THERMAL ISOMERIZATION OF 3,3-DIHALO-1,2-DIPHENYLAZIRIDINES

R. R. Kostikov, A. F. Khlebnikov,
and K. A. Ogloblin

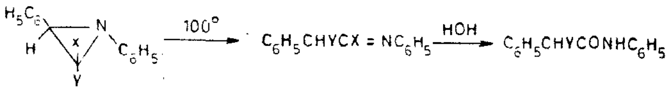
UDC 542.952.1: 547.717

The kinetics of thermal isomerization of 3,3-dihalo-1,2-diphenylaziridines containing fluorine, chlorine, or bromine atoms in the ring were studied, and the activation parameters of the reaction were determined. A concerted mechanism for the formation of imidoyl halides from haloaziridines that includes conrotatory opening of the aziridine ring with halogen migration of the 1,2 type is proposed on the basis of the data obtained.

In [1-6] it is shown that when C-chloro-substituted aziridines are heated, a chlorine atom migrates to the adjacent carbon atom with simultaneous opening of the opposite C—N bond and the formation of imidoyl halides. Halogen-containing N-aminoaziridines are converted to aldehyde hydrazones via the same scheme [7].

A transition state with ionic character has been proposed on the basis of a study of the kinetics of thermal isomerization of 3,3-dichloro- and 3,3-dibromo-1,2-diphenylaziridines (I, II) [5]. In the present research we investigated the isomerization of aziridines III-VI containing different halogen atoms in the ring. The phenyl groups in the investigated aziridines are trans-oriented [8, 9].

The corresponding imidoyl halides IX-XI are obtained when solutions of aziridines III-VI in CCl_4 or C_2Cl_4 are heated. Only IX was obtained from aziridines III and IV, while X and XI, respectively, were obtained from aziridines V and VI. The structure of the imidoyl halides was confirmed by spectral methods (Table 1) and by hydrolysis to phenylhaloacetic acid anilides XII and XIII. 2-Chloro-2-phenylacetanilide (XII) is formed in quantitative yield by hydrolysis of imidoyl halide X and VII, and 2-bromo-2-phenylacetanilide (XIII) is formed by hydrolysis of VIII, IX, and XI.



I - VI VII - XI XII, XIII

I, VII X = Y = Cl ; II, VIII X = Y = Br ; III, IX X = Cl, Y = Br ; IV X = Br, Y = Cl ;
V, X X = F, Y = Cl ; VI, XI X = F, Y = Br ; XII Y = Cl ; XIII Y = Br

As in the case of aziridines I and II [5], the rates of thermal isomerization of aziridines III-VI were determined by IR and PMR spectroscopy: in the first case from the change in the intensity of the band at ~1400 cm^{-1}, and in the second case from the change in the intensity of the signals of the aziridine proton at 3.5-3.7 ppm and the methylidyne proton of imidoyl halides VIII-XI at 5.5-5.9 ppm. It was found that the kinetics of isomerization of the aziridines correspond to a first-order reaction. According to the PMR data, the rates of consumption of the aziridine and accumulation of the imidoyl halide are identical (Table 2). Special experiments demonstrated that the isomerization rate constant increases when the aziridine concentration in solution is increased above 2%. The rate constants for the isomerization of aziridines III and IV were determined by a study of mixtures of the same compounds containing 88 and 60% aziridine III (Table 2).

It is apparent from the data in Table 3 that the rate of thermal isomerization of the aziridines depends on both the nature of the halogens and on their position relative to the other substituents in the aziridine ring. With respect to their ability to undergo migration the halogens can be arranged in the order Br > Cl > F, which corresponds to the order of strengths of carbon—halogen bonds [10]. It follows from a comparison of the rates of isomerization of aziridines III and IV that a bromine atom that is syn-oriented with respect to the unshared electron pair of the nitrogen atom migrates more readily.* In addition, the migration of a halogen from a

---

*The orientation of the halogen is subsequently defined in the text relative to the unshared electron pair of the nitrogen atom.

A. A. Zhdanov Leningrad State University, Leningrad 199004. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 1, pp. 48-53, January, 1978. Original article submitted January 28, 1977.

TABLE 1. Spectral Characteristics of N-Phenyl-2-halo-2-phenylacetimidoyl Halides (IX-XI)*

Compound	UV spectrum, λmax, nm (log ε)	Absorption bands in the IR spectrum, cm^{-1}			PMR spectrum, δ, ppm (J, Hz)	
		N=C	C_6H_5	other frequencies	CHX	C_6H_5
IX	225 (4,20), 272 (4,22)	1685 s 1740 s	1460, 1500 s, 1604 s, 3042, 3075, 3095	697 s, 857, 910, 920, 1005, 1035, 1080, 1095, 1175, 1198, 1215, 1226, 1280 w, 1345 w	5,82 s	6,8—7,6 m
X	224 (4,12), 255sh (3,91)	1705 s 1730 s	1455, 1500 s, 1540 s, 1610 s, 3040, 3075, 3095	696 s, 707 s, 890, 905 w, 1006 w, 1035, 1080, 1100, 1180, 1200, 1230, 1320 w	5,56 d (14)	7,0—7,7 m
IX	224 (3,96), 255sh (3,84)	1730 s	1465, 1500 s, 1606 s, 3045, 3075, 3097	700 s, 890, 910, 1010 w, 1035, 1080, 1120, 1180, 1230 s, 1290 w	5,57 d (15,5)	7,0—7,7 m

*In the UV spectra the abbreviation "sh" indicates shoulder. Intensities in the IR spectra: s is strong, w is weak, and the remaining bands are of medium intensity. A doublet signal at ~122 ppm (with respect to C_6F_6) with J_{HF} ~15 Hz is observed in the ^{19}F NMR spectra of X and XI.

TABLE 2. Rate Constants for the Isomerization of Aziridines II-VI [$k \cdot 10^{-5}$, sec^{-1} (temp., °C)]*

Compound	IR spectroscopy	PMR spectroscopy	
		A	B
II	†	59,1±2,1 (110)	56,2±2,1 (110)
III	2,20 (95), 17,2 (115), 42,0 (125)	32,2±1,9 (115)	45,5±1,8 (115)‡
IV	5,67 (95), 27,5 (115), 64,9 (125)	79,8±4,5 (115)	
V	3,64±0,10 (80), 15,8±0,3 (95), 62,7±1,8 (110)	22,5±0,6 (95)	21,9±0,9 (95)
VI	2,97±0,45 (30), 12,3±0,8 (45), 61,2±3,5 (60)	10,8±0,8 (45)	13,3±0,8 (45)

*The aziridine concentration in solution in the determination by IR spectroscopy was 1.7%, as compared with ~10% in the case of determination by PMR spectroscopy; A) determined from the aziridine consumption, B) determined from the imidoyl halide accumulation.

†The rate constants were presented in [5].

‡For a mixture containing 60% aziridine III and 40% aziridine IV.

TABLE 3. Kinetic Parameters of the Isomerization of 3,3-Dihalo-1,2-diphenylaziridines (at 100°C)

Compound	k, sec^{-1}	k_{rel}	$\Delta H^{\neq}$, kJ/mole	$\Delta S^{\neq}$, J/deg-mole
I*	$5,85 \cdot 10^{-6}$	1	106±1	− 62±3
II	$1,52 \cdot 10^{-4}$	25,8	108±4	− 30±11
III	$3,76 \cdot 10^{-5}$	6,4	117±2	− 18±5
IV	$8,56 \cdot 10^{-5}$	14,5	95±4	− 70±10
V	$2,54 \cdot 10^{-4}$	43,1	104±1	− 37±2
VI	$1,51 \cdot 10^{-2}$	2560	81±5	− 64±17

*Taken from [5].

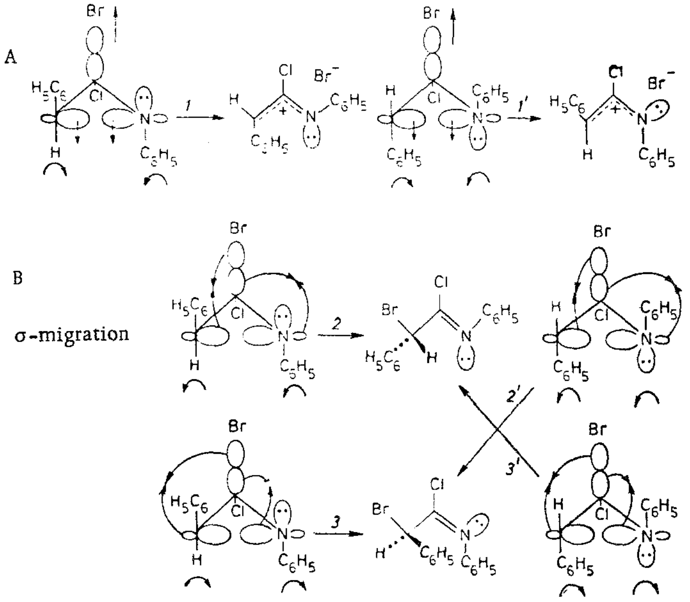
syn orientation has a lower entropy of activation. A considerable increase in the reaction rate is observed on passing to fluorine-containing aziridines V and VI; this increase is probably associated with a decrease in the strength of the carbon—"leaving" halogen bond under the influence of the fluorine atom and with stabilization by it of the positive charge that develops in the transition state. It is known that among the halogens, fluorine has the greatest mesomeric stabilizing effect on the cationic center [11, 12]. Data on the entropy of activation of aziridines III, V, and VI indicate greater orderliness of the transition state in the isomerization of aziridines V and VI. A comparison of rates of isomerization of aziridines I, III, V, and VI makes it possible to assume that the chlorine atom in aziridine I that is syn-oriented relative to the unshared electron pair of the nitrogen atom migrates faster (by a factor of nine) than an anti-oriented chlorine atom. This is also confirmed by the closeness of the entropies of activation in the isomerization of aziridine I and aziridine IV. A comparison of the rates and activation parameters for the isomerization of aziridine II with the analogous values for aziridines I, III, and IV makes it possible to conclude that in the isomerization of aziridine II a bromine atom may migrate from both positions and that the syn-oriented bromine migrates more rapidly (by a factor of 1.5) than the anti-oriented bromine atom.

The isomerization of aziridines may take place via a two-step mechanism including concerted heterolytic cleavage of the carbon–halogen bond and disrotatory opening of the resulting C-aziridinyl cation to an azaallyl ion followed by coordination of the ion pair to give an imidoyl halide (mechanism A).

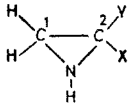
Another pathway in which 1,2 migration of halogen and cleavage of the C–N bond in the aziridine occur simultaneously without the formation of an ion pair (mechanism B) can also be proposed.*

In accordance with the Woodward–Hoffmann rules [14], this process is classified as a $_{\sigma}2_s + _{\sigma}2_u$ reaction, and the aziridine ring undergoes conrotatory opening in the case of σ migration and disrotatory opening in the case of p migration. Isomerization pathways A and B can also be regarded as S_N1 and S_N2 reactions, respectively. Conrotatory ring opening during σ migration of halogen via concerted mechanism B (pathways 2 and 3') is most favorable for the thermal isomerization of aziridines III and IV. The formation of an azaallyl ion via mechanism A by disrotatory opening of the aziridine ring is more sterically hindered, since in this case one of the phenyl groups moves within the ring.

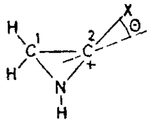
To obtain additional information regarding the mechanism of the isomerization we calculated model aziridines XIV-XVI and aziridinyl cations XVII and XVIII by the CNDO/2 method.† The calculations were made with parameters from [15, 16] and with the following bond lengths (Å): $C^1-N = C^1-C^2 = C^2-N = 1.485$, $C-F = 1.32$, $C-Cl = 1.70$, $C-H = 1.08$, and $N-H = 1.00$; angles $HCH = XCY = 118°$, $HNC^1 = HNC^2 = 115°$. Angle θ in the ions was varied from 59 to −59°.



Analysis of the results of the calculations shows that in aziridines XIV-XVI the W_{ij} indices, which characterize the bond strengths [17], are larger for the syn-Cl–C^2 and syn-Cl–C^1 bonds, respectively, than for the anti-Cl–C^2 and anti-Cl–C^1 bonds.

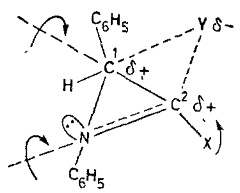


XIV-XVI



XVII, XVIII

XIV X = Y = Cl ; XV X = Cl, Y = F ; XVI X = F, Y = Cl ;
XVII X = Cl ; XVIII X = F



XIX

---

*A similar mechanism has been examined from a theoretical point of view for the thermal isomerization of gem-dihalocyclopropanes [13].

†The program for the calculations was composed by V. Ya. Bespalov, to whom the authors express their thanks.

The formation of a nonplanar aziridinyl cation ($\theta = \pm 59°$) from aziridine is more favorable (by 1.3 kJ/mole) in the case of splitting out of chlorine from the anti position than in the case of splitting out of chlorine from the syn position. In this case the W_{ij} indices of the C^1-N bond decrease, and the W_{ij} indices of the C^2-N bond increase by 0.047 and 0.25-0.30, respectively, during removal of syn-chlorine, as compared with 0.030 and 0.20-0.23 in the case of removal of anti-chlorine.

Compression of the aziridine cation ($\theta \rightarrow 0$) leads to appreciable stabilization, to a greater degree for the XVIII ion than for the XVII ion: The energies of conversion to the planar ions are 204.5 and 151.8 kJ/mole, respectively. This stabilization of the ions is realized primarily through interaction of the cation center with the unshared electron pairs of the halogen atom. The W_{ij} indices of the C^1-C^2 and $N-C^2$ bonds decrease and the W_{ij} index of the C^1-N bond increases simultaneously during compression of the ions.

These data provide evidence that in the case of isomerization of the gem-dihaloaziridines via mechanism A one should observe equally probable (from the point of view of the energies involved) splitting out of syn- or anti-halogen and the formation of a planar aziridinyl cation, which subsequently undergoes ring opening to give an azaallyl ion. At the same time, concerted pathway B, which includes the formation of transition state XIX similar to the nonplanar aziridinyl cation ($\theta \neq 0°$) XVII or XVIII, should proceed with greater ease for syn-halogen than for anti-halogen. The latter conclusion is in agreement with the experimental results.

The data on the entropy of activation ($\Delta S^{\neq} < 0$) (Table 3) and the constancy of the entropy of activation of the isomerization of aziridine I in solvents with different polarities [5] are in agreement with the proposed highly ordered cyclic transition state. In addition, according to the calculations the corresponding W_{ij} indices for the $Cl-C^1$ bonds increase on passing from aziridine XIV to XV and XVI, whereas they decrease for the $Cl-C^2$ bonds, and the polarity of the $Cl-C^2$ bond simultaneously increases. Consequently, the tendency of the other halogen attached to the C^2 atom to migrate should increase when fluorine is attached to the C^2 atom; this is in agreement with the experimental results (Table 3).

Thus the experimental and calculated data make it possible to assume that the isomerization of gem-dihaloaziridines takes place via a concerted mechanism that includes a cyclic polar transition state with a σ-migrating halogen and conrotatory ring opening (XIX).

EXPERIMENTAL

The UV spectra of solutions of the compounds in heptane were recorded with a Perkin–Elmer M-402 spectrophotometer. The IR spectra of 10% solutions of the compounds IX-XI in CCl_4 in a 100 μ cuvette were recorded with a UR-20 spectrometer. The PMR spectra of 10% solutions of the compounds in CCl_4 were obtained with a Varian HA-100D-15 spectrometer.

The methods for the determination of the rate constants and calculation of the activation parameters were taken from [5]. The solvent was tetrachloroethylene. The rate constants for the isomerization of aziridines III and IV (Table 2) were found by IR spectroscopy from data obtained for ~2% solutions of mixtures of 88% III and 12% IV and 60% III and 40% IV. The following $k \cdot 10^{-5}$ (sec^{-1}) values were obtained (the temperatures in degrees centigrade are given in parentheses): for the first mixture 2.62 ± 0.11 (95), 18.4 ± 0.6 (115), and 44.8 ± 0.9 (125); for the second mixture 3.6 ± 0.4 (95), 21.3 ± 0.6 (115), and 51.2 ± 1.4 (125). According to the IR spectroscopic data, the rate constant ($k \cdot 10^{-5}$, sec^{-1}) for the isomerization of a mixture of 88% aziridine III and 12% aziridine IV at 115°C depends on the concentration of the solution as follows: 16.6 ± 1.3 for 0.5%, 18.4 ± 0.6 for 1.7%, and 30.4 ± 1.9 for 10% solutions.

N-Phenyl-2-halo-2-phenylacetimidoyl Halides (IX-XI). A solution of 0.5 g of aziridines III-VI [1, 8] in 10 ml of CCl_4 was heated in an ampul at 120°C for, respectively, 3, 3, and 3.5 h. Evaporation of the solvent in vacuo gave 0.5 g of a dark oil (Table 1).

2-Halo-2-phenylacetanilides XII and XIII. A mixture of 0.4 g of imidoyl halide IX-XI and 10 ml of water was allowed to stand at 20°C for 2 days, after which the precipitate was separated, washed with water until the wash waters were neutral, and recrystallized. Anilide XII was isolated in quantitative yield from imidoyl halide V, and anilide XIII was isolated from IX and XI. The constants of the anilides were in agreement with the values presented in [5, 18].

LITERATURE CITED

1. R. R. Kostikov, A. F. Khlebnikov, and K. A. Ogloblin, Dokl. Akad. Nauk SSSR, 223, 1375 (1975).
2. H. W. Heine and A. B. Smith, Angew. Chem., 75, 669 (1963).

3. R. E. Brooks, J. O. Edwards, G. Levey, and F. Smith, Tetrahedron, 22, 1279 (1966).
4. K. Ichimura and M. Ohta, Bull. Chem. Soc. Jpn., 40, 1933 (1967).
5. P. P. Kostikov, A. F. Khlebnikov, and K. A. Ogloblin, Zh. Org. Khim., 11, 585 (1975).
6. D. Seyferth, W. Tronich, and H.-M. Shih, J. Org. Chem., 39, 158 (1974).
7. D. J. Anderson, T. L. Gilchrist, D. C. Horwell, and C. W. Rees, J. Chem. Soc., C, No. 4, 576 (1970).
8. R. R. Kostikov, A. F. Khlebnikov, and K. A. Ogloblin, Zh. Org. Khim., 13, 1857 (1977).
9. B. A. Arbuzov, S. G. Vul'fson, R. R. Kostikov, L. A. Monetina, A. F. Khlebnikov, and A. N. Vereshchagin, Izv. Akad. Nauk SSSR, Ser. Khim., No. 6, 1300 (1975).
10. L. V. Gurvich, G. V. Karachevtsev, V. N. Kondrat'ev, Yu. A. Lebedev, V. A. Medvedev, V. K. Potapov, and Yu. S. Khodeev, Energies of Cleavage of Chemical Bonds. Ionization Potentials and Electron Affinities [in Russian], Nauka, Moscow (1974).
11. R. J. Blint, T. B. McMahon, and J. L. Beauchamp, J. Am. Chem. Soc., 96, 1269 (1974).
12. G. A. Olah, G. Liang, and Y. K. Mo, J. Org. Chem., 39, 2394 (1974).
13. A. I. Ioffe and O. M. Nefedov, Izv. Akad. Nauk SSSR, Ser. Khim., No. 7, 1536 (1974).
14. R. B. Woodward and R. Hoffmann, Conservation of Orbital Symmetry, Academic Press.
15. J. A. Pople and G. A. Segal, J. Chem. Phys., 44, 3289 (1966).
16. D. P. Santry and G. A. Segal, J. Chem. Phys., 47, 158 (1967).
17. K. B. Wiberg, Tetrahedron, 24, 1083 (1968).
18. R. R. Kostikov, A. F. Khlebnikov, and K. A. Ogloblin, Zh. Org. Khim., 9, 2346 (1973).

PYRROLES FROM KETOXIMES AND ACETYLENE

I.* STRUCTURAL SPECIFICITY OF THE REACTION WITH UNSYMMETRICAL KETOXIMES. PMR SPECTRA OF 1-VINYLPYRROLES AND THE EFFECTS OF ALKYL SUBSTITUENTS

B. A. Trofimov, A. I. Mikhaleva,
A. N. Vasil'ev, and M. V. Sigalov

UDC 547.742: 543.422.25

The reaction between ketoximes $CH_3(RCH_2)C=NOH$ and acetylene in the presence of KOH and dimethyl sulfoxide at 120°C leads exclusively to 1-vinyl-2-methyl-3-R-pyrroles in 73-87% yields. The regiospecificity of the reaction is disrupted when the temperature is raised, and the fraction of a second isomer (1-vinyl-2-RCH_2-pyrrole) reaches 20-50% at 140°C. Regioselectivity is not observed for $R^1CH_2(R^2CH_2)C=NOH$ (R^1 and R^2 = n-alkyl). The relative shifts of the signals of the ring protons and the vinyl group for a number of 2-alkyl-1-vinyl- and 2,3-dialkyl-1-vinylpyrroles were measured. Alkyl substituents have a distinct effect on the chemical shifts of the protons of the 4−5 bonds. As the volume of the 2-alkyl substituent increases the β protons of the N-vinyl group are deshielded by 0.10-0.13 ppm, and the 4-H ring proton is shielded by 0.05-0.16 ppm; this is explained by steric inhibition of the p−π conjugation in the N-vinyl group during an s-trans(anti)-gauche conformational transition.

The present communication is a continuation of a series of papers on the study of the reaction of ketoximes with acetylene, which leads to pyrroles and N-vinylpyrroles.

In the case of an unsymmetrical ketoxime this reaction in the presence of KOH and dimethyl sulfoxide (DMSO) gives [2] two isomeric pyrroles (or an N-vinylpyrrole in the case of excess acetylene).

The following questions are important for an understanding of the reaction mechanism and for better preparative use of the reaction: Which of the two groups of the ketoxime – the methyl or methylene group (when

---

*This is actually communication XVI. The first publications (for example, see [1-3] and the literature cited in them) were not numbered.

Irkutsk Institute of Organic Chemistry, Siberian Branch, Academy of Sciences of the USSR, Irkutsk 664033. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 1, pp. 54-59, January, 1978. Original article submitted February 9, 1977.