MASS-SPECTRAL STUDY OF ESTERS OF KETO ACIDS OF THE INDOLE SERIES

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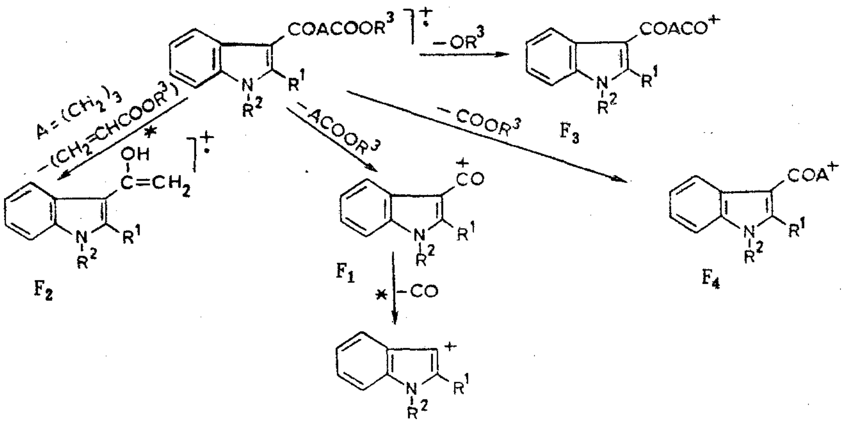
UDC 543.51:547.757

Under the influence of electron impact, esters of saturated keto acids of the indole series undergo the fragmentation typical for 3-acylindoles, whereas esters of unsaturated and aromatic 3-indolyl keto acids have specific mass spectra that reflect the peculiarities of their structure and the mutual orientation of the substituents.

It has been established that the most intense ions in the mass spectra of isomeric 2- and 3-acylindoles [1, 2] are the indoyl cations, which subsequently lose a CO molecule. In the present research we have investigated the mass spectra (Table 1) of esters of keto acids of the indole series (I-XVI) containing residues of saturated, unsaturated, and aromatic keto acids in the 3 position. The intensities of the principal fragment ions and the stabilities of the molecular ions of the investigated compounds with respect to electron impact are given in Table 2. From an analysis of these data it follows that the molecular ions with an aliphatic keto acid residue, i.e., the ions of II, III, V-VII, and X-XII are less stable by a factor of three than the ions of the corresponding aromatic derivatives XIII-XVI. At the same time, the ions of VIII and IX, which each contain a multiple bond in the side chain, have stabilities that are practically the same as the stabilities of the ions of the corresponding saturated compounds. Reduction of the keto group to a methylene group leads to a certain amount of stabilization of the molecular ion (for IV, $W_M = 12.8\%$). The introduction of methyl groups in the 1 and 2 positions of the indole ring does not have a substantial effect on the overall stability of the molecular ion relative to electron impact. The same can be stated regarding an increase in the number of methylene groups separating the carbalkoxy and keto groups. Thus, for example, the molecular ions of I, which does not contain methylene groups, and of XI, which contains three methylene groups, have practically identical stabilities (5.9 and 6.1%, respectively).

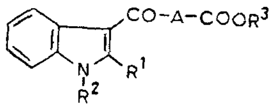
Scheme 1



$A = (CH_2)_n$, $n = 0, 2, 3$; CH=CH, o-C_6H_4

M. V. Lomonosov Moscow State University. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 2, pp. 194-199, February, 1976. Original article submitted February 4, 1975.

TABLE 1. Mass Spectra of Esters of Keto Acids of the Indole Series



Compound	R^1	R^2	R^3	A	m/e (% of the maximum ion)*	Recording temp. °C
I	H	H	C_2H_5	—	217 (10), 145 (10), 144 (100) 116 (21), 89 (24), 63 (4)	160
II	H	H	CH_3	$(CH_2)_2$	231 (13), 200 (4), 145 (7), 144 (100), 116 (11), 89 (11)	110
III	H	H	C_2H_5	$(CH_2)_2$	245 (27), 200 (15,5), 145 (10), 144 (100), 116 (35), 115 (4,5), 97 (4), 89 (11), 83 (5), 71 (5), 69 (6), 63 (3)	80
IV		Methyl 4-(3-indolyl)-butyrate			217 (25), 186 (4), 144 (3), 143 (25), 131 (11), 130 (100), 129 (3), 103 (4), 77 (7)	70
V	CH_3	H	CH_3	$(CH_2)_2$	245 (22), 214 (6), 159 (7), 158 (100), 130 (8), 103 (3), 77 (4)	150
VI	H	CH_3	CH_3	$(CH_2)_2$	245 (12), 214 (5), 158 (100), 130 (9), 103 (9), 79 (7), 77 (10)	140
VII	CH_3	CH_3	CH_3	$(CH_2)_2$	259 (10), 173 (5), 172 (100), 115 (4), 85 (8), 83 (7), 81 (9), 73 (11), 71 (15), 69 (29)	95
VIII	H	H	CH_3	CH=CH	229 (9), 170 (4), 145 (3), 144 (100), 116 (5), 89 (4,5)	150
IX	CH_3	H	CH_3	CH=CH	243 (15), 185 (4), 184 (100), 158 (48), 130 (10), 103 (4), 77 (7)	195
X	H	H	CH_3	$(CH_2)_3$	245 (20), 214 (8), 172 (3), 159 (12), 144 (100), 116 (5), 115 (5), 89 (15), 82 (6), 73 (6), 69 (6)	150
XI	CH_3	H	CH_3	$(CH_2)_3$	259 (13), 228 (9), 173 (7), 158 (100), 144 (4), 130 (11,5), 129 (6), 103 (9), 102 (4), 77 (6), 69 (4)	145
XII	CH_3	CH_3	CH_3	$(CH_2)_3$	273 (36), 173 (16,5), 172 (100) 145 (4,5), 144 (6), 143 (4,5), 115 (6), 85 (4), 81 (12), 71 (9), 69 (48)	110
XIII	H	H	CH_3	o-C_6H_4	279 (50), 163 (7), 145 (14), 144 (100), 116 (20), 89 (17)	200
XIV	CH_3	H	CH_3	o-C_6H_4	293 (15), 260 (8), 234 (18), 204 (5), 163 (100), 158 (35), 130 (14), 103 (4), 77 (9)	190
XV	H	CH_3	CH_3	o-C_6H_4	293 (52), 158 (100), 137 (6), 130 (9), 103 (10)	145
XVI	C_6H_5	H	CH_3	o-C_6H_4	355 (69), 354 (14), 221 (15), 220 (100), 191 (8), 165 (28), 163 (5,5), 162 (6), 97 (28), 96 (10), 95 (10)	180

*Ions with intensities of no less than 3% of the maximum ion are presented.

The difference in the mass-spectral behavior shows up more clearly in the intensities of the fragment ions. Three principal fragment ions, which are formed from the molecular ion with loss of an alkoxy group (ion F_3, scheme 1), a carbalkoxy group (ion F_4), or with loss of an alkyl carbalkoxy group (ion F_1), can be isolated. The F_1 ion is, as a rule, the maximum peak in the spectrum and subsequently loses CO to give an indolyl cation; this is characteristic for 3-acylindoles.

The intensity of the F_3 ions is usually low and ranges from 1 to 3% of the total ion current (see Table 2). The intensity of the F_4 ions is, as a rule, also low and does not exceed 0.6% of the total ion current. This is associated with the low stability of both the primary alkyl and primary acyl cations. We observed only F_1-fragment ions in the spectra of all of the compounds containing two methylene groups between the keto and carbalkoxy groups, and we did not note any rearranged ions. However, the F_2 ion, formed from the molecular ion with McLafferty rearrangement, appears when the chain length is increased to three CH_2 group-

TABLE 2. Intensities of the Principal Fragment Ions and Stabilities of the Molecular Ions of Esters of Keto Acids of the Indole Series with Respect to Electron Impact

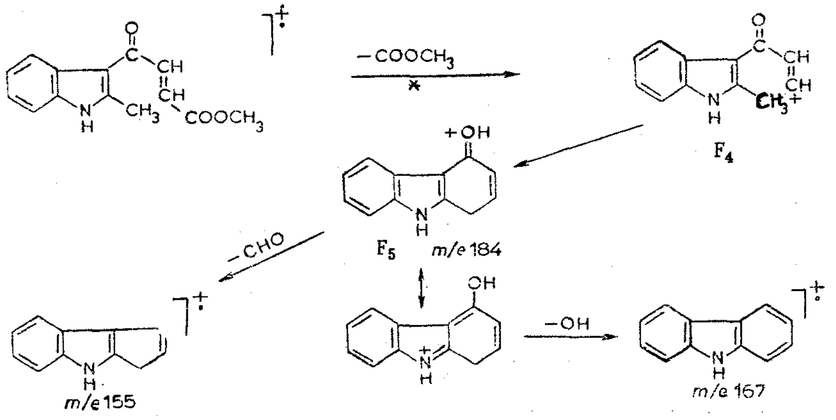
Compound	W_M	F_1	F_2	F_3
I	5,9	56,2	—	56,20
II	8,2	58,0	2,3	0.23
III	7,3	23,3	3,6	0,60
IV	12,8	45,9	2,1	0,05
V	11,6	48,1	2,8	0,78
VI	6,7	51,5	2,6	0,15
VII	5,3	51,0	0,9	0,50
VIII	7,5	75,5	0,5	2,90
IX	7,8	22,8	0,3	48,00
X	6,5	27,8	2,3	0,29
XI	6,1	34,8	3,1	0,65
XII	7,8	61,0	1,4	0,18
XIII	18,0	31,5	2,2	0,90
XIV	7,0	18,5	0,4	6,00
XV	20,4	35,2	0,6	0,25
XVI	20,7	26,8	0,3	0,38

ings (in the mass spectra of X-XII), and the intensity of this ion reaches 3.6% in the case of X but falls sharply as the number of methylene groups in the molecule increases (2.4% for XI, and 0.7% for XII); this is probably associated with the high stabilization of the positive charge on the carbonyl group due to the +I effect of the methyl groups, which reduces the probability of the rearrangement. It is interesting to note that the McLafferty rearrangement proceeds only on the "ketone" side, and the ion peak with m/e 74 that is characteristic for methyl esters of aliphatic acids is completely absent in the mass spectra of X-XII. This fact also constitutes evidence in favor of the fact that the positive charge in the molecular ion is evidently localized on the ketone carbonyl group.

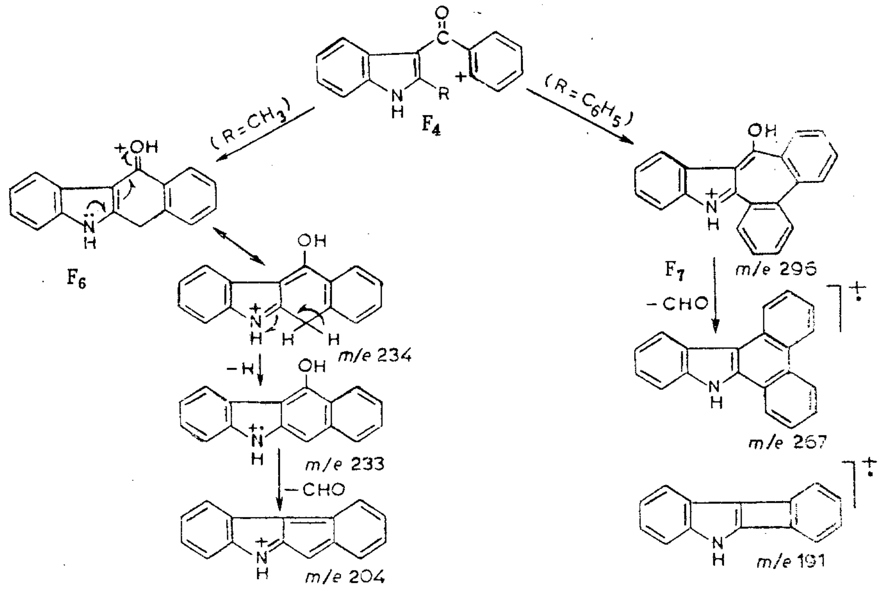
It should be noted that M–R ions [3] are completely absent in the mass spectra of the investigated compounds, and this indicates the absence, in our case, of the oxygen rearrangement [3] characteristic for esters of aralkanoic acids in which the aryl and carbalkoxy groups are separated by two carbon atoms [4].

As we have already mentioned, the intensity of the F_4 ions is extremely low in most cases, but the intensity of this ion increases by two orders of magnitude in the case of IX, which contains an unsaturated keto acid residue in the 3 position of the indole ring and a methyl group in the position. Similar facts also are obtained for XIV, which contains an aromatic ring. These differences can be explained by possible stabilization of the resulting fragment ion due to cyclization with the substituent in the 2 position. In this case, ions F_5 (IX, scheme 2), F_6, and F_7 (XIV and XVI, respectively, scheme 3) are formed. The mass spectra of aroylindoles [2] and aroylindolizines [5] were previously explained by the formation of similarly constructed cyclic ions. An indirect confirmation of the possibility of the formation of F_{5-7} ions is the presence in the mass spectra of IX, XIV, and XVI of ions formed with loss of the indicated fragments of 17 (OH, IX) and 29 amu (CHO, XIV and XVI); this is characteristic for the mass spectra of aroylindoles and aroylindolizines. The ion with m/e 267,

Scheme 2



Scheme 3



formed after loss of a CHO group by the F_7 ion, in the mass spectrum of XVI subsequently loses 76 atomic units (dehydrobenzene) to give an intense ion with m/e 191. Although the intensity of the F_4 ion in the mass spectrum of XVI is low, the indicated subsequent fragmentation constitutes evidence that a cyclic ion due to the phenyl group in the 2 position of the indole ring is also formed in this case. The compositions of some of the ions presented in scheme 3 and observed in the mass spectra of XIV and XVI are confirmed by the high-resolution mass spectra (see Table 3).

EXPERIMENTAL

The mass spectra were recorded with an MKh-1303 spectrometer with direct introduction of the sample into the ion source at an ionizing-electron energy of 50 eV. The high-resolution mass spectra were recorded with a JEOL JMS-01-S6-2 double-focus spectrometer at an ionization energy of 75 eV. The IR spectra of mineral oil suspensions of the compounds were recorded with a UR-10 spectrometer. The UV spectra of alcohol solutions were recorded with a Cary-15 spectrophotometer. The individuality of the compounds obtained in this research was monitored by means of thin-layer chromatography (TLC) on activity-II Al_2O_3 in a benzene–methanol (9:1) system.

The synthesis of esters II, V, VI, VII, X, XI, and XIII-XVI are described in [6]. Ester III was synthesized by the method in [6] and had mp 121-122°. Found, %: C 68.8; H 6.4. $C_{14}H_{15}NO_3$. Calculated, %: C 68.6; H 6.1. Ester XII was synthesized by the method used to prepare ester VII [6] and had mp 96-97° (from methanol). Found, %: C 70.5; H 7.0. $C_{16}H_{19}\cdot NO_3$. Calculated, %: C 70.3; H 7.0.

Methyl 3-(2-Methyl-3-indolyl)acrylate (IX). A stream of dry hydrogen chloride was bubbled through a cooled (to 0°) suspension of 1.15 g (0.005 mole) of the keto acid in 50 ml of methanol for 3 h (until the keto acid had dissolved completely), after which the reaction mixture was poured over ice, and the aqueous mixture was neutralized with solid sodium carbonate. The resulting precipitate was removed by filtration, washed with water, dried, and

TABLE 3. High-Resolution Mass Spectra

Compound	Ion composition	Observed m/e value	Calc. m/e value
XIV	$C_9H_7O_3$	163.0422	163,0395
	$C_{15}H_{10}N$	204,0833	204,0813
	$C_{16}H_{11}NO$	233,0829	233,0840
	$C_{16}H_{12}NO$	234,0921	234,0918
	$C_{17}H_{10}NO_2$	260,0728	260,0711
XVI	$C_{14}H_9N$	191,0733	191,0734

dissolved in a small amount of benzene–methanol (9:1). The solution was filtered through a layer of aluminum oxide, the filtrate was vacuum evaporated, and the residue was recrystallized from benzene containing a small amount of methanol to give 0.5 g (41%) of ester IX with mp 225-226° and R_f 0.43. IR spectrum: 1630 (CO), 1710 ($COOCH_3$), and 3170 cm^{-1} (NH). PMR spectrum (in CF_3COOH): singlet at 2.80 ($2\text{-}CH_3$), singlet at 3.85 (CH_3COO), doublets at 6.92 and 8.03 (olefinic protons, J 16 Hz), multiplet at 7.80 (4-H), and multiplet at 7.33 ppm (the remaining aromatic protons). Found, %: C 69.1; H 5.5. $C_{14}H_{13}NO_3$. Calculated, %: C 69.1; H 5.4.

Methyl 3-(3-Indolyl)acrylate (VIII). As in the preceding experiment, 0.3 g (35%) of ester VIII with mp 184-185° and R_f 0.41 was obtained from 0.7 g (0.003 mole) of 3-(3-indoyl)-acrylic acid in 30 ml of methanol. IR spectrum: 1655 (CO), 1735 (CH_3COO), and 3175 cm^{-1} (NH). Found, %: C 68.2; H 5.0. $C_{13}H_{11}NO_3$. Calculated, %: C 68.1; H 4.8.

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SYNTHESIS AND SPECTRAL CHARACTERISTICS OF PHOTOCHROMIC 1',3',3'-TRIMETHYL-6-NITRO-7-PHENYL-2H-CHROMENE-2-SPIRO-2'-INDOLINE

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UDC 541.145:547.752'814.1.07:543.422.6

5-Nitro-4-phenylsalicylaldehyde, from which the corresponding photochromic indolinespirochromene was obtained, was synthesized. The introduction of a phenyl substituent in the 7 position brings about a substantially smaller change in the longwave band in the electronic absorption spectrum of the merocyanine form than introduction of this substituent in the 8 position.

Continuing our study of the structural factors that affect the spectral characteristics of the colored form of spirochromenes [1], in order to compare the effect of a phenyl substituent in the 7 and 8 positions we attempted to synthesize a photochromic spiran (VII) with a phenyl substituent in the 7 position.

We obtained 4-phenylsalicylaldehyde (II) in low yield by formylation of 3-hydroxydiphenyl (I) [2] by the Duff method [3]; the structure of II was confirmed by oxidation to 4-phenylsalicylic acid (III) [4], which has been distinguished from 2-phenylsalicylic acid (IV) [5]. Thus the formyl group enters the 4 position in the formylation of 3-hydroxydiphenyl by the Duff method.

Scientific-Research Institute of Organic Intermediates and Dyes, Moscow. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 2, pp. 200-203, February, 1976. Original article submitted February 23, 1975.