TRIMERIC MECHANISM OF

PROTON TRANSFER IN IMIDAZOLE

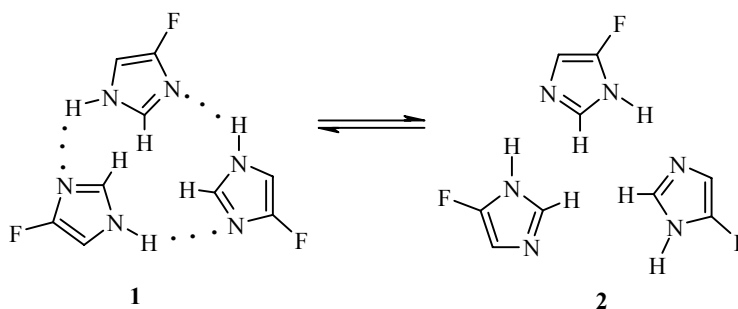**T. J. Kikalishvili and J. A. Kereselidze**

The energy, electronic, and structural characteristics of the tautomeric transformation of imidazole were calculated by the quantum-chemical semiempirical AM1 method. It was concluded on the basis of the calculated data that proton transfer in the tautomeric transformation 1H-imidazole $\rightleftarrows$ 3H-imidazole can take place by a trimeric mechanism.

Keywords: imidazole, trimer, quantum-chemical calculation, tautomerism.

The tautomeric transformation 1H-imidazole $\rightleftarrows$ 3H-imidazole largely arises from the mobility of the proton at the pyrrole-type nitrogen atom. Experimental detection of the tautomeric forms is often hindered as a result of the high exchange rate of the proton in the NH group. It is not impossible that such exchange may be intermolecular in nature, i.e., takes place with the participation of two or more molecules of imidazole [1, 2].

The dimeric, trimeric, and tetrameric mechanisms of proton transfer in pyrazole have been confirmed by many authors [3-6], but there are no analogous data for imidazole in the literature. This is probably due to steric hindrance of 1H–3H proton transfer in imidazole in contrast to pyrazole, in which the nitrogen atoms are in the *ortho* position.

We are proposing a trimeric mechanism for the 1H–3H tautomeric transformation, since the dimeric mechanism is not realized for geometric reasons.

To obtain a quantitative description of the simultaneous transfer of three protons for the case of imidazole trimer **1** the energy, electronic, and structural characteristics of this process in the reaction coordinates were calculated by the quantum-chemical semiempirical AM1 method. The geometry of the tautomeric structure was fully optimized. The direct distance R_{NH} between the end atoms in the triad of hydrogen bonds amounts to 2.94 Å, while the angle $\varphi_{NHN} = 154.3°$. The distances between the hydrogen atoms located at the center of the trimeric structure are in the range of 1.28-1.48 Å.
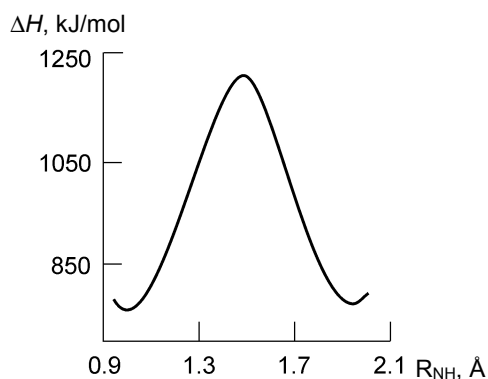

Fig. 1. The dependence of the enthalpy ΔH of proton transfer in the imidazole trimer **1** on the reaction coordinate R_{NH}.

The energy diagram of the tautomeric process is shown in Fig. 1. The high value of the enthalpy of activation ($\Delta\Delta H^{\#} = 454.4$ kJ/mol) and the low value of the heat of reaction ($\Delta\Delta H = 3.8$ kJ/mol) form the basis of a proposal concerning tunnel proton transfer in the imidazole trimer **1** (for the oligomer **3** $\Delta\Delta H = 3.7$ kJ/mol). A similar argument was put forward earlier [8, 9] on the basis of the discovery of an almost symmetrical two-well potential for the intermolecular hydrogen bond HN⋯H in imidazole.

The constant of the tautomeric trimeric equilibrium (K_T) was calculated according to formula similar to the previously proposed formula [10]:

$$K_T = \frac{P_{NH}^2 \, P_{N=C}^2 \, (P_{CN}^1 \, P_{HN}^2 - P_{CN}^2 \, P_{HN}^1)}{P_{CN}^2 \, P_{HN}^2 \, (P_{NH}^1 \, P_{N=C}^2 - P_{NH}^2 \, P_{N=C}^1)} , \qquad (1)$$

where P_{ij}^1 and P_{ij}^2 are the values of the bond orders for the first and second terms.

We also considered an oligomeric mechanism of proton transfer in imidazole:
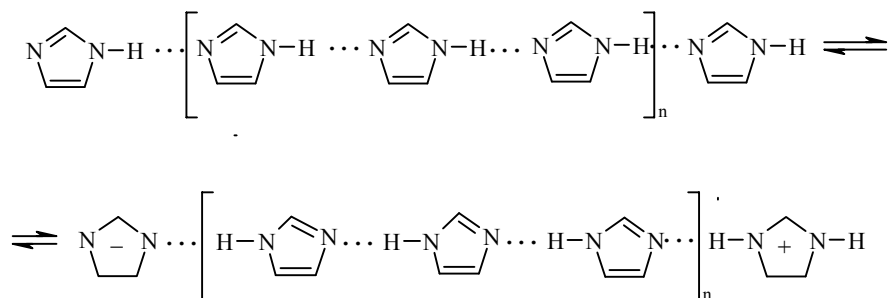
3

For this structure it was not possible to calculate the enthalpy of activation on account of its extremely high value, due probably to the ionic forms of the end molecules in the oligomeric chain of the imidazole **3** [9].

With regard to the dependence of the equilibrium constant on the mechanism of proton transfer the values calculated according to Eq. (1) (for the trimer $\log K_T = -1.96$, for the oligomer $\log K_T = -1.72$) seem more real, since the classical thermodynamic formula $\log K_T = -\Delta H/2.3 \, RT$ proved insensitive to the mechanism (for the trimer and oligomer $\log K_T = -0.67$).

1070

It can be concluded from the results of the quantum-chemical calculations that the 1H–3H tautomeric transformation in imidazole takes place by a trimeric mechanism with tunnel proton transfer.

REFERENCES

1. M. R. Grimmett, in: D. Barton and W. D. Ollis (editors) *Comprehensive Organic Chemistry* [Russian translation], Vol. 8, Khimiya, Moscow (1985), p. 429.
2. B. S. Hickman, M. Maskal, J. J. Titman, and I. G. Wood, *J. Am. Chem. Soc.*, **121**, 11486 (1999).
3. A. Baldy, J. Elguero, R. Faure, M. Pierot, and E. J. Vinset, *J. Am. Chem. Soc.*, **107**, 5290 (1985).
4. C. Foces-Foces, A. L. Llamas-Saiz, R. M. Claramunt, C. Lopez, and J. Elguero, *J. Chem. Soc. Chem. Commun.*, 1143 (1994).
5. A. L. Llamas-Saiz, C. Foces-Foces, I. Sobrados, J. Elguero, and W. Mautermans, *Acta Crystallogr.*, **C49**, 724 (1993).
6. T. Sugarava and I. Takasu, *Adv. Phys. Org. Chem.*, **32**, 219 (1985).
7. M. J. S. Dewar, E. G. Zoebisch, E. F. Healy, and J. J. P. Stewart, *J. Am. Chem. Soc.*, **107**, 3902 (1985).
8. H. Zimmerman, *Z. Electrochem.*, **65**, 821 (1961).
9. A. N. Nesmeyanov, E. B. Zavelovich, V. N. Babin, N. S. Kochetkova, and E. I. Fedin, *Tetrahedron*, **31**, 1461 (1975).
10. J. A. Kereselidze, *Khim. Geterotsikl. Soedin.*, 752 (1999).