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MASS-SPECTRAL STUDY OF 9-[α(β,γ)-PICOLYLIDENE]-1(4)-AZAFLUORENES

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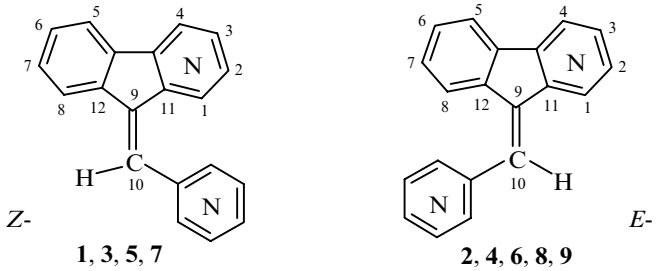
A mass-spectral study was carried out on the behavior of the Z- and E-isomers of 9-picolylideneazafluorenes. A possible mechanism for the elimination of a hydrogen atom from the M^+ ion of the Z- and E-isomers of 1(4)-azafluorene derivatives was examined. Mass spectrometry permitted a distinction between compounds isomeric relative to the position of the nitrogen atom in the azafluorene fragments and also the Z- and E-isomers of picolylidene derivatives of 1- and 4-azafluorenes possessing β- and γ-pyridyl substituents.

Keywords: *Z*- and *E*-isomers, 9-[α(β,γ)-picolylidene]-1(4)-azafluorenes, mass spectrometry, fragmentation.

Some 9-arylideneazafluorenes possess bactericidal and psychotropic activity and also display properties of plant growth regulators [1]. Considerable attention has been given to the preparation of such compounds, while ^{1}H NMR spectroscopy and mass spectrometry have been used to establish the structures of their *Z*- and *E*-isomers. A study of the fragmentation of 9-benzylideneazafluorenes showed that their decomposition is accompanied by cyclization upon formation of the fragment ions, while the mass spectra of their *Z*- and *E*-isomers are almost identical [2].

In the present work, we studied the dissociative ionization of geometrical isomers of 9-picolylideneazafluorenes in order to establish the mass spectral criteria for identifying their *Z*- and *E*-isomers taking into account the position of the nitrogen atoms in the azafluorene and picolylidene fragments. Pure *Z*- and *E*-isomers were studied: 9-(γ-picolylidene)-1-azafluorene (**1** and **2**), 9-(β-picolylidene)-1-azafluorene (**3** and **4**), 9-(γ-picolylidene)-4-azafluorene (**5** and **6**), 9-(α-picolylidene)-4-azafluorene (**7** and **8**), and the *E*-isomer of 9-(α-picolylidene)-1-azafluorene (**9**).



1, **3**, **5**, **7** **2**, **4**, **6**, **8**, **9**

1–**4**, **9** – 1-aza; **5**–**8** – 4-aza; **1**, **2**, **5**, **6** γ-pyridyl; **3**, **4** β-pyridyl; **7**–**9** α-pyridyl

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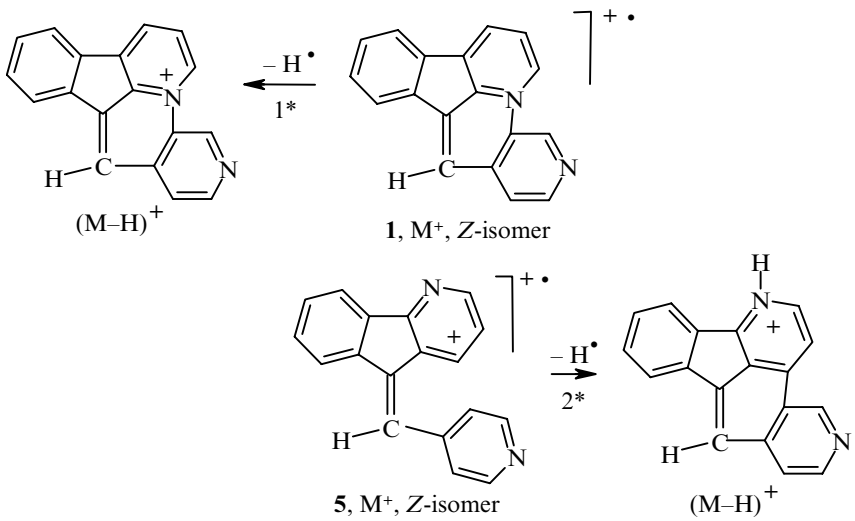
The mass spectra of compounds **1-9** (Table 1) show strong peaks for the molecular ion and $(M\text{-}H)^+$ ion. The dissociative ionization of these compounds is largely due to the consecutive elimination of a hydrogen atom and HCN molecule (Table 1).

The greatest interest is found in the removal of a hydrogen atom from the M^+ ion since the $I_{(M\text{-}H)^+}/I_{M^+}$ ratio permits a reliable distinction between the *Z*- and *E*-isomers of compounds **1-4**, which are isomeric relative to the position of the nitrogen atom in the azafluorene and pyridine moieties.

The probability of the $(M\text{-}H)^+$ ion formation is highly dependent on the arrangement of the nitrogen atoms in the azafluorene system and pyridine substituent. The intensity of the $(M\text{-}H)^+$ ion is maximal for 1-azafluorene derivatives **1-4** and **9** and picolylidene-4-azafluorenes **6-8**. The magnitude of this peak in the mass spectrum of compound **5** is much less than for the molecular ion peak (Table 1). This discrepancy is probably related to the direction of the cyclization of the pyridyl group to the azafluorene fragment upon elimination of a hydrogen atom. A strong $(M\text{-}H)^+$ ion is formed in the case of N–C-cyclization for compounds **1, 3,** and **7-9** (Scheme 1, pathway 1*). Such a pathway for cyclization is characteristic for many N-heteroaromatic compounds [3-5].

Scheme 1



The cyclization of compound **2** and **4-6** may proceed only between the carbon atoms of the azafluorene fragment and pyridyl group with simultaneous migration of a hydrogen atom to an the azafluorene nitrogen atom. In this case, the probability of the $(M\text{-}H)^+$ ion appearance should be much lower (Scheme 1, pathway 2*). However, the high intensity of the $(M\text{-}H)^+$ ion in the mass spectra of **2** and **4** indicates pathway 1*. This finding may be understood assuming a low energy barrier for isomerization of the M^+ ion of *E*-isomers **2** and **4** to give the M^+ ions of *Z*-isomers **1** and **3** as a result of the energy effect of the electron impact. However, the observed large discrepancy between the relative intensities of the M^+ and $(M\text{-}H)^+$ ions for *Z*- and *E*-isomers **5** and **6** indicates the lack of *Z,E*-isomerization since such a process should level out the structural differences of these isomers and, thus, the differences in their mass spectra. Such a rearrangement is also not observed in the decomposition of *cis* and *trans* isomers of unsaturated dicarboxylic acids since the mass spectra of these isomers differ strongly [6].

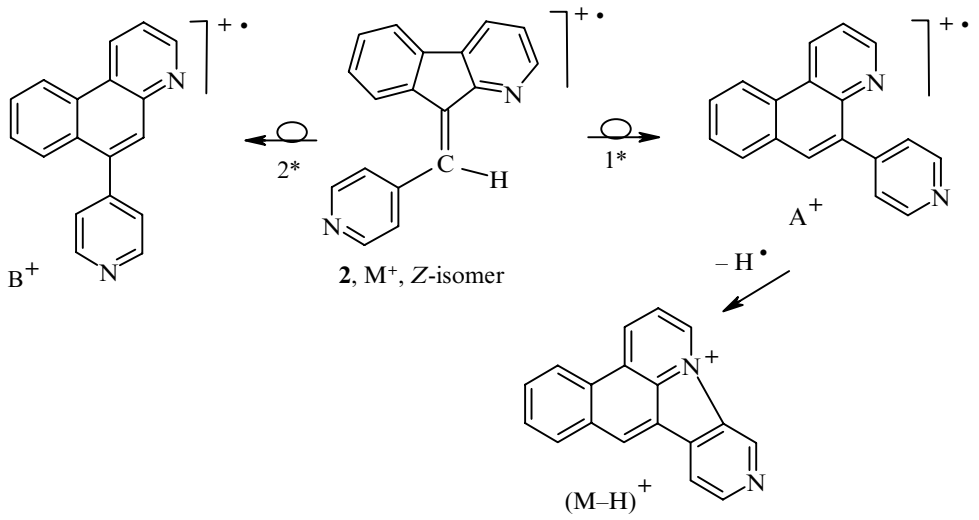
The high intensity of the $(M\text{-}H)^+$ ions in the mass spectra for *E*-isomers of 1-azafluorene derivatives **2** and **4** may be explained assuming rearrangement of the molecular ions of both the *Z*- and *E*-isomers to ions A^+ and B^+ with common structure (Scheme 2) occurring for all the compounds studied **1-9**. Ion A^+ readily loses a hydrogen atom in the case of the dissociative ionization of both isomers. An analogous process for expansion of a five-membered ring to a six-membered ring due to inclusion of an exocyclic carbon atom has been postulated to explain the course of fragmentation for fulvene derivatives [7] and the mass spectra of natural coumarins containing a dihydrofuran ring [8]. Thus, this process is presumably rather common [9-12].

TABLE 1. Intensities of Ion Peaks (% of Maximal) in the Mass Spectra of **1-9***

Compound	$I_{(M-H)^+}/I_{M^+}$	M^+ 256	$(M-H)^+$ 255	$(M-HCN)^+$ 229	$(M-H-HCN)^+$ 228	178	167	166	140	139	115	114
1	3.0	33.4	100	1.2	17.4	5.4	4.3	8.7	1.5	2.2	1.7	0
2	2.2	45.7	100	0.9	11.0	0	5.0	4.0	1.4	2.8	1.1	2.2
3	6.1	16.4	100	1.2	6.9	2.1	5.2	2.5	0	2.1	1.8	2.3
4	3.5	28.4	100	0	8.6	4.0	12.2	7.3	4.5	5.2	3.2	0
5	0.11	100	10.9	0.5	0.5	2.2	5.4	0.7	0.7	1.0	0	0
6	1.3	96.9	100	5.0	2.5	1.2	2.7	2.5	0.5	0.6	0	0
7	1.47	67.9	100	1.5	0.5	1.2	1.2	0.5	0.5	0.4	0	0
8	1.48	67.7	100	0.5	0.5	2.1	3.3	0	0.5	0.5	0.5	0
9	1.92	52.1	100	0.5	0.5	0.5	2.8	0.5	0.7	0.8	0	0

* The M^+ ion and 10 strongest ion peaks in the mass spectra of these compounds are given.

Scheme 2



The rearrangement shown in Scheme 2 accounts not only for the high intensity of the $(M-H)^+$ ion in the mass spectra of *E*-isomers **2** and **4** but also the higher probability of the hydrogen atom elimination for *Z*-isomers **1** and **3** than for *E*-isomers **2** and **4**. This follows from the results of a PPP quantum-chemical calculation [13] for the M^+ ions of compounds **1-4** (Table 2). The probability of the rearrangement for the M^+ ions of the *Z*- and *E*-isomers to give ions A^+ and B^+ (Scheme 2) likely depends both on their thermodynamic stability, a component of which is E_π of the M^+ ions, and a kinetic factor, namely, the dissociation energy of the proposed bond, which is proportional to the π order of this bond. The E_π values calculated for compounds **1-4** do not show any significant differences for M^+ of the *Z*- and *E*-isomers, while the ΔP values given in Table 2 suggest a qualitative (or semiquantitative) explanation for the observed differences in their mass spectral behavior. Thus, we rely specifically on the ΔP values in Table 2, where the minimal difference for all the values of 0.006 (for **6**) primarily indicates that ΔP is greater than zero and not less. This is a sufficient condition for a qualitative interpretation of the experimental data.

Since isomerization to ions A^+ and B^+ should occur as a result of dissociation of the $C_{(9)}$–$C_{(11)}$ and $C_{(9)}$–$C_{(12)}$ bonds, respectively, we examined the π-components of the orders of these bonds for the molecular ions of compounds **1-4** and, for comparison, the π-orders of the exocyclic $C_{(9)}$–$C_{(10)}$ bonds for these ions (Table 2). Analysis of the latter shows that the orders of the exocyclic bonds $P_{9\text{-}10}$ are somewhat higher for the M^+ ions of the *E*-isomers than of the *Z*-isomers, while the bond orders $P_{9\text{-}11}$ and $P_{9\text{-}12}$, in our opinion, predict the experimental results if the latter are explained by isomerization of the molecular ions of the *Z*- and *E*-isomers to ions A^+ and B^+ (Scheme 2). Table 2 shows that for all isomers **1-4**, dissociation of the $C_{(9)}$–$C_{(12)}$ bonds, leading to formation of ion B^+, is more likely than dissociation of the $C_{(9)}$–$C_{(11)}$ bonds, giving rise to ion A^+, which produces the $(M-H)^+$ fragment (Scheme 2, pathway 1*).

Thus, the calculated data show that the amount of B^+ ions for compounds **1-4** should be greater than the amount of A^+ ions. However, the difference $\Delta P = P_{9\text{-}11} - P_{9\text{-}12}$, which is proportional to the excess of B^+ ions over A^+ ions, varies for each isomer. Table 2 indicates that *Z*-isomers **1** and **3** form more A^+ ions than *E*-isomers **2** and **4**. Thus, the calculation predicts greater intensity of the $(M-H)^+$ ion peaks in the mass spectra of *Z*-isomers **1** and **3** than in the mass spectra of *E*-isomers **2** and **4**, which is in accord with experiment (Table 1, $I_{(M-H)^+}/I_{M^+}$ ratio). Furthermore, the calculation also accounts for the significantly greater probability for loss of a hydrogen atom by the *Z*-isomer for the isomer pair **3** and **4** in comparison with the pair **1** and **2**. It can be concluded from the fact that, according to the calculation, ΔP, which is proportional to the amount of B^+ ions, is five times less for *Z*-isomer **3** than for *E*-isomer **4**, while it is only two times less for *Z*-isomer **1** than for *E*-isomer **2**.

TABLE 2. π-Bond Orders of the Molecular Ions of *Z*- and *E*-Isomers **1-6**

Bond order P_{ik}	**1**, *Z*-isomer	**2**, *E*-isomer	**3**, *Z*-isomer	**4**, *E*-isomer	**5**, *Z*-isomer	**6**, *E*-isomer
$P_{9\text{-}10}$	0.637	0.643	0.627	0.629	0.632	0.631
$P_{9\text{-}11}$	0.433	0.445	0.419	0.430	0.464	0.473
$P_{9\text{-}12}$	0.396	0.378	0.413	0.399	0.384	0.376
ΔP*	+0.037	+0.067	+0.006	+0.031	+0.080	+0.097

* $\Delta P = P_{9\text{-}11} - P_{9\text{-}12}$.

Opposite behavior is observed in the mass spectra of azafluorene *Z*-isomer **5** and *E*-isomer **6**: the probability for loss of a hydrogen atom is much greater for the *E*-isomer (Table 1). Since direct cyclization at the nitrogen for ions A^+ and B^+ in these isomers is excluded, this discrepancy probably occurs since cyclization in the case of the *Z*-isomer should take place by the attack of the β-carbon atom of the pyridyl substituent at electron-deficient $C_{(1)}$, while cyclization in the case of the *E*-isomer should take place by attack of the same β-carbon atom at $C_{(8)}$ of the azafluorene system. The probability of elimination of a hydrogen atom by the M^+ ion for isomer pair **7** and **8** is virtually identical since this process is the result of cyclization of the nitrogen atom in the α-pyridyl group at $C_{(1)}$ or $C_{(8)}$ of the azafluorene system for both *Z*-isomer **7** and *E*-isomer **8**, respectively. This process, as expected, proceeds more readily than C–C cyclization for the isomer pair **5** and **6** but is much more difficult than in the fragmentation of isomers **1,2** and **3,4**. This finding indicates that the probability for cyclization of the azafluorene nitrogen atom at a carbon atom is higher than the pyridine nitrogen atom at the same carbon atom.

Chromatographic analysis of the reaction mixture and ^{1}H NMR spectroscopy showed that only the *E*-isomer is formed in the synthesis of 9-(α-picolylidene)-1-azafluorene (**9**). The probability of elimination of a hydrogen atom by the molecular ion of *E*-isomer **9** is 30% higher than for *E*-isomer **7** and *Z*-isomer **8**, which, similar to compound **9**, have an α-pyridyl group at $C_{(10)}$. This finding is likely also related to the more facile cyclization of the carbon atom of its α-pyridyl substituent at $C_{(10)}$ at the azafluorene nitrogen atom in the molecular ion of form A^+ of isomer **9** in comparison with the cyclization of the pyridine nitrogen atom at $C_{(1)}$ in the 4-azafluorene system in the molecular ions of form A^+ of compounds **7** and **8**.

The probability of loss of a hydrogen atom for γ- and β-picolylidene-1-azafluorenes **1-4** is higher for the *Z*-isomers, while this value is higher for the *E*-isomer in the decomposition of the γ- and α-picolylidene-4-azafluorenes (see Table 1). Analysis of the fragmentation of these picolylideneazafluorenes shows that the $I_{(M\text{-}H)^+}/I_{M^+}$ ratio, which gives the proportional probability of loss of a hydrogen atom from the M^+ ion, may be used to distinguish these isomers differing in the position of the nitrogen atom in the azafluorene and, in some cases, pyridine rings as well as to identify the *Z*- and *E*-isomers of 1- and 4-azafluorene derivatives.

EXPERIMENTAL

The mass spectra of **1-9** were taken on an MKh-1303 mass spectrometer with direct sample inlet into the ion source with 70 eV ionizing voltage and exposure temperatures 105 (**1, 2**), 145 (**3, 4**), 150 (**5, 6**), 110 (**7, 8**), and 140°C (**9**). These compounds were prepared according to our previous procedure [14]. The purity of the products was monitored by thin-layer chromatography, ^{1}H NMR spectroscopy, and mass spectrometry. The PPP calculation for the M^+ ions of **1-4** was carried out by the usual closed shell procedure [13]. After carrying out the self-consistency procedure, the electron energy of the ion was calculated using the formula $E_\pi = E_\pi^{\text{closed}} - 0.25J_{mn}$, where E_π is the energy calculated using the closed shell variant and J_{mn} is the Coulomb integral (the indices *m* and *n* related to MO with unpaired electrons).

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