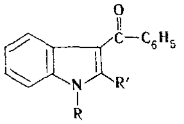
STUDY OF THE PRODUCTS OF OXIDATIVE REARRANGEMENT IN THE INDOLE SERIES BY MASS SPECTROMETRY

R. A. Khmel'nitskii, N. A. Klyuev,
T. A. Kozik, V. N. Rusinova,
and N. N. Suvorov

UDC 547.757+543.51

The principle pathways of dissociative ionization upon electron impact of 3-substituted 3-benzoylindoles are discussed. Alternative localization of the positive charge on the N or O atoms of the molecular ion determines the most probable pathways of its disintegration. The isomerization of the molecular ion and the existence of tautomeric forms in the starting molecule or in the molecular ion promote the appearance of low-intensity peaks that are valuable for identification purposes.

We have previously discovered a new oxidative rearrangement in the indole series that leads to the formation of 3-benzoylindole and its 2-substituted derivatives [1, 2]. In the present study we have investigated the mass spectra of compounds corresponding to the following formula:



I R=R'=H; II R=H, R'=CN; III R=H, R'=OH; IV R=H, R'=NHBu; V R=H, R'=COOH; VI R=CH$_3$, R'=H; VII R=CH$_3$, R'=COOH

TABLE 1. Mass-Spectral Characteristics of 2-Substituted 3-Benzoylindoles at an Ionizing-Electron Energy of 50 eV (in percent of the maximum peak in the spectrum)*

3-Benzoylindole (I) 222 (9,9), 221 (64,0), 220 (5,4), 165 (5,4), 145 (13,4), 144 (100), 116 (30,0), 115 (5,1), 89 (17,0), 77 (8,6). $W_M=23{,}0$, $S_{1/2}=2$.

2-Cyano-3-benzoylindole (II) 247 (5,6), 246 (46,2), 245 (9,4), 170 (7,9), 169 (100), 141 (14,8), 114 (21,0), 105 (21,9), 77 (43,1). $W_M=15{,}7$, $S_{1/2}=2$.

3-Benzoyl-2-ketoindoline (III) 238 (8,2), 237 (69,5), 160 (16,0), 159 (100), 131 (5,8), 105 (69,5), 104 (7,1), 103 (10,4), 77 (51,2). $W_M=21{,}8$, $S_{1/2}=2$.

2-(n-Butylamino)-3-benzoylindole (IV) 293 (9,3), 292 (60,7), 291 (13,7), 263 (18,8), 249 (17,1), 235 (11,4), 160 (9,1), 145 (6,0), 131 (5,0), 111 (8,3), 106 (6,0), 105 (100), 98 (5,1), 97 (16,3), 96 (7,2), 91 (37,5), 84 (6,1), 83 (16,3), 82 (7,2), 81 (8,6), 77 (33,8), 73 (8,0). $W_M=10{,}7$, $S_{1/2}=7$.

3-Benzoylindole-2-carboxylic acid (V) 266 (6,7), 265 (57,6), 247 (20,6), 221 (5,4), 220 (6,7), 219 (14,7), 191 (5,9), 190 (8,0), 188 (32,0), 171 (5,0), 170 (20,0), 165 (7,5), 145 (5,9), 144 (100), 116 (11,7), 115 (7,2), 114 (59,7), 105 (20,0), 97 (7,2), 89 (12,0), 83 (8,0), 77 (51,2), 71 (6,9), 69 (8,8). $W_M=12{,}3$, $S_{1/2}=4$.

N-Methyl-3-benzoylindole (VI) 236 (8,6), 235 (49,5), 234 (5,5), 159 (14,1), 158 (100), 130 (14,5), 103 (15,7), 102 (6,7), 89 (5,9), 83 (7,5), 81 (8,6), 77 (20,4), 71 (9,8), 69 (14,1). $W_M=21{,}6$, $S_{1/2}=2$.

N-Methyl-3-benzoylindole-2-carboxylic acid (VII) 280 (9,6), 279 (46,2), 235 (32,1), 234 (10,2), 203 (8,9), 202 (48,6), 190 (6,1), 159 (12,4), 158 (100), 130 (18,4), 128 (8,3), 115 (6,1), 105 (10,0), 103 (13,2), 102 (8,5), 91 (8,5), 89 (10,8), 77 (48,6), 51 (12,5). $W_M=11{,}4$, $S_{1/2}=4$.

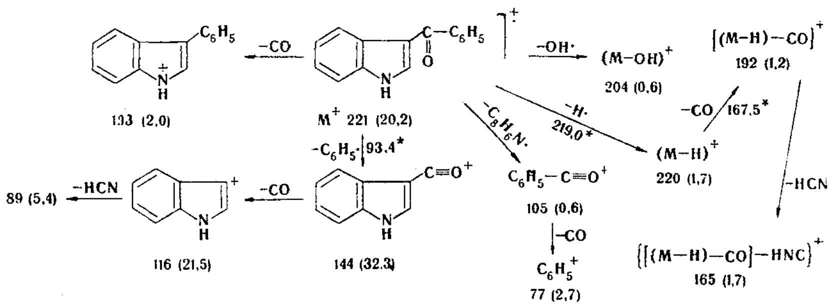
---

* Peaks with intensities >5% are given.

D. I. Mendeleev Moscow Chemical-Engineering Institute. K. A. Timiryazev Moscow Agricultural Academy. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 9, pp. 1240-1244, September, 1974. Original article submitted September 12, 1973.

The mass spectra of the investigated compounds, the stabilities of the molecules with respect to electron impact (W_M) in percent, and the selectivities of the disintegration ($S_{1/2}$) are presented in Table 1.

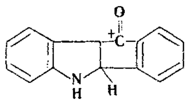
The dissociative ionization of I is associated with the formation of an oxonium structure, the development of which is possible only in the case of primary localization of the positive charge in the molecular ion on the oxygen atom. In this case the disintegration of I is similar to the dissociative ionization of ketones [3] with characteristic cleavage of the α bond relative to the carbonyl group, which is responsible for the appearance in the spectrum of ion peaks with masses 77, 105, 116, and 144.*

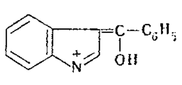


The listed ions represent 57% of the total ion current at an ionizing-electron energy of 50 eV.

It is interesting to note that the intensity of the ion peak with mass 105 ($Ph-C\equiv O^+$) increases substantially as the energy of the ionizing voltage decreases. Thus, for example, the ratios of the intensities of the formation of $(M-Ph)^+$ and $PhCO^+$ ions are 56.0, 47.2, 31.8, and 17.6 for ionizing-electron energies of 30, 25, 20, and 15 eV, respectively.

The ion peak with mass 204 is of low intensity and is apparently associated with removal of a hydroxyl group from the molecular ion. Its formation can be explained either by intramolecular cyclization of the molecular ion to give structure A, as has been described for the Ar–X–Ar systems (X = NH, S, O) [4] and for 2-aroylindoles [5], or with the possibility of the formation of a tautomeric indolenine structure of both the starting molecule and of the molecular ion (structure B). The $(M-17)^+$ peak is also observed in the spectrum of N-methyl-3-benzoylindole (VI) and is of approximately the same intensity.


A


B

However, it should be noted that most of the molecular ions in the dissociative ionization are represented by the ketone form, and structures A and B are responsible only for the formation of low-intensity peaks, which can be used as characteristic peaks. The ion peak with mass 193 is due to the energetically advantageous rearrangement process associated with ejection of a neutral CO particle and subsequent migration of the phenyl radical to the indole ring.

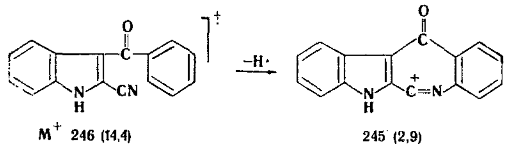
The introduction of a substituent into the 2-position of the indole ring has a substantial effect on the character and direction of the disintegration of II-V. The probability of localization of positive charge on the oxygen atom of the carbonyl group increases sharply, and, as a consequence of this process, the formation of a fragment benzoyl ion is increased by a factor of 10-50 as compared with unsubstituted 3-benzoylindole. The ratio of the intensities (I_{COPh}) of the COPh (mass 105) peaks in the mass spectra of III and I is 10, as compared with 50 in the case of IV and I.

The elimination of a radical in the 2-position of the indole ring, which leads to the appearance of an $(M-R')^+$ ion in the spectrum, makes it possible with sufficient reliability to monitor one or another substituent. Successive elimination of ethyl, propyl, and butyl fragments from the molecular ion is also observed in the case of the NHBu radical (IV); this corresponds to the appearance in the spectrum of a number of peaks of fragment $(M-C_2H_5)^+$, $(M-C_3H_7)^+$, and $(M-C_4H_9)^+$ ions with masses of 263, 249, and 235.

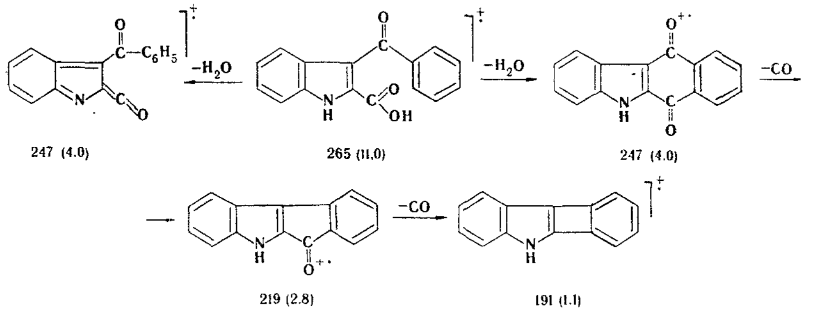
---

* Here and subsequently, the numbers under the formulas indicate the mass numbers of the ions, the numbers in parentheses indicate the peak intensities in percent relative to the total ion current, and the numbers with asterisks indicate the apparent mass of the metastable process.

The observed elimination of a hydrogen atom from the molecular ion in II possibly occurs with the formation of an azatropone structure conjugated with the indole and benzene rings.

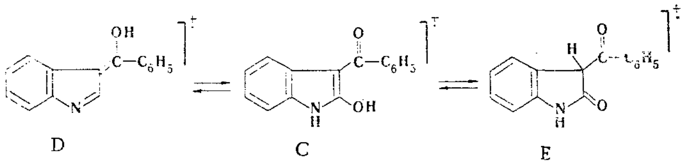


This sort of participation of the phenyl ring is also possible when a H_2O molecule is stripped from the molecular ion of V. This probably proceeds through a six-membered intermediate state and leads to a structure of the anthraquinone type, which then disintegrates with successive ejection of two CO molecules or via the pathway described in [7] (scheme 3); in addition, the disintegration of this compound is characterized by elimination of COOH and CO_2 particles.



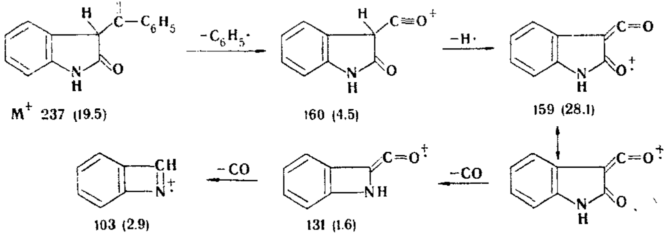
The disintegration of VII also proceeds in a manner similar to the dissociation of V. However, in this case the elimination of a water molecule from the molecular ion is less likely, and the $(M-H_2O)^+$ peak is 2.6% of the maximum peak in the spectrum.

The presence of a hydroxyl group in III makes the existence of a molecular ion in three isomeric forms (C, D, E) possible.



The presence of enol form D explains the relatively high intensity of the peak of the fragment $(M-OH)^+$ ion as compared with the same process described for I.

In addition to the observed peaks of fragment ions with mass numbers 160, 132, 105, and 77, the spectrum of III also contains peaks of ions with masses 159, 131, and 103, the formation of which requires additional explanation. The peaks of metastable processes with apparent masses of 158.0 and 107.9 that appear in the spectrum of III make it possible to assume that successive elimination of a hydrogen atom and a CO particle occurs after detachment of a phenyl group from the molecular ion; this will lead to ring contraction.



The ion with mass 159 formed in this case corresponds to the maximum peak in the spectrum, and this confirms the preferred existence of the molecular ion in the keto form [8]. The stability of the corresponding ion is due to delocalization of the positive charge between two oxygen atoms.

EXPERIMENTAL

The mass spectra were recorded with an MKh-1303 spectrometer with a modified system for introduction of the sample (direct introduction into the ion source) and a system for recording at an ionizing-electron energy of 50 eV; the cathode emission current was 1.5 mA, and the vaporization temperature for the samples was ~110°. The reproducibility of the mass spectra was 5% (relative).

3-Benzoyl-2-ketoindoline (III). 3-Indolylphenylacetonitrile was treated with n-butylamine in the presence of alkali, after which the aqueous filtrate was acidified, and bright-yellow indole III with mp 190.5-192° (from benzene) was isolated. The product gave an intense coloration with ferric chloride. UV spectrum (in alcohol), λ_{max}, nm (log ε): 230 (4.16), 268 (4.04), and 326 (3.95). IR spectrum (in mineral oil): 1620, 1635, and 1670 (C=O), and 3200 cm^{-1} (N–H). Found, %: C 76.7; H 4.7; N 6.0. $C_{15}H_{11}NO_2$. Calculated, %: C 76.6; H 4.7; N 5.9.

1-Methyl-3-benzoylindole-2-carboxylic Acid (VII). This compound was obtained by methylation of 3-benzoylindole-2-carboxylic acid with dimethyl sulfate and had mp 165-166° (from benzene–petroleum ether) (mp 165-166° [9]).

LITERATURE CITED

1. V. N. Rusinova, Yu. I. Smushkevich, and N. N. Suvorov, Tr. MKhTI im. D. I. Mendeleeva, 66, 125 (1970).
2. V. N. Rusinova, Yu. I. Smushkevich, T. A. Kozik, and N. N. Suvorov, Zh. Organ. Khim., 8, 1735 (1972).
3. J. Beynon, Mass Spectrometry and Its Applications to Organic Chemistry, Elsevier, Amsterdam (1960).
4. I. E. Eland and C. I. Danby, J. Chem. Soc., 5935 (1965).
5. E. D. Matveeva, Author's Abstract of Master's Dissertation, Moscow State University, Moscow (1972).
6. I. H. Beynon and A. E. Williams, Appl. Spectroscopy, 14, 156 (1960).
7. N. S. Vul'fson, V. I. Zaretskii, A. V. Kisin, N. N. Suvorov, and Zh. D. Ovchinnikova, Khim. Geterotsikl. Soedin., 502 (1967).
8. A. R. Katritzky and J. M. Logowski, Adv. Heterocyclic Chem., 2, 1 (1963).
9. R. S. Staynton and A. Tophan, J. Chem. Soc., 1889 (1953).