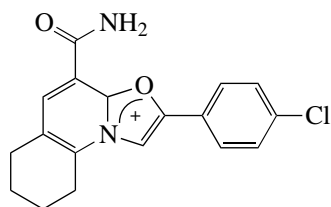
Table 8. Selected bond angles ω (deg) in structure **III**

Angle	ω	Angle	ω
C(11)–N(1)–C(10)	129.9(11)	C(6)–C(7)–C(8)	111.2(13)
C(11)–N(1)–C(2)	106.7(10)	C(7)–C(8)–C(9)	110.7(12)
C(10)–N(1)–C(2)	123.3(11)	C(10)–C(9)–C(8)	112.2(11)
O(2)–C(2)–C(3)	129.4(12)	C(5)–C(10)–N(1)	116.4(12)
O(2)–C(2)–N(1)	109.3(10)	C(5)–C(10)–C(9)	126.4(11)
C(3)–C(2)–N(1)	121.3(12)	N(1)–C(10)–C(9)	117.1(12)
C(2)–O(2)–C(12)	106.8(10)	C(12)–C(11)–N(1)	108.3(11)
C(4)–C(3)–C(2)	115.3(12)	C(11)–C(12)–O(2)	108.9(11)
C(4)–C(3)–C(31)	119.5(12)	C(11)–C(12)–C(13)	133.8(13)
C(2)–C(3)–C(31)	125.0(12)	O(2)–C(12)–C(13)	117.3(12)
O(31)–C(31)–N(31)	126.0(13)	C(17)–C(16)–Cl(16)	119.0(14)
O(31)–C(31)–C(3)	117.7(13)	C(15)–C(16)–Cl(16)	120.7(14)
N(31)–C(31)–C(3)	116.1(12)	O(14)–Cl(1)–O(11)	109.51(10)
C(3)–C(4)–C(5)	123.2(12)	O(14)–Cl(1)–O(12)	109.49(11)
C(10)–C(5)–C(4)	120.2(11)	O(11)–Cl(1)–O(12)	109.46(9)
C(10)–C(5)–C(6)	118.6(13)	O(14)–Cl(1)–O(13)	109.48(10)
C(4)–C(5)–C(6)	121.1(12)	O(11)–Cl(1)–O(13)	109.46(11)
C(7)–C(6)–C(5)	113.2(12)	O(12)–Cl(1)–O(13)	109.44(9)

Table 9. Selected bond lengths d (Å) in structure **IV**

Bond	d	Bond	d	Bond	d	Bond	d
N(1)–C(11)	1.379(4)	C(31)–O(31)	1.226(4)	C(6)–C(7)	1.465(4)	C(16)–Cl(16)	1.736(4)
N(1)–C(10)	1.395(4)	C(31)–N(31)	1.376(5)	C(7)–C(8)	1.500(5)	C(19)–C(20)	1.469(4)
N(1)–C(2)	1.461(4)	N(31)–H(31A)	0.86	C(8)–C(9)	1.488(4)	C(19)–N(2)	1.523(4)
C(2)–C(3)	1.390(5)	N(31)–H(31B)	0.86	C(9)–C(10)	1.372(5)	C(20)–C(21)	1.480(4)
C(2)–N(2)	1.442(4)	C(4)–C(5)	1.390(8)	C(9)–C(12)	1.431(4)	C(21)–C(22)	1.538(3)
C(3)–C(4)	1.458(5)	C(5)–C(6)	1.456(6)	C(11)–C(12)	1.380(4)	C(22)–C(23)	1.516(3)
C(3)–C(31)	1.506(4)	C(5)–C(10)	1.478(8)	C(12)–C(13)	1.486(5)	C(23)–N(2)	1.482(4)

under investigation is more adequately described by a superposition of resonance forms *B* and *C* (see Scheme 4):

**Scheme 4**

One more structural feature of molecule **III** is that the N(1)–C(10) bond is shortened compared to the C–N single bond. This feature can be associated with the conjugation of a lone electron pair of the bridging nitrogen atom with the exocyclic amide group through the diene fragment.

In molecule **IV** (Fig. 5), the C(31), C(13), and N(2) atoms lie in the plane of the cycloannulated tricyclic fragment. The amide group of the molecule is rotated with respect to this plane through 57.3(1)°.

It can be seen from Table 9 that, in the indolizine fragment of the molecule, the formally single C–C

Table 10. Selected bond angles ω (deg) in structure **IV**

Angle	ω	Angle	ω
C(11)–N(1)–C(10)	105.6(2)	C(10)–C(9)–C(8)	122.1(3)
C(11)–N(1)–C(2)	134.1(2)	C(12)–C(9)–C(8)	131.4(3)
C(10)–N(1)–C(2)	120.2(3)	C(9)–C(10)–N(1)	110.6(3)
C(3)–C(2)–N(2)	133.3(3)	C(9)–C(10)–C(5)	126.1(4)
C(3)–C(2)–N(1)	116.7(3)	N(1)–C(10)–C(5)	123.3(4)
N(2)–C(2)–N(1)	109.5(3)	N(1)–C(11)–C(12)	110.7(3)
C(2)–C(3)–C(4)	122.6(3)	C(11)–C(12)–C(9)	106.3(3)
C(2)–C(3)–C(31)	125.8(3)	C(11)–C(12)–C(13)	125.4(3)
C(4)–C(3)–C(31)	111.5(3)	C(9)–C(12)–C(13)	127.8(2)
O(31)–C(31)–N(31)	120.6(3)	C(17)–C(16)–Cl(16)	120.3(12)
O(31)–C(31)–C(3)	120.7(3)	C(15)–C(16)–Cl(16)	120.2(3)
N(31)–C(31)–C(3)	118.0(3)	C(20)–C(19)–N(2)	112.7(3)
C(5)–C(4)–C(3)	122.0(5)	C(19)–C(20)–C(21)	108.6(3)
C(4)–C(5)–C(6)	131.1(6)	C(20)–C(21)–C(22)	110.7(2)
C(4)–C(5)–C(10)	115.1(5)	C(23)–C(22)–C(21)	112.5(2)
C(6)–C(5)–C(10)	113.9(5)	N(2)–C(23)–C(22)	113.4(2)
C(5)–C(6)–C(7)	121.6(4)	C(2)–N(2)–C(23)	132.1(2)
C(6)–C(7)–C(8)	122.1(3)	C(2)–N(2)–C(19)	110.3(2)
C(9)–C(8)–C(7)	113.5(3)	C(23)–N(2)–C(19)	114.5(2)
C(10)–C(9)–C(12)	106.5(3)		

Table 11. Selected bond lengths d (Å) in structure **V**

Bond	d	Bond	d	Bond	d	Bond	d
N(1)–C(2)	1.334(6)	C(4)–C(5)	1.392(7)	C(9)–C(10)	1.512(7)	C(12)–C(13)	1.496(6)
N(1)–C(10)	1.346(6)	C(5)–C(10)	1.399(6)	C(11)–C(31)	1.389(6)	C(16)–Cl(16)	1.729(5)
C(2)–O(2)	1.355(5)	C(5)–C(6)	1.507(6)	C(11)–C(12)	1.415(7)	C(31)–N(31)	1.345(7)
C(2)–C(3)	1.388(6)	C(6)–C(7)	1.469(9)	C(11)–O(2)	1.416(6)	N(31)–H(31A)	0.95(7)
C(3)–C(4)	1.389(6)	C(7)–C(8)	1.429(10)	C(12)–O(12)	1.255(6)	N(31)–H(31B)	0.79(6)
C(3)–C(31)	1.435(7)	C(8)–C(9)	1.507(7)				

bonds are substantially shortened and the formally double C–C bonds are significantly lengthened. However, it is possible to distinguish the bond chain [C(2)–C(3), C(4)–C(5), C(9)–C(10), C(11)–C(12) bonds]

that corresponds to a tetraene structure typical of indolizine.

The piperidine fragment of the molecule adopts a chair conformation: the plane passes through the C(19),

Table 12. Selected bond angles ω (deg) in structure **V**

Angle	ω	Angle	ω
C(2)–N(1)–C(10)	114.4(4)	C(5)–C(10)–C(9)	120.8(4)
N(1)–C(2)–O(2)	121.3(4)	C(31)–C(11)–C(12)	126.7(4)
N(1)–C(2)–C(3)	126.7(4)	C(31)–C(11)–O(2)	109.9(4)
O(2)–C(2)–C(3)	112.0(4)	C(12)–C(11)–O(2)	123.2(4)
C(2)–C(3)–C(4)	117.4(5)	O(12)–C(12)–C(11)	117.4(4)
C(2)–C(3)–C(31)	106.0(4)	O(12)–C(12)–C(13)	118.6(4)
C(4)–C(3)–C(31)	136.5(5)	C(11)–C(12)–C(13)	124.0(5)
C(3)–C(4)–C(5)	118.4(4)	C(17)–C(16)–Cl(16)	118.9(4)
C(4)–C(5)–C(10)	118.6(4)	C(15)–C(16)–Cl(16)	120.0(4)
C(4)–C(5)–C(6)	119.9(4)	C(2)–O(2)–C(11)	105.6(3)
C(10)–C(5)–C(6)	121.4(4)	N(31)–C(31)–C(11)	126.2(5)
C(7)–C(6)–C(5)	114.0(4)	N(31)–C(31)–C(3)	127.5(4)
C(8)–C(7)–C(6)	117.7(7)	C(11)–C(31)–C(3)	106.3(4)
C(7)–C(8)–C(9)	115.5(6)	C(31)–N(31)–H(31A)	118(4)
C(8)–C(9)–C(10)	115.1(5)	C(31)–N(31)–H(31B)	123(5)
N(1)–C(10)–C(5)	124.4(5)	H(31A)–N(31)–H(31B)	119(7)
N(1)–C(10)–C(9)	114.7(4)		

Table 13. Parameters of interatomic contacts in the studied structures

<i>D</i> –H	<i>d</i> (<i>D</i> –H)	<i>d</i> (H··· <i>A</i>)	ω <i>DHA</i>	<i>d</i> (<i>D</i> ··· <i>A</i>)	<i>A</i>
III					
N(31)–H(31A)	0.86(1)	2.06(1)	164.6(8)	2.90(2)	O(12) [– <i>x</i> + 3/2, <i>y</i> + 1/2, – <i>z</i> + 3/2]
N(31)–H(31B)	0.86(1)	2.24(1)	130.9(7)	2.87(2)	O(2)
N(31)–H(31B)	0.86(1)	2.54(1)	120.9(7)	3.07(2)	O(13) [– <i>x</i> + 1/2, <i>y</i> + 1/2, – <i>z</i> + 3/2]
IV					
N(31)–H(31A)	0.86	2.22	138	2.92	O(31) [– <i>x</i> + 1, – <i>y</i> + 1, – <i>z</i>]
N(31)–H(31B)	0.86	2.13	159	2.95	O(31) [<i>x</i> , <i>y</i> – 1, <i>z</i>]
V					
N(31)–H(31A)	0.95(7)	2.10(7)	124(5)	2.750(7)	O(12)
N(31)–H(31B)	0.79(6)	2.47(7)	150(6)	3.176(7)	N(1) [<i>x</i> + 1, <i>y</i> , <i>z</i>]

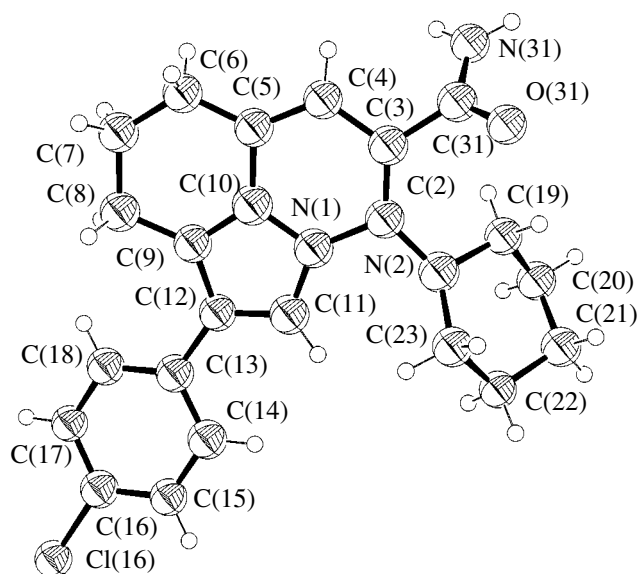


Fig. 5. Molecular structure and atomic numbering for compound **IV**.

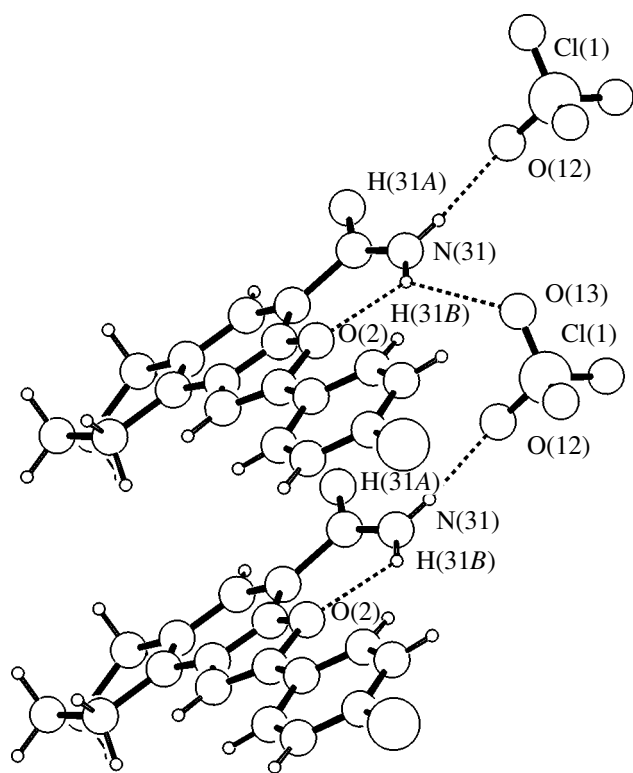


Fig. 7. Spatial arrangement of hydrogen bonds in structure **III**.

C(20), C(22), and C(23) atoms, and the C(21) and N(2) atoms deviate from the plane by 0.70 and -0.47 Å, respectively. The piperidine ring is rotated with respect to the plane of the heterocyclic fragment by $58.3(1)^\circ$.

The plane of the phenyl ring is rotated with respect to the plane of the heterocyclic fragment by $17.6(5)^\circ$.

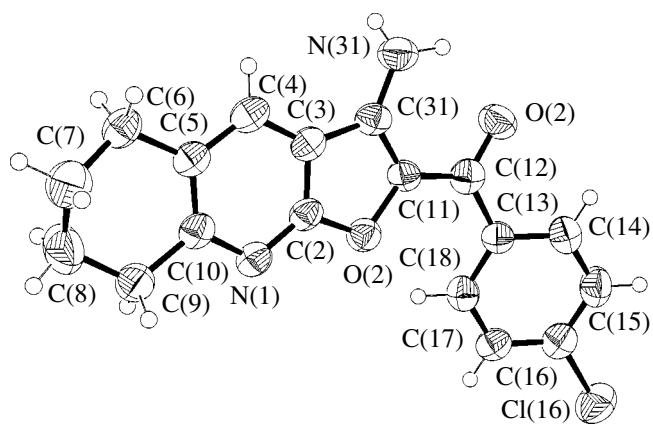


Fig. 6. Molecular structure and atomic numbering for compound **V**.

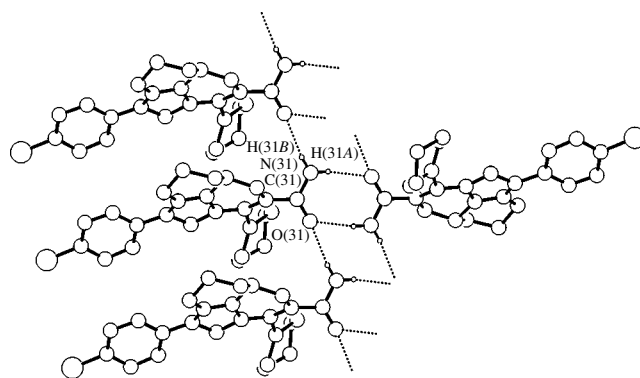


Fig. 8. Spatial arrangement of hydrogen bonds in structure **IV**.

The amide group of the molecule forms a system of hydrogen bonds in which the hydrogen atoms of the NH_2 group simultaneously interact with the oxygen atoms of the amide fragments of two different molecules. The parameters of the hydrogen bonds are presented in Table 13, and their spatial arrangement is given in Fig. 8.

In molecule **V**, the C(6) and C(9) atoms and the exocyclic amine group are located in the plane of the heterocyclic bicycle, whereas the C(7) and C(8) atoms deviate from this plane by -0.28 and 0.23 Å, respectively. As in molecule **IIa**, the C(7)–C(8) distance is shortened as a result of strong anisotropy of thermal vibrations of these atoms. However, taking into account the correction for anisotropy of thermal vibrations [16], this distance corresponds to the C–C single bond between the sp^3 -hybridized carbon atoms.

The dihedral angle between the planes of the phenyl ring and the heterocyclic bicycle is equal to $20.0(2)^\circ$. This suggests a weak conjugation of the phenyl ring with the heterocyclic fragment.

The hydrogen atoms of the amino group and the nitrogen atom of the pyridine ring of the molecule form

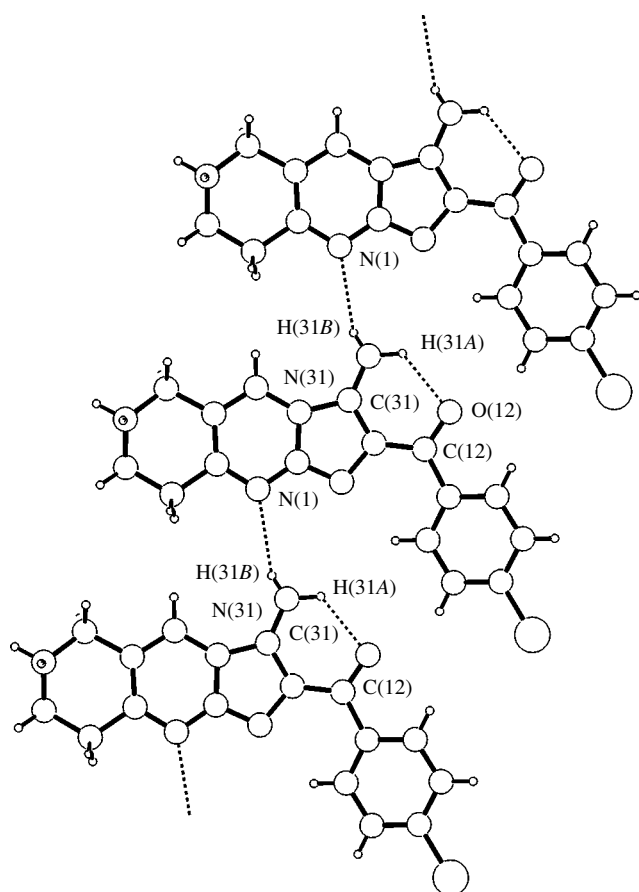


Fig. 9. Spatial arrangement of hydrogen bonds in structure V.

intermolecular hydrogen bonds that link molecules into chains. The amino group also participates in the formation of the N(31)–H(31A)···O(12) intramolecular hydrogen bond and is responsible for the planar structure of the N(31)H₂–C(31)=C(11)–C(12)=O(12) fragment with the maximum deviation (by 0.03 Å) from the plane. The parameters of the hydrogen bonds are listed in Table 13, and their spatial arrangement is shown in Fig. 9.

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