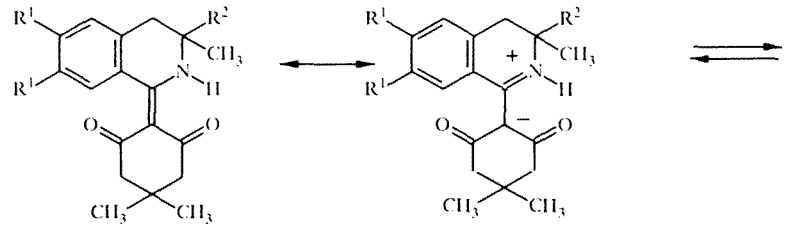
Chemistry of Heterocyclic Compounds, Vol. 31, No. 7, 1995

THE EFFECT OF 6- AND 7-SUBSTITUENTS ON THE STRUCTURE AND TAUTOMERIC CONVERSIONS OF 3,3-DIMETHYL-1-(4,4-DIMETHYLCYCLOHEXA-2,6-DION-1-YL)-3,4-DIHYDROISOQUINOLINE

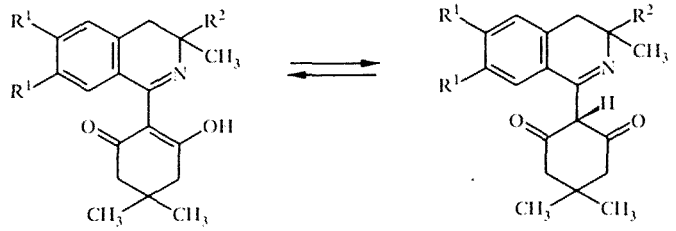
V. V. Davydov, V. I. Sokol, E. V. Balebanova, Yu. V. Shklyaev, V. F. Zakharov, S. L. Kuznetsov, and B. E. Zaitsev

The crystalline and molecular structure of 3,3-dimethyl-6,7-dimethoxy-1-(4,4-dimethylcyclohexa-2,6-dion-1-yl)-3,4-dihydroisoquinoline (I) have been determined. The effects of 6- and 7- substituents on the structure and tautomeric conversion of 3,3-dimethyl-1-(4,4-dimethylcyclohexa-2,6-dion-1-yl)-3,4-dihydroisoquinoline in solution have been studied by IR, electronic, x-ray electronic, and NMR spectroscopy and using quantum-chemical calculations in the MNDO/H approximation. It was found that I exists in the enamine-diketone tautomeric form in the crystalline state and in solution. The 6- and 7- substituents cause a change in molecular conformation and a corresponding redistribution of electron density.

A study of the complex formation of Cu(II) salts with 3,3-dimethyl-6,7-dimethoxy- (I), 3,3-dimethyl- (II), and 3-methyl (III) derivatives of 1-(4,4-dimethylcyclohexa-2,6-dion-1-yl)-3,4-dihydroisoquinoline has shown that the nature of the substituents at positions 6 and 7 affects the composition and structure of the ligand metallocomplexes synthesized under identical conditions. Hence $CuCl_2$ and II form the polymeric complex $[CuL^2Cl_2]_n$ in which the ligand occurs as the enamine–diketone tautomer



(a′) (a″)



(b) (c)

I $R^1 = OCH_3$, $R^2 = CH_3$; II $R^1 = H$, $R^2 = CH_3$; III $R^1 = R^2 = H$; IV $R^1 = R^2 = CH_3$

Russian University of National Friendship, Moscow 117198. N. S. Kurnakov Institute of General and Inorganic Chemistry, Russian Academy of Sciences, Moscow 117000. Institute of Technical Chemistry, Ural Section, Russian Academy of Sciences, Perm' 614600. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 7, pp. 922-933, July, 1995. Original article submitted April 15, 1995.

0009-3122/95/3107-0803$12.50

TABLE 1. Bond Lengths in I

Bond	d, Å	Bond	d, Å
	Dihydroisoquinoline fragment		
O(3)—C(4)	1,36(2)	C(3)—C(4)	1,35(2)
O(3)—C(20)	1,46(2)	C(4)—C(5)	1,42(3)
O(4)—C(5)	1,37(2)	C(5)—C(6)	1,37(3)
O(4)—C(21)	1,43(2)	C(6)—C(7)	1,39(2)
N(1)—C(1)	1,28(2)	C(7)—C(8)	1,51(2)
N(1)—C(9)	1,49(2)	C(8)—C(9)	1,51(2)
C(1)—C(2)	1,45(2)	C(9)—C(10)	1,52(3)
C(2)—C(3)	1,39(3)	C(9)—C(11)	1,54(2)
C(2)—C(7)	1,39(2)	N(1)—H(1N1)	0,9(1)
	Dimedone fragment		
O(1)—C(13)	1,23(2)	C(14)—C(15)	1,51(2)
O(2)—C(17)	1,24(2)	C(15)—C(16)	1,51(2)
C(12)—C(13)	1,43(2)	C(15)—C(18)	1,53(2)
C(12)—C(17)	1,43(2)	C(15)—C(19)	1,53(2)
C(13)—C(14)	1,55(2)	C(16)—C(17)	1,50(2)
	Bond joining fragments		
C(1)—C(12)	1,45(2)		

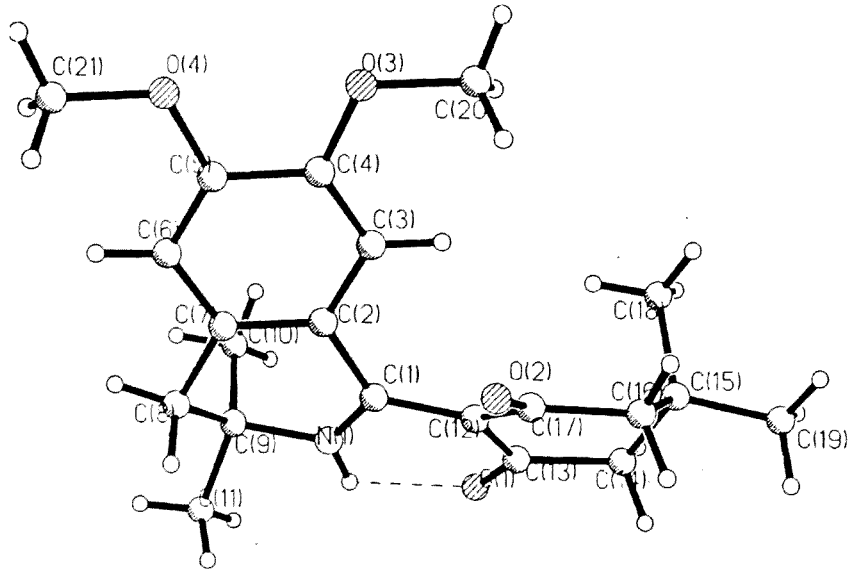


Fig. 1. Structure of 3,3-dimethyl-6,7-dimethoxy-1-(4′,4′-dimethylcyclohexa-2′,6′-dion-1′-yl)-3,4-dihydroisoquinoline.

(*a*) and behaves as a cross link adding to Cu(II) via the oxygen atoms [1]. Under the same conditions, I and $CuCl_2$ form the complex $[CuL^1(H_2O)Cl_2]$ in which the ligand also occurs as the enamine–diketone tautomer but adds to Cu(II) only monodentately via the oxygen atom of one of the C=O groups [2]. Treatment of $Cu(ClO_4)_2 \cdot 6H_2O$ with II and III gives the complexes $Cu(ClO_4)_2L \cdot H_2O$ and with the dimethoxy derivative I the complex $[CuL_4(ClO_{42}] \cdot 2CH_3CN$ where L is the new ligand 3,3-dimethyl-6,7-dimethoxy-3,4-dihydroisocarbostyril formed from I during the reaction [3]. It can be assumed that the reason for this effect is associated with the electronic properties and molecular structure of I. The structures of II and III were discussed in [4, 5] but that of I was not considered in detail. This report concerns a study of the dimethoxy derivative I and of 3,3,6,7-tetramethyl-1-(4,4-dimethylcyclohexa-2,6-dion-1-yl)-3,4-dihydroisoquinoline (IV) in the solid state and in solution by quantum chemical calculations, x-ray structural analysis, and IR, electronic, x-ray electronic, and NMR spectroscopy.

TABLE 2. Valence Angles in I

Angle	ω, degrees	Angle	ω, degrees
	Dihydroisoquinoline fragment		
$C_{(4)}O_{(3)}C_{(20)}$	115(1)	$O_{(4)}C_{(5)}C_{(4)}$	113(1)
$C_{(5)}O_{(4)}C_{(21)}$	115(1)	$O_{(4)}C_{(5)}C_{(6)}$	127(1)
$H_{(1N1)}N_{(1)}C_{(1)}$	128(7)	$C_{(4)}C_{(5)}C_{(6)}$	120(2)
$H_{(1N1)}N_{(1)}C_{(9)}$	106(7)	$C_{(5)}C_{(6)}C_{(7)}$	120(2)
$C_{(1)}N_{(1)}C_{(9)}$	126(1)	$C_{(2)}C_{(7)}C_{(6)}$	120(2)
$N_{(1)}C_{(1)}C_{(2)}$	118(1)	$C_{(2)}C_{(7)}C_{(8)}$	119(1)
$N_{(1)}C_{(1)}C_{(12)}$	116(1)	$C_{(6)}C_{(7)}C_{(8)}$	121(1)
$C_{(2)}C_{(1)}C_{(12)}$	126(1)	$C_{(7)}C_{(8)}C_{(9)}$	110(1)
$C_{(1)}C_{(2)}C_{(3)}$	123(1)	$N_{(1)}C_{(9)}C_{(8)}$	106(1)
$C_{(1)}C_{(2)}C_{(7)}$	118(1)	$N_{(1)}C_{(9)}C_{(10)}$	109(1)
$C_{(3)}C_{(2)}C_{(7)}$	119(2)	$N_{(1)}C_{(9)}C_{(11)}$	107(1)
$C_{(2)}C_{(3)}C_{(4)}$	122(2)	$C_{(8)}C_{(9)}C_{(10)}$	113(1)
$O_{(3)}C_{(4)}C_{(3)}$	126(2)	$C_{(8)}C_{(9)}C_{(11)}$	109(1)
$O_{(3)}C_{(4)}C_{(5)}$	115(2)	$C_{(10)}C_{(9)}C_{(11)}$	112(1)
$C_{(3)}C_{(4)}C_{(5)}$	119(2)		
	Dimedone fragment		
$C_{(1)}C_{(12)}C_{(13)}$	120(1)	$C_{(14)}C_{(15)}C_{(18)}$	110(1)
$C_{(1)}C_{(12)}C_{(17)}$	120(1)	$C_{(14)}C_{(15)}C_{(19)}$	108(1)
$C_{(13)}C_{(12)}C_{(17)}$	120(1)	$C_{(16)}C_{(15)}C_{(18)}$	111(1)
$O_{(1)}C_{(13)}C_{(12)}$	125(2)	$C_{(16)}C_{(15)}C_{(19)}$	110(1)
$O_{(1)}C_{(13)}C_{(14)}$	119(1)	$C_{(18)}C_{(15)}C_{(19)}$	110(1)
$C_{(12)}C_{(13)}C_{(14)}$	116(1)	$C_{(15)}C_{(16)}C_{(17)}$	115(1)
$C_{(13)}C_{(14)}C_{(15)}$	116(1)	$O_{(2)}C_{(17)}C_{(12)}$	126(1)
$C_{(14)}C_{(15)}C_{(16)}$	107(1)	$O_{(2)}C_{(17)}C_{(16)}$	115(1)
		$C_{(12)}C_{(17)}C_{(16)}$	120(1)

TABLE 3. Absorption Maxima in the 1750-1500 cm^{-1} Region in the IR Spectra of the Dihydroisoquinolines I-IV

Compound	Solvent*2	ν, cm^{-1} (A × 10^{-4})*
I	KBr	1656(3,13), 1630(1,85), 1611/1602/1590, 1570, 1539/1515
	CCl_4	1670(1,14), 1638(2,58)
	CH_3CN	1714, 1653 w, 1647, 1635, 1628, 1624, 1617
II	KBr	1643/1638(5,97), 1608, 1590/1580/1576, 1544/1522 sh/1505 sh
	CCl_4	1644(3,39)
III	KBr	1629(4,93), 1608, 1587/1568/1547/1522 sh/1509 sh
	CCl_4	1645(2,97)
IV	KBr	1658/1653, 1635, 1615, 1589, 1566/1558, 1534/1522 sh/1509 sh
	CCl_4	1674(4,95), 1641(0,66), 1618
	CH_3CN	1664/1654, 1633, 1617

*In Kg·$mole^{-1}$·cm^{-2} for solids and liter·$mole^{-1}$·cm^{-2} for solutions.

*2Solution concentrations $1 \cdot 10^{-3}$ molar.

All of I, II, and III could potentially exist as the enamine–diketone (*a*), azomethine–enol (b), or azomethine–diketone (c) tautomers. This proposal is based on the known data for azomethine–enamine and keto–enol tautomerism in 3,4-dihydroisoquinoline and 5,5-dimethylcyclohexa-1,3-dione (dimedone) [6-11]. The tautomeric conversions in these compounds in solution is determined by the nature of the solvent, the temperature, and their aggregate nature.

Solid State. Monocrystals of I were obtained by recrystallization in acetone. X-ray investigation showed that its structure was similar to that of II in which the 6 and 7 positions are not substituted (Fig. 1). Compound I occurs in the same tautomeric form (*a*) as in II [4] and, overall, is similar in structure. However, crystals of I have a higher symmetry than II.

TABLE 4. Chemical Shift (δ, ppm) in the PMR Spectra of Dihydroisoquinolines I, II and IV in Solvents

Assignment	Compound				
	I			II, $CDCl_3$	IV, $CDCl_3$
	$CDCl_3$	DMSO	Acetone		
	Dihydroisoquinoline fragment A				
3-CH_3(6H)	1,14	1,04	1,09	1,14	1,14
4-H(2H)	2,80	2,79	2,86	2,87	2,79
	2,84	2,83	—	—	2,83
NH	12,95	12,75	13,00	13,21	13,04
	5,77	7,45	—	—	5,84
R	3,70	3,57	3,73	—	2,21
	3,81	3,66	3,83	—	2,28
	3,92	3,78	3,86	—	—
	—	3,86	3,88	—	—
	Dimethylcyclohexanedione fragment B				
3-H, 5-H(4H)	2,42	2,33	2,37	2,44	2,43
4-CH_3(6H)	1,29	1,20	1,27	1,28	1,26
	—	1,22	1,28	—	1,29

TABLE 5. Electronic Absorption Data for I-IV

Compound	Solvent	λ_{max}, nm (log ε)					
I	EtOH	219(4,29)	246(4,26)	265(4,18)	283(3,85)	313(3,76)	364(4,08)
	CH_3CN		~245(4,40)	~260(4,26)	298(3,86)	308(3,85)	366(4,14)
	Acetone						366(4,17)
	CCl_4			~265(4,26)		313(3,92)	373(4,06)
II [4]	EtOH	226(3,53)		265(4,22)		321(3,62)	370(3,90)
	CH_3CN			259(4,29)		311(3,66)	373(3,00)
	Acetone						370(3,99)
	CCl_4			263(4,29)		318(3,69)	369(3,94)
III [4]	EtOH	219(3,53)		266(4,24)		318(3,64)	366(3,92)
	CCl_4			238(4,31)		291(3,73)	372(3,94)
IV	EtOH	214(4,54)	234(4,47)	264(4,64)	~280(4,29)	~335(3,20)	366(4,23)
	CH_3CN		~232	257(4,16)	280(3,70)	329(3,64)	373(3,78)
	Acetone						
	CCl_4						375(3,66)

In the rhombic cell (space group Pbc*a*) of I the molecule has one defined form whereas the monoclinic cell of II (space group $P2_1$) exists in two crystallographically independent molecules differing from one another in the conformation of the dimethylcyclohexanedione (B) fragments. In one molecule it is a flattened chair and in the other a flattened boat. The latter shows first that this ring is conformationally mobile and second that the particular conformation of fragment B does not overall have a significant effect on the electronic structure of the molecule.

Fragment B of molecule I has a boat conformation, flattened at the C_{12} apex. Its deviation from the $C_{13}C_{14}C_{16}C_{17}$ plane is +0.199 Å (see Fig. 1). The second apex formed by the methylated C_{15} deviates much more from this plane (+ 0.690 Å). Moreover, the twist angles of the plane from the $C_{13}C_{17}$ and $C_{14}C_{16}$ lines are 16 and 45°. Achievement of such a conformation is apparently connected with the packing conditions of I in the crystals and is one consequence of the presence of the methoxy groups. In the same way as crystalline II, fragment B of I occurs in the diketone form. This differs from the structure of free 5,5-dimethylcyclohexa-1,3-dione (dimedone) in which the crystals occur as a keto–enol tautomer [12, 13]. In contrast to dimedone, the β-diketone system bonds of I show an even greater equivalence for the C=O bonds than in II. Hence in I the O_1-C_{13} and O_2-C_{17} bonds have almost identical lengths (1.234 × 0.004 Å), and in II they are a little different at 1.227(4) and 1.236(4) Å, whereas in dimedone this difference is 0.08 Å (the C=O and C–OH bond lengths are 1.246 and

TABLE 6. Calculation of the Energetic and Conformational Parameters for the Tautomers of I* and II*

Parameter	I*			II*		
	(a)	(b)	(c)	(a)	(b)	(c)
$\Delta H°_{form.}$, Kcal/mole	-124,26	-131,85	-96,05	-46,10	-53,55	-16,68
E_{HOMO}, eV	-8,83	-9,18	-9,38	-8,76	-9,19	-9,32
E_{LUMO}, eV	-0,93	-0,70		-0,75	-0,52	
μ, D	2,68	2,01	3,14	3,01	2,10	2,48
Twist angle						
$N_{(1)}C_{(1)}C_{(12)}C_{(17)}$, degree	20	31	59	20	31	65
$C_{(1)}-C_{(12)}$, Å	1,410	1,486	1,548	1,411	1,486	1,549
Sum of charges						
fragment A	0,45	0	0	0,47	0	-0,03
fragment B	-0,45	0	0	-0,47	0	0,03
Charge on atoms						
$N_{(1)}$	-0,373	-0,367	-0,264	-0,373	-0,368	-0,279
$O_{(1)}$	-0,374	-0,257	-0,241	-0,376	-0,259	-0,273
$O_{(2)}$	-0,323	-0,303	-0,265	-0,322	-0,301	-0,267
$O_{(3)}$	-0,291	-0,291	-0,292			
$O_{(4)}$	-0,294	-0,294	-0,290			

TABLE 7. Crystallographic Data for I

Parameter	Value	Parameter	Value
Size of crystal, mm		μ (MoKα), cm^{-1}	0,08
Color		$2\theta_{max}$, degree	50
Space group	Pbca	Scanning	$\theta/2\theta$
a, Å	11,919(8)	N	1804
b, Å	12,496(4)	N*	1186
c, Å	25,59(2)	Number of independent parameters in the least squares analysis in MHK	225
V, $Å^3$	3811(4)	R	0,038
Z	8	R_w	0,040
ρ (calc.), g/cm^3	1,23	GOOF	0,96

1.326 Å respectively). The same effect is observed in the C−C bonds conjugated to the carbonyl groups in I $C_{12}-C_{13}$ and $C_{12}-C_{17}$ have the same length (1.43(2) Å); in II they show a slight non-equivalence (1.458(6) and 1.445(6) Å), and in dimedone one bond is longer by almost 0.07 Å (C−COH 1.418 Å and C−CO 1.351 Å). The observed change in the β-diketone bond network shows an apparently greater similarity of fragment B in I than the II to the anion of dimedone for which there is also a marked equivalence of the CO and CC bonds [14]. The remaining C−C bonds and valence angles of this fragment in I are close to those in II and in dimedone and have standard values (Tables 1 and 2).

The dimethyldihydropyridine rings of I and II have a distorted half chair conformation. Four of the C atoms are coplanar with the C atoms of the conjugated benzene ring to within 0.02 Å but the N and C_9 atoms deviate to the same side of this plane by 0.37 Å (N) and 0.91 Å (C_9) respectively. Overall, fragment B in I and II is found as the enamine tautomer, the NH hydrogen is located by difference synthesis analysis of the electron density and its parameters refined by least squares analysis in the isotropic approximation. The presence of the CH_3O substituent in the benzene ring and the associated change in molecular conformation affects the size of the CN multiple bond. In I the C_1-N_1 bond is shortened to 1.28(2) Å with a simultaneous increase in C_9-N_1 to 1.50(2) Å (a difference of 0.22 Å). In II the first bond is 1.312(6) Å and the second 1.474(6) Å (difference 0.16 Å). A similar localization of the C=N bond was previously found in the 1-benzyl-3,4-dihydroisoquinoline hydrochloride cation [15]. In the indicated compound with two independent crystalline molecules these bonds are 1.286(6) and 1.271(6) Å (C=N) and 1.478(7) and 1.495(8) Å (C−N). The nearly identical difference in values for the multiple and single CN bonds (0.192 and 0.224 Å in the first and second molecules) to those in I encourages the view that the CH_3O substituent leads the dimethoxydihydroisoquinoline fragment of I to approach that in the cationic form. The CH_3 groupl ies almost in the plane of the benzene ring (coplanar to within 0.012 Å). The oxygen atoms are displaced slightly (+0.05

TABLE 8. Coordinates of Independent Atoms in Parts of the Axes of the Unit Cell and Thermal Corrections B(iso) and B(eq) for 3,3-Dimethyl-6,7-dimethoxy-1-(4′,4′-dimethylcyclohexa-2′,6′-dion-1′-yl)-3,4-dihydroisoquinoline (I)

Atom	x	y	z	B (iso) /B (eq)
O(1)	0,4572(9)	0,2229(9)	0,7269(4)	4,8(4)
O(2)	0,1964(7)	0,299(1)	0,6016(4)	4,3(4)
O(3)	0,323(1)	0,525(1)	0,4809(4)	4,0(4)
O(4)	0,4230(7)	0,4153(9)	0,4119(4)	3,9(4)
N(1)	0,497(1)	0,185(1)	0,6304(5)	4,0(5)
C(1)	0,422(1)	0,251(1)	0,6166(5)	3,1(5)
C(2)	0,425(1)	0,296(2)	0,5638(5)	2,6(5)
C(3)	0,372(1)	0,394(2)	0,5490(6)	2,8(7)
C(4)	0,371(1)	0,430(2)	0,4989(7)	2,7(6)
C(5)	0,429(1)	0,369(2)	0,4608(6)	3,1(6)
C(6)	0,486(1)	0,276(1)	0,4751(6)	3,3(6)
C(7)	0,483(1)	0,237(2)	0,5265(7)	2,6(6)
C(8)	0,545(1)	0,134(1)	0,5428(6)	3,5(5)
C(9)	0,589(1)	0,150(2)	0,5971(6)	3,6(6)
C(10)	0,676(1)	0,239(2)	0,6004(5)	5,6(7)
C(11)	0,628(1)	0,036(1)	0,6179(5)	5,4(4)
C(12)	0,348(1)	0,284(1)	0,6575(5)	2,5(5)
C(13)	0,377(1)	0,272(1)	0,7111(6)	3,6(6)
C(14)	0,302(1)	0,330(1)	0,7515(5)	4,0(5)
C(15)	0,229(1)	0,421(2)	0,7305(6)	4,0(7)
C(16)	0,170(1)	0,370(1)	0,6848(5)	4,1(5)
C(17)	0,241(1)	0,317(1)	0,6440(6)	2,9(5)
C(18)	0,294(1)	0,524(1)	0,7139(6)	5,7(6)
C(19)	0,151(1)	0,453(1)	0,7738(5)	5,0(6)
C(20)	0,260(1)	0,587(1)	0,5192(6)	4,3(6)
C(21)	0,474(1)	0,352(2)	0,3715(6)	5,4(4)
H(1N1)	0,507(9)	0,15(1)	0,661(4)	1(3)
H(3A)	0,334	0,435	0,575	
H(6A)	0,528	0,238	0,449	
H(8A)	0,602	0,121	0,518	
H(8B)	0,498	0,071	0,543	
H(10A)	0,698	0,249	0,636	
H(10B)	0,735	0,216	0,580	
H(10C)	0,648	0,309	0,587	
H(11A)	0,656	0,043	0,652	
H(11B)	0,567	-0,013	0,618	
H(11C)	0,681	0,006	0,595	
H(14A)	0,346	0,362	0,778	
H(14B)	0,257	0,276	0,767	
H(16A)	0,129	0,427	0,668	
H(18A)	0,343	0,500	0,687	
H(18B)	0,248	0,581	0,700	
H(18C)	0,334	0,553	0,743	
H(19A)	0,111	0,387	0,783	
H(19B)	0,189	0,481	0,804	
H(19C)	0,102	0,510	0,761	
H(20A)	0,230	0,653	0,504	
H(20B)	0,203	0,538	0,531	
H(20C)	0,305	0,607	0,548	
H(21A)	0,469	0,390	0,338	
H(21B)	0,548	0,339	0,380	
H(21C)	0,437	0,282	0,369	

and −0.02 Å) on opposite sides of this plane. The methyl groups are oppositely directed to one another, the angles at the oxygen atoms being 115°. The $O-C_{phenyl}$ bonds are shorter (mean value 1.37(1) Å) than $O-C_{methyl}$ (1.44(1) Å). The remaining C−C bond lengths and valence angles of the dimethoxydihydroisoquinoline fragment are close to analogs in II and to standard values (Tables 1 and 2).

The central C_1-C_{12} bond joining the cyclic fragments A and B of the molecule are slightly larger in I than II (1.45(2) and 1.435(1) Å respectively) but it is still shorter than a $C(sp^2)-C(sp^2)$ single bond (1.466 Å) [16]. This infers a weakening of the π-conjugation between fragments B and A in I when compared with II. This is supported by the increase in angle between the mean planes of A and B to 36° compared with 32° in II. However, despite some increase in the rotation of fragments A and B, in I as in II the atoms $N_1H_1O_1C_{13}C_{12}C_1$ from the nonplanar six membered rings involving an intramolecular N−H···O hydrogen bond. According to the parameters it is weaker in I than II: in I the N−H, H···O lengths and NHO angle are 0.87, 2.17 Å and 122° and in II 0.78, 1.92 Å and 140°. The H and O atoms deviate on different sides of the mean plane of the six membered ring by +0.12 and −0.17 Å respectively. The connecting units at atoms N_1, C_1, and C_{12} in I have a planar configuration. However a significant nonequivalence of the endo- and exocyclic angles is found at atoms N_1 and C_1. Hence there are marked increases in the intracyclic angle $C_1N_1C_9$ (to 125°) and exocyclic angle $C_2C_1C_{12}$ (to 126°). It is important to note that the angle $C_2C_1C_{12}$ is greater than $N_1C_2C_{12}$. The difference between them in I (Δ 10°) exceeds the value for the corresponding angles in II in the free state (cf. 4.4°) [4] and in the copper II chloride complex (3.7°) [1] as well as in the same copper complex of compound I (5.6°) [2]. This is evidently due to the presence of the MeO substituents in I. Because of intramolecular repulsion the central C_1-C_{12} bond deviates from the methoxy substituent towards the six membered H-ring.

In the crystal, I has shortened contacts between the O_2 oxygen atom and the hydrogens of the methyl group and the benzene ring of the neighboring molecule $O_2\cdots H_{6C6}$ (−1/2 + x, 1/2−y, −z) 2.51 Å and $O_2\cdots H_{C20}$ (−1/2−x, −1/2 + y, +z) 2.67 Å.

The observed conformational properties and spread of bond lengths and valence angles are also reflected in their spectroscopic parameters.

Although I-III exist in the solid state in the same tautomeric state (*a*), their IR spectra show significant differences. In the $\nu_{C=O}$ and $\nu_{C=N}$ region (1720-1620 cm^{-1}) compound I shows not one but two bands, the sum of whose integrated intensities is close to that of the mainly $\nu_{C=O}$ band in the spectra of II and III (Table 3).

According to [17, 18] the $\nu_{C=O}$ band maxima in the 2-nitro and 2-(quinolin-2-yl) derivatives of dimedone (which exist in the enol form) are located at 1661 and 1638 cm^{-1} [11]. The absorption maximum for $\nu_{C=N}$ in the spectrum of 1,3,3-trimethyl-3,4-dihydroisoquinoline is found at 1629-1630 cm^{-1} [19]. Thus the above difference in the spectra of I-III might be explained by the existence of I as the azomethine enol tautomer (b). In this case the high frequency bands in the region 1658-1653 cm^{-1} can be assigned to $\nu_{C=O}$ in the dimedone fragment and at 1635-1630 cm^{-1} predominantly to $\nu_{C=N}$ in the dihydroisoquinoline. However, this contradicts the x-ray data and suggests that use of the above bands for tautomer assignment needs care. The high frequency band at 1656 cm^{-1} is assigned to $\nu_{C=O}$ of the free 6′ C=O group and low frequency band (1630 cm^{-1}) to the hydrogen bonded C=O group at 2′. The latter band overlaps the ν_{CN} band of the dihydroisoquinoline fragment. Hence their number and relative intensities are altered. In the ν_{NH} absorption region of I a high frequency shift of the "center of gravity" of the broad band is in agreement with the data already discussed for weakened intramolecular H-bonding in I. The presence of the 6- and 7- methoxy groups in I gives new, strong bands (not in II-IV) with maxima at 1282 and 1085 cm^{-1}. In agreement with [20 and 16, page 209] these are assigned to the antisymmetric and symmetric $\nu_{AR}-O-CH_3$ stretching vibrations.

The IR spectrum of IV, which has methyl groups at 6- and 7-, is very similar to that of I hence it seems to have an analogous structure in the solid state.

X-ray electronic spectra show that the bond energy (E_{bond}) for the O1s electrons in I increase to 533.0 eV compared with 531.3 eV in the spectra of II. This evidently occurs via the O atoms of the CH_3O groups; individual lines due to the O atoms, CH_3 groups and C=O of the dimedone fragment are not found. The bond energy of the N1s electrons in I (399.7 eV) is slightly lower than II (399.9 eV) in agreement with the increased C=N bond multiplicity in this molecule.

Solutions. It was previously shown [4] that the tautomeric forms of II and III are not changed from the crystalline state to solutions in inert solvents or in solutions with proton donor or proton acceptor (not excluding the possible formation of an equilibrium mixture of tautomers (*a*) and (b)). The PMR spectra of I and IV in $CDCl_3$ differ from those of II by the presence of not one but two signals for the "acidic" protons at 12.95-13.04 and 5.77-5.84 ppm (Table 4). Their overall intensity corresponds to one proton and their ratio to about 7:3. Since the signal at 13.21 ppm in the specimen of II corresponds to the NH proton in (*a*) the signal at 5.77-5.84 ppm must be either the OH proton of tautomer (b) or the NH proton of tautomer (*a*) having the form of a conformer in which intramolecular H bonding of the dimedone fragment is broken. Since doubling of the signals for the protons of the CH_2 and CH_3 groups of the dimedone fragment of the molecules is not observed we deduce that

tautomer (b) is not formed and the H signals with δ 5.77 and 5.84 ppm are due to the NH group in tautomers (*a*) of I and IV (in which intramolecular H-bonding is absent).

The presence of two forms of I and IV in solution in the ratio of about 70:30 is also confirmed by doubling of the signals for the 4-CH_2 group protons with virtually the same intensity ratio. The aromatic H signals are also doubled.

Increasing the solution temperature from 298 to 330°K did not change the intensity ratio of the indicated signals within experimental error.

In DMSO-D_6 solution, I also exists in two forms as shown by the presence of two signals for the "acidic" proton and by the nonequivalence of the methoxy group protons and doubling of the CH_2 signals in the isoquinoline fragment. According to the intensity ratios for the NH signals at 12.75 and 7.45 ppm and for the CH_2 group the relative concentration of the minor form (conformational tautomer (*a*) without intramolecular H bonding) is increased in DMSO-D_6 solution when compared with $CDCl_3$ solution to around 50-60%.

The existence of I and IV in two forms in solution is also confirmed by their IR spectra in CCl_4 solution. In fact, by contrast with the spectra of II and III, in I and IV there are two (and not one) bands at 1700-1619 cm^{-1} with different intensities. By analogy with the spectra of II and III the bands at 1641-1638 cm^{-1} are principally due to $\nu_{C=O}$ of the enamine–diketone tautomer (*a*) as the conformer with intramolecular H-bonding and those at 1670-1674 cm^{-1} to that without the H-bond. Two bands are also seen in the ν_{NH} region in the spectrum of I. The broad band centered on 3269 cm^{-1} is due to ν_{NH} in the associated NH group and that at 3429 cm^{-1} to the free group. Similar bands at about 3180 and 3415 cm^{-1} are also observed in solution spectra of IV.

In the electronic absorption spectra of I and IV and of II and III there are seen strong bands with maxima at 364-375 nm, typical of π-interaction between the dihydroisoquinoline and dimedone parts of the molecule (Table 5). The presence of the CH_3O or CH_3 groups in positions 6 and 7 in I and IV leads to an increase in the number of bands in the EtOH or CH_3CN solutions when compared with II and III. This might be due to an equilibrium mixture of two conformers of tautomer (*a*) in the solutions (agreeing with PMR and IR spectral data) or connected with a change in molecular symmetry because of the addition of substituents at positions 6 and 7.

Hence the spectroscopic parameters for I and IV allow us to propose that they exist in solutions as a mixture of two conformers of the enamine–diketone tautomer (*a*), the relative content of which depends on the type of solvent.

Quantum-chemical Calculations. To calculate the relative stability of tautomers (*a*)-(c) in the absence of intramolecular interaction we carried out MNDO/H quantum-chemical calculations on the tautomers of 3,3-dimethyl-6,7-dimethoxy- (I^*) and 3,3-dimethyl- (II^*) derivatives of 1-(cyclohexa-2,6-dion-1-yl)-3,4-dihydroisoquinoline. Calculated interatomic distances and conformational parameters (twist angle data) were close to those found experimentally for I and II [4] thus showing the reliability of this data.

The calculated heats of formation ($\Delta H°_{form.}$) of I^* and II^* tautomers (c) are significantly (by 29-37 Kcal/mole) less than those of tautomers (*a*) and (b) (Table 6) hence tautomers (c) are energetically unfavored. The difference in calculated heats of formation for tautomers (*a*) and (b) for each of the dihydroisoquinolines I^* and II^* (7.5-7.6 Kcal/mole) is comparable with the energy of the H-bond hence the probability of interconversion is quite high. According to the calculation, in the absence of intermolecular interactions, independently of the nature of the substituents at positions 6 and 7, the azomethine–enol tautomer (b) is energetically more favored than (*a*), the presence of the OCH_3 groups in I^* additionally increasing its stability. In addition, the dipole moment of tautomer (b) is less, hence nonspecific solvation must favor a shift of the equilibrium towards the azomethine–diketone tautomer (*a*). The values of the twist angles $N_9C_{21}C_{19}C_{10}$ for the corresponding tautomers of I^* and II^* are almost identical, in agreement with the calculation.

The distribution of electron density in molecules of the enamine–diketone tautomers (*a*) in I^* and II^* agrees with the proposal that they can be considered as pseudo-bipolar; the sum of atomic charges in the dihydroisoquinoline fragment A equals approximately +0,5 e and the cyclohexanedione B −0.5 e. A similar separation of charges is not observed for the azomethine–enol tautomers (b). The methoxy substituents in positions 6 and 7 are simultaneously π-donor and Δ-acceptors, having an insignificant effect on the degree of transfer of electron density from fragment B to A (as can be seen from the overall charge on the fragment atoms and the molecular dipole moment values).

Hence the above consideration of the structural characteristics of I in the crystalline state and in solution infers that the 6- and 7-CH_3O groups affect the distribution of electron density and can lead to two trends.

1. In I when compared with II the contribution of coulombic interaction between the dihydroisoquinoline and cyclohexanedione fragments A and B is increased, i.e., the saturated structure (*a''*). Supporting this point are the localization of the multiple C=N bond in fragment A and the averaging of the C=O and CC bonds in fragment B as well as the calculated

distribution of electronic charge in fragments S and B. Hence I can be considered as an intramolecularly polarized structure. As a result the bond between A and B is strengthened.

2. At the same time there is clearly revealed a second tendency which weakens the first effect, i.e., weakening of the π-interaction between fragments A and B which is confirmed by lengthening of the central C_1-C_{12} bond and increasing the angle between the mean planes of these fragments thus weakening the intramolecular H-bond and increasing the difference in the exocyclic angles at C_1.

Hence these two tendencies oppose one another and the overall effect is evened out so that the structure of molecule I in the crystal is only a little different from that of II. In addition, these effects appear to a much higher extent in I in solutions and in reaction with complex forming metal salts. Hence in reactions with copper chloride they lead not only to another method of coordination but to a considerable change in the structure of molecule I behaving as a ligand [2] and (through reaction of I with copper perchlorate) to the formation of a new ligand and complex [3].

EXPERIMENTAL

X-Ray Analysis. An experimental set of intensities was obtained on a four circle automatic Engraf Nonius CAD4 diffractometer (λMoKα, graphite monochromator, $\theta/2\theta$ scanning). Crystallographic parameters are given in Table 7. The structure was solved by a direct method, semi heavy atoms being localized with subsequent analysis of electron density synthesis and refined initially in the isotropic and then anisotropic approximation. The NH atom was localized from difference synthesis with its parameters refined isotropically. The positional parameters of the remaining H atoms were calculated from geometrical considerations (with the C–H length specified as 0.96 Å and U_j = 0.08 A^2). Anisotropic refinement based on fixed H atoms was carried out to R = 0.038. All of the calculations were performed using the SHELX-76 program on an IBM PC/386. Bond lengths and the values of valence angles and coordinates of the independent atoms are given in Tables 1, 2, and 8 respectively. The numbering of the atoms and molecular configuration are given in Fig. 1. IR spectra were recorded on a Specord 75-IR instrument for KBr tablets and for 10^{-2}-10^{-3} molar solutions. Absorption band integrated intensities were measured by the Ramsay method [21]. PMR spectra were taken on a Bruker WP-80 instrument. Electronic absorption spectra of solutions were recorded on Specord M-40 and UV-vis spectrophotometers using standard method with a 10 mm cuvette. X-ray electronic spectra were taken on a Kratos XSAM-80 instrument using MgKα irradiation in a vacuum of about 10^{-10} torr. Sample charge correlation was carried out using the C1s line (285.0 eV).

Quantum chemical calculations were carried out using an LCAO MO method in the MNDO/H approximation and the program [22].

3,3-Dimethyl-6,7-dimethoxy-1-(4,4-dimethyl-2,6-dioxocyclohexyliden-1)-1,2,3,4-tetrahydroisoquinoline (I, $C_{21}H_{27}NO_4$). A mixture of dimedone (1.4 g, 0.01 mole) and 6,7-dimethoxy-1-methylthio-3,3-dimethyl-3,4-dihydroisoquinoline (2.65 g, 0.01 mole) in glacial acetic acid (20 ml) was refluxed for 2 h, poured into water (100 ml), basified with aqueous ammonia to pH 9-10, filtered, dried, and recrystallized from ethanol. The yield of I was 80% with mp 198°C. Found, %: C 70.4, H 7.8, N 4.1. $C_{21}H_{27}NO_4$ Calculated: C 70.6, H 7.6, N 3.9.

3,3,6,7-Tetramethyl-1-(4,4-dimethyl-2,6-dioxocyclohexyliden-1)-1,2,3,4-tetrahydroisoquinoline (IV, $C_{21}H_{27}NO_2$) was prepared similarly in 75% yield with mp 166°C. Found, %: C 77.4, H 8.23, N 4.2. $C_{21}H_{27}NO_2$ Calculated: C 77.5, H 8.4, N 4.3.

REFERENCES

1. V. V. Davydov, V. I. Sokol, E. V. Balebanova, V. K. Belyaeva, Yu. V. Shklyaev, I. N. Marov, B. E. Zaitsev, and M. A. Porai-Koshits, Koordinats. Khimiya, **19**, 803 (1993).
2. V. I. Sokol, V. V. Davydov, E. V. Balebanovs, M. A. Porai-Koshits, Yu. V. Shklyaev, and B. E. Zaitsev, Koordinats. Khimiya, **21**, in the press (1995).
3. V. I. Sokol, V. V. Davydov, E. V. Balebanovs, M. A. Porai-Koshits, Yu. V. Shklyaev, and B. E. Zaitsev, Koordinats. Khimiya, **21**, in the press (1995).
4. V. V. Davydov, V. I. Sokol, E. V. Balebanova, Yu. V. Shklyaev, A. V. Sergeev, V. A. Nikanorov, B. E. Zaitsev, and M. A. Porai-Koshits, Izv. Russ. Akad. Nauk, Ser. Khim., No. 2, 331 (1993).

5. A. A. Gorbunov, M. Yu. Dormidontov, V. S. Shklyaev, and Yu. V. Shklyaev, Khim. Geterotsikl. Soedin., No. 12, 1651 (1992).
6. V. S. Shklyaev, B. B. Aleksandrov, M. S. Gavrilov, and A. G. Mikhailovskii, Enamines in Organic Synthesis [in Russian], Ural Section, Academy of Sciences of the USSR, Sverdlovsk (1989), p. 80.
7. B. B. Aleksandrov, M. S. Gavrilov, M. I. Vakhrin, and V. S. Shklyaev, Khim. Geterotsikl. Soedin., No. 6, 794 (1985).
8. A. K. Grinvalde, É. Ya. Gren, and Ya. P. Stradyn', Izv. Akad. Nauk Latv. SSR., Ser. Khim., No. 1, 126 (1963).
9. É. Ya. Gren, A. K. Grinvalde, and G. Ya. Vanag, Khim. Prir. Soedin., **6**, 262 (1967).
10. É. Ya. Gren, A. K. Grinvalde, and G. Ya. Vanag, Khim. Prir. Soedin., **7**, 382 (1967).
11. É. Ya. Gren, A. K. Grinvalde, and Ya. P. Stradyn' Izv. Akad. Nauk Latv. SSR., Ser. Khim., No. 6, 732 (1972).
12. D. Semmingsen, Acta Chem. Scand., **B28**, 169 (1974).
13. J. Singh and C. Calvo, Can. J. Chem., **53**, 1046 (1975).
14. G. Vanag, Cyclic β-Diketones [in Russian], Izd.-Vo Akad. Nauk. Latv, SSR., Riga (1961), p. 372.
15. K. Simon and S. Meszaros, Cryst. Struc. Comm., **4**, 135 (1975).
16. R. Ford and A. Gordon, Companion to Chemistry [Russian translation], Mir, Moscow (1976), p. 529.
17. O. Ya. Neiland and Ya. Polis, Izv. Akad. Nauk Latv, SSR., Ser. Khim., No. 2, 192 (1963).
18. Ya. Ya. Katsen and O. Ya. Neiland, Izv. Akad. Nauk Latv. SSR., Ser. Khim., No. 5, 606 (1970).
19. V. S. Shklyaev, B. B. Aleksandrov, G. I. Legotkina, M. I. Vakhrin, M. S. Gavrilov, and A. G. Mikhailovskii, Khim. Geterotsikl. Soedin., No. 11, 1560 (1983).
20. D. Brown, A. Floyd, and M. Sainsbury, Spectroscopy of Organic Compounds [Russian translation], Mir, Moscow (1992), p. 76.
21. D. Ramsay, J. Am. Chem. Soc., **74**, 72 (1952).
22. V. A. Zaets, A. T. Pilichenko, V. D. Khavryuchenko, and E. P. Falendish, Zh. Strukt. Khim., **28**, No. 5, 155 (1987).