RESEARCH IN PYRAZOLIDINE CHEMISTRY

XXII.* STABILITY OF THE N–N BOND OF 3,5-DIOXOPYRAZOLIDINE ENOLATES WITH RESPECT TO HYDROGENOLYSIS IN THE PRESENCE OF RANEY NICKEL

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UDC 547.772.2'775:542.941.7

An increase in the resistance of the N–N bond to hydrogenolysis on Raney nickel in alkaline media is observed not only for 1,2,4-trisubstituted 3,5-dioxopyrazolidines but also for other types of 3,5-dioxopyrazolidines that are capable of enolization. 3,5-Dioxopyrazolidines that are capable of forming betaines also do not undergo hydrogenation in neutral ethanol. The use of the potentiometric method of Sokol'skii and Druz' made it possible to establish very slight adsorption of the enolates and betaines on the catalyst surface. The decrease in adsorbability is explained by a decrease in the effective charges on the nitrogen atom of the heteroring; this is in agreement with the results of calculations of the enolate and enol by the Pariser–Parr–Pople method. An assumption regarding the greater aromatic character of the enolate as compared with the enol is expressed on the basis of a comparison of the bond lengths.

1,2,4-Trisubstituted 3,5-dioxopyrazolidines, in contrast to their behavior in neutral ethanol [2], do not undergo hydrogenolysis at the N–N bond of the heteroring in ethanol with added alkali in the presence of Raney nickel. It seemed of interest to examine the behavior of other enolized 3,5-dioxopyrazolidines during hydrogenolysis in alkaline media, to examine the possible reasons for the increased stability of the N–N bond, and to attempt to link them to the quantum-chemical characteristics of the molecules.

It was found that not only 1,2,4-trisubstituted dioxopyrazoldienes, for example, 1,2-diphenyl-4-butyl-3,5-dioxopyrazolidine (IV), but also compounds that are capable of simultaneous keto-enol and lactim-lactam tautomerism – 1-phenyl- (I), 1,4-diphenyl- (II), and 5-isoamyl-3,5-dioxopyrazolidines (III) – are incapable of undergoing hydrogenation in ethanol containing two to three equivalents of potassium hydroxide. The trisodium salt of the enol of 4-butyl-1,2-di(p-sulfophenyl)-3,5-dioxopyrazolidine (V) does not undergo hydrogenolysis in neutral ethanol, but 4-diethylaminoethyl-1,2-diphenyl-3,5-dioxopyrazolidine (VI), which apparently exists in the betaine form in neutral ethanol, is hydrogenated at a significantly lower rate than its 4-alkyl analogs, for example, IV (Fig. 1). As already described in [3], 4-(p-aminobenzylidene)- (VII) and 4-(p-nitrobenzylidene)-1,2-diphenyl-3,5-dioxopyrazolidines (VIII) in neutral ethanol are hydrogenated only to 4-(p-aminobenzyl)-1,2-diphenyl-3,5-dioxopyrazolidine (IX) (which is capable of forming a betaine), in contrast to 4-benzylidene-1,2-diphenyl derivative X, which is hydrogenated under these same conditions with cleavage of the N–N bond to butylmalonic acid dianilide (XIa).

It is characteristic that 4-(p-acetamidobenzylidene)-1,2-diphenyl-3,5-dioxopyrazolidine (XII), which is unable to form a betaine, is also hydrogenated to p-acetamidobenzylmalonic acid dianilide (XIc).

* See [1] for communication XXI.

Leningrad Pharmaceutical-Chemistry Institute. A. E. Arbuzov Institute of Physical and Organic Chemistry, Academy of Sciences of the USSR, Kazan. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 3, pp. 403-407, March, 1974. Original article submitted March 23, 1973.

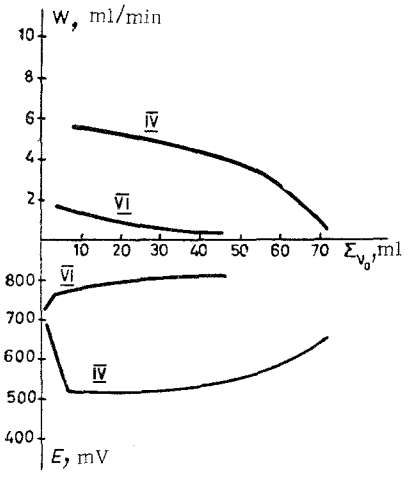


Fig. 1. Kinetic and potentiometric curves of the hydrogenation of 3.25 mmole of IV and VI in ethanol at 30°C.

The above data constitute an additional confirmation of the fact of the decrease in the rate of hydrogenolysis of the N–N bond of enolates of the 3,5-dioxopyrazolidine series. The reasons for this may be an increase in the strength of the Ni···H bond in alkaline media [4], a decrease in the adsorption of the enolate on the catalyst, or an increase in the strength of the N–N bond of the heterocycle.

In considering the first of the possible reasons, one should note that the hydrogenation of some compounds of other series occurs even in very alkaline media [5]. We have also established that substituted benzylidenemalonic acid dianilides are hydrogenated only in neutral media and not in alkaline media [3]. 1,2-Diphenyl-4-butyl-4-methyl-3,5-dioxopyrazolidine (XIII), which is incapable of enolization, is cleaved in alkaline media to methylbutylmalonic acid mono(N,N'-diphenylhydrazide), which is then hydrogenated to methylbutylmalonic acid monoanilide [2]. It follows from the above data that the increase in the strength of the Ni···H bond in alkaline media cannot be the only reason for the sharp decrease in the rate of hydrogenation of the enolate of 3,5-dioxopyrazolidine.

In order to ascertain whether the adsorption of 3,5-dioxopyrazolidine enolates on the catalyst changes, we studied the reaction of IV-VI with the Raney nickel surface using the potentiometric method of Sokol'skii and Druz' [6]. It was found that IV in ethanol in the presence of two to three equivalents of alkali shifts the catalyst potential (1090 mV) to the anode side by only 25 mV, while a shift of 200 mV is observed in neutral ethanol (Fig. 1). Compounds V and VI in neutral ethanol do not shift the catalyst potential at all to the anode side. These results are evidence in favor of the assumption that the primary reason for the decrease in the rate of hydrogenolysis of the N–N bond of 3,5-dioxopyrazolidine enolates is the decrease in their adsorbability on the catalyst surface.

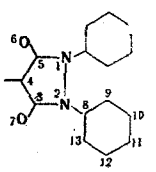
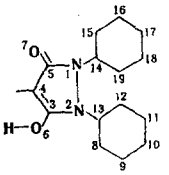
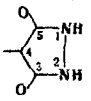
The latter may be caused by a change in the electronic charge of the molecules and the decrease, as a consequence of this, in the effective charges on the nitrogen atoms of the hydrazine fragment. We recently expressed the assumption that the magnitudes of the effective charges on the nitrogen atoms in the 3 and 5 positions of the heterocycle, which depend on the nature of the substituents, affect the rate of hydrogenolysis of the N–N bond of variously substituted 3,5-dioxopyrazolidines. The inverse dependence between the magnitude of the rate of hydrogenolysis and the calculated (by the Hückel MO method) effective charges on the 3- and 5-C atoms of 4-substituted 1,2-diphenyl-3,5-dioxopyrazolidines [7] was in accord with this assumption.

From this point of view, it seemed of interest to compare the molecular diagrams of the enolate and enol of 3,5-dioxopyrazolidine, which we calculated within the π-electron approximation by the Pariser–Parr–Pople method with the use of semiempirical parameters [8, 9] (Table 1). The parameters were selected in such a way as to satisfy the principal physicochemical properties of simple molecules with N–N, N–C, and C=O bonds. The role of phenyl groups in stabilization of the anion was examined simultaneously. The phenyl rings in structures A and B deviate from the conjugation plane by 30° because of steric hindrance, while conjugation is artifically excluded in structure C. As in [10, 11], the total energy of the fragments was broken down into physical components. Conjugation with the phenyl substituents raises the stability of the anionic structure by 26 kcal/mole, and the resonance component of the energy plays the dominant role here.

It follows from the data presented in Table 1 that the effective charges of the nitrogen atoms in enolate A (0.196) are appreciably lower than in enol C (0.318 and 0.357); this is in agreement with the above assumption regarding the effect of the magnitude of the effective charges of the nitrogen atoms and with the experimental data on the decrease in the rate of hydrogenolysis of dioxopyrazolidine enolates at the N–N bond.

From a comparison of the calculated (as in [8, 9] from the expression $R_{mn} = a p_{m-n} + b$) bond lengths of the enol and enolate of 1,2-diphenyl-3,5-dioxopyrazolidine it follows also that the aromatic character of the enolate is higher. The bond lengths in the enolate are considerably more equalized than in the enol: the maximum difference in the calculated bond lengths in the enolate is 0.036 Å, while that in the enol is is 0.120 Å. Thus the increase in the aromatic character in the 1,2-diphenyl-3,5-dioxopyrazolidine enolate

TABLE 1. Results of Quantum-Chemical Calculations*

m	Δq_m	m–n	P_{m-n}	R_{m-n}	m	Δq_m	m–n	P_{m-n}	R_{m-n}
									
		A					B		
2	0,196	1—2	0,120	1,431	1	0,318	1—2	0,225	1,412
3	0,175	2—3	0,349	1,395	2	0,357	1—5	0,494	1,369
4	−0,245	3—4	0,609	1,408	3	0,029	1—14	0,229	1,417
6	−0,650	3—6	0,632	1,251	4	−0,300	2—3	0,547	1,360
8	0,022	2—8	0,275	1,408	5	0,185	2—8	0,222	1,418
9	−0,039	8—9	0,639	1,402	6	0,035	3—4	0,746	1,324
10	−0,017	8—13	0,636	1,402	7	−0,573	3—6	0,188	1,331
11	−0,042	9—10	0,671	1,396	8	0,003	4—5	0,427	1,440
12	−0,009	10—11	0,664	1,397	9	0,007	5—7	0,702	1,239
13	0,006	11—12	0,660	1,398	10	0,009	8—9	0,648	1,400
		12—13	0,675	1,395	11	−0,003	8—13	0,649	1,400
					12	0,003	9—10	0,671	1,396
		C			13	−0,027	10—11	0,664	1,397
2	0,137	1—2	0,100	1,435	14	0,011	11—12	0,665	1,397
3	0,178	2—3	0,376	1,390	15	0,004	12—13	0,669	1,397
4	−0,290	3—4	0,610	1,407	16	0,004	14—15	0,647	1,401
6	−0,670	3—6	0,618	1,254	17	0,012	14—19	0,647	1,401
					18	0,005	15—16	0,670	1,396
					19	0,030	16—17	0,664	1,397
							17—18	0,664	1,397
							18—19	0,670	1,396

* Symbols: m and n are the atom numbers, Δq_m is the effective atomic charge, m–n is the bond, P_{m-n} is the π-bond order, and R_{m-n} is the calculated bond length in angstroms.

may also be one of the reasons for the increase in the resistance of the N–N bond to hydrogenolysis over Raney nickel.

However, we were unable to delimit the effect of aromatization and of the decrease in adsorption of the enolate on the catalyst by comparison of the stability of IV during its hydrogenation without a catalyst by nascent hydrogen in acidic and alkaline media (ethanol). Under these conditions, IV is not hydrogenated in either alkaline or acidic media; this confirms the high specificity of Raney nickel as a catalyst for the hydrogenolysis of the N–N bond of 3,5-dioxopyrazolidines.

EXPERIMENTAL

Starting compounds I, II, and IV-VI were previously described in [12]. Compound III was obtained by the method in [13].

The hydrogenolysis of I-VI and the measurement of the catalyst potential were accomplished with the previously described variant of the Sokol'skii–Druz' apparatus [6].

Attempted Reduction of Dioxopyrazolidine IV in Homogeneous Media. A) Zinc dust was added in small portions in the course of 5 h with periodic shaking at room temperature to 0.5 g of IV in 50 ml of a 15% ethanol solution of HCl. The filtrate was diluted with water to bring about precipitation. A total of 0.45 g of starting compound containing no XI (according to TLC) was obtained. Similar results were obtained when the mixture was refluxed.

B) Zinc dust was added in small portions in the course of 2 h to a refluxing mixture of 0.5 g of IV and 50 ml of 50% NaOH solution. The filtrate was acidified and worked up to give 0.45 g of the starting compound containing no XI.

Similar results were obtained when the reaction was carried out in alkaline ethanol solution.

(β-Diethylaminoethyl)malonic Acid Dianilide (XIb). A 7.0 g sample of VI and 3 g of Raney nickel were refluxed in 50 ml of ethanol for 20 h with chromatographic monitoring on activity III aluminum oxide in ethanol–ammonia–ethyl acetate (9.5 : 1 : 20) of the decrease in the concentration of the starting com-

pound (the R_f of VI is 0.61, and the R_f of dianilide XIb is 0.83). After separation of the catalyst, the filtrate was evaporated to dryness, and the residue was treated with 60 ml of 30% ethanol to remove the residual starting compound. Recrystallization from ethanol gave 5.9 g (84%) of a colorless crystalline substance with mp 153°. IR spectrum: 1666, 1610, 1550, 1518, 1320, 1260 cm^{-1}. UV spectrum (in neutral, acidic, and alkaline ethanol): 246 nm (log ε 4.4). Found: N 12.1%. $C_{21}H_{27}N_3O_2$. Calculated: N 11.9%. The hydrochloride was obtained in benzene as a colorless crystalline substance with mp 206-207°. Found: N 11.1; Cl 9%; equiv. wt. 398. $C_{21}H_{27}N_3O_2 \cdot HCl$. Calculated: N 10.9; Cl 9.1%; equiv. wt. 390.

1,2-Diphenyl-4-(p-acetamidobenzylidene)-3,5-dioxopyrazolidine (XII). A solution of 0.6 g of aminobenzylidenedioxopyrazolidine VII in 10 ml of acetic anhydride was heated at 130-140° for 4 h. The cooled reaction mixture was poured into water, and the aqueous mixture was worked up to give 0.67 g (90%) of a red substance with mp 338-339° (from acetic acid). IR spectrum: 3450, 3300, 1705, 1677, 1613, 1568, and 1500 cm^{-1}. UV spectrum, λ_{max}, nm (log ε): acidic ethanol 243 (4.49), 384 (4.58); alkaline ethanol 251 (4.52). Found: C 70.1; H 4.7; N 9.6%. $C_{24}H_{19}N_3O_3 \cdot 0.5CH_3COOH$. Calculated: C 70.4; H 4.9; N 9.8%.

p-Acetamidobenzylmalonic Acid Dianilide (XIc). A 0.3 g sample of dioxopyrazolidine XII was hydrogenated in 30 ml of ethanol over 2 g of Raney nickel until hydrogen absorption had ceased. The catalyst was separated, and the filtrate was evaporated to give 0.25 g of a colorless crystalline substance with mp 238-239° (from aqueous dioxane). IR spectrum: 1675, 1655, 1600, 1531, and 1500 cm^{-1}. UV spectrum, λ_{max}, nm (log ε): neutral and acidic ethanol 248 (4.62); alkaline ethanol 248 (4.69). Found: C 71.8; H 5.7; N 10.7%. $C_{24}H_{23}N_3O_3$. Calculated: C 71.8; H 5.7; N 10.5%.

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