Mass Spectrometry in Structural and Stereochemical Problems. LXXIV.[1] A Study of the Fragmentation of N-Acylpyrrolidines[2]

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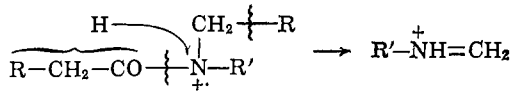
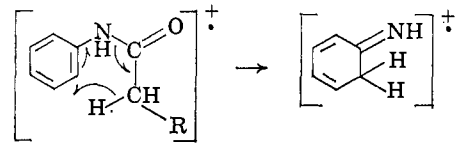
The fragmentation upon electron impact of N-acylpyrrolidines (acyl = acetyl, n-propionyl, and n-valeryl) has been clarified by examining the mass spectra of deuterated analogs. α-Cleavage to nitrogen of the respective molecular ion followed by hydrogen rearrangement from C-2 of the acyl chain and elimination of a ketene resulted in the formation of prominent ions in the spectra of the three amides studied. A four-membered transition state is therefore preferred even when other alternatives are open. Less abundant ions in the spectra of N-n-propionyl- and N-n-valerylpyrrolidine resulted by hydrogen transfer from C-2 and C-4 of the acyl chain followed by rupture of the nitrogen–acyl linkage. The most abundant ion in the spectrum of N-n-valerylpyrrolidine arose by hydrogen transfer from the γ-carbon of the acyl group through a McLafferty rearrangement. The origin of the other principal ions in the spectra of N-n-acetyl-, N-n-propionyl-, and N-n-valerylpyrrolidine have been rationalized from a study of the spectra of deuterated analogs. High-resolution mass measurements are recorded for the major peaks in the spectrum of N-n-valerylpyrrolidine as further support for the proposed fragmentation modes.

The mass spectra of several primary, secondary, and tertiary amides have been reported by Gilpin[4] who observed that substituted amides produced intense ions whose origin could be reconciled with the following scheme.

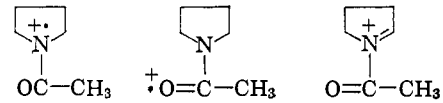


Loss of the acyl group from primary and secondary N-acetates has been established[5] by deuterium-labeling studies to involve transfer of hydrogen from the acetyl group to nitrogen *via* a four-membered intermediate; this mechanism has been used in rationalizing the origin of ions formed in the mass spectrometric fragmentation of alkaloids containing N-acetyl groups.[6] Furthermore, a four-membered transition state has been identified as participating in the expulsion, subsequent to electron impact, of substituted ketene radicals from five- and six-membered lactams.[7] Dickelman[8] showed by deuterium labeling that the loss of ketene from butyranilide occurred by transfer of hydrogen from C-2 of the acyl chain, but this example may not necessarily be applicable to aliphatic amides in general since transfer of a γ-hydrogen atom in alkylbenzenes with charge retention on the aromatic ring is known to be a facile process,[9] which may conceivably proceed through a six-membered intermediate as



The present study was undertaken to determine if N-substituted amides transferred hydrogen from one specific position of the alkyl chain through a four-membered intermediate in the rearrangement process formulated by Gilpin[4] or whether larger ring size intermediates were also operative. In this connection deuterated analogs of N-acetyl-, N-*n*-propionyl-, and N-*n*-valerylpyrrolidine were prepared, and from a study of their mass spectra it was possible to formulate mechanisms for the origin of the principal ions found in the spectra of the parent compounds.

N-Acetylpyrrolidine. The mass spectrum (Figure 1) of N-acetylpyrrolidine displays a substantial molecular ion which can best be represented by Ia and Ib. Loss of a hydrogen atom yields an M − 1 species of low abundance (Figure 1) which can be designated as *a* (*m/e* 112) since it was displaced to *m/e* 115 in N-acetyl-d_3-pyrrolidine. This assignment is analogous to the M − 1 species in pyrrolidine and N-methylpyrrolidine.[10]



A peak of low abundance at *m/e* 98 (M − 15) in the spectrum of N-acetylpyrrolidine corresponds to the elimination of the acetylmethyl group as this peak was unaffected in the spectrum of the d_3-acetyl derivative and must correspond to *b* (*m/e* 98) or one of its resonance forms. A more abundant ion at mass 85 (M − 28) was shifted by three mass units in the spectrum of

(1) Paper LXXIII: R. T. Aplin, H. Budzikiewicz, and C. Djerassi, *J. Am. Chem. Soc.*, 87, 3180 (1965).

(2) We are indebted to the National Institutes of Health of the U. S. Public Health Service for financial support (Grants No. AM-04257 and GM-11309).

(3) Postdoctoral Research Fellow, 1963–1965.

(4) J. A. Gilpin, *Anal. Chem.*, 31, 935 (1959).

(5) Z. Pelah, M. A. Kielczewski, J. M. Wilson, M. Ohashi, H. Budzikiewicz, and C. Djerassi, *J. Am. Chem. Soc.*, 85, 2470 (1963).

(6) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Structure Elucidation of Natural Products by Mass Spectrometry," Vol. 1, Holden-Day Inc., San Francisco, Calif., 1964, p. 166.

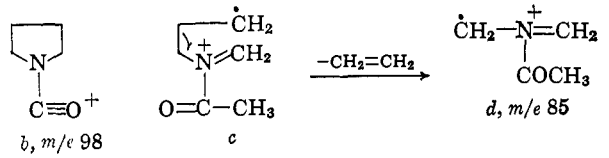
(7) A. M. Duffield, H. Budzikiewicz, and C. Djerassi, *J. Am. Chem. Soc.*, 86, 5536 (1964).

(8) Quoted by K. Biemann, "Mass Spectrometry," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, p. 112.

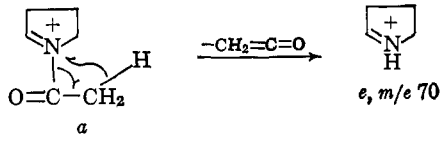
(9) See, for instance, ref. 8, p. 122.

(10) A. M. Duffield, H. Budzikiewicz, D. H. Williams, and C. Djerassi, *J. Am. Chem. Soc.*, 87, 810 (1965).

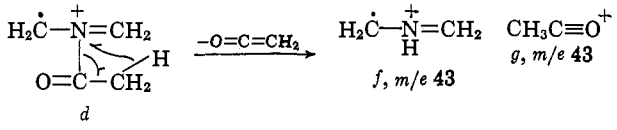
the d_3-acetyl derivative. This shift is consistent with the origin of this fragment occurring by initial α-cleavage of the molecular ion (Ia) to *c* followed by loss of ethylene to generate *d* (*m/e* 85).



A prominent ion of mass 70 (M − 43) in the spectrum (Figure 1) of N-acetylpyrrolidine was quantitatively located at mass 71 in the spectrum of the N-d_3-acetyl analog. The origin of this ion can be envisaged as proceeding from the M − 1 species *a via* hydrogen transfer from the acetyl group and expulsion of ketene yielding *e* (*m/e* 70) as the charged fragment.



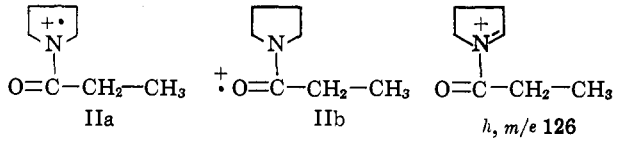
The molecular ion (Ia) of N-acetylpyrrolidine can undergo α-cleavage with retention of the acyl group by either of two processes: (i) Ia → *a* (*m/e* 112) or (ii) Ia → *c* → *d* (*m/e* 85). Just as the α-cleavage product *a* yielded *e* so can the species *d* eliminate ketene to afford the ion radical *f* (*m/e* 43). Verification of the process *d* → *f* was obtained by recognition of a metastable ion in the spectrum of N-acetylpyrrolidine at *m/e* 21.7 ($43^2/85 = 21.8$). Additional evidence for the occurrence of the decomposition *d* → *f* was forthcoming from the spectrum of N-acetyl-d_3-pyrrolidine in which the ion of mass 43 in the unsubstituted compound had increased by one mass unit (*m/e* 44) to the extent of 70%. A second genesis, consistent with the results from deuterium labeling, for the ion *f* is illustrated by *k* → *f* (see below).

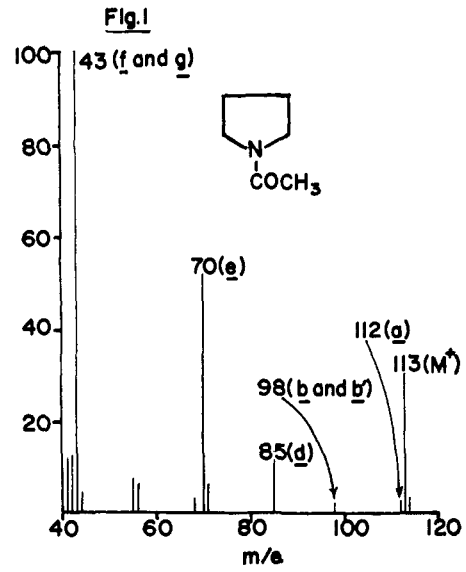


The loss of ketene from N-acetylpyrrolidine by either of the mechanisms Ia → *a* → *e* (*m/e* 70) or Ia → *d* → *f* (*m/e* 43) is consistent with the previously formulated[5] mechanism for loss of ketene from N-acetates.

The remainder of the unassigned ion yield (30%) at *m/e* 43 in the spectrum of N-acetylpyrrolidine corresponds to the acetyl ion *g* since this amount was located at *m/e* 46 in the spectrum of N-acetyl-d_3-pyrrolidine.

N-n-Propionylpyrrolidine. The mass spectrum (Figure 2) of N-*n*-propionylpyrrolidine displays a strong molecular ion (IIa and IIb) together with a less abundant M − 1 species which was unaffected in the spectrum of N-*n*-propionyl-2,2-d_2-pyrrolidine and hence can be represented as *h* (*m/e* 126).





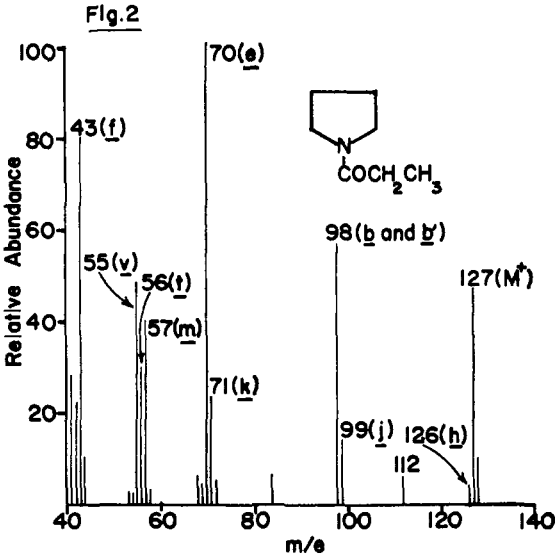
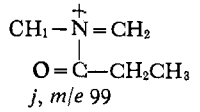


Figure 1. Mass spectrum of N-acetylpyrrolidine.
Figure 2. Mass spectrum of N-*n*-propionylpyrrolidine.

Loss of a methyl radical from N-propionylpyrrolidine affords a small peak at *m/e* 112 which was displaced to *m/e* 114 in the spectrum of the 2,2-d_2-propionyl derivative. The reduced intensity of this peak is consistent with the relatively unfavored β-cleavage to the heteroatom as compared to α-fission with concomitant loss of an ethyl group leading to the abundant ion *b* (*m/e* 98), which was unaffected in the 2,2-d_2-propionyl analog.

Loss of 28 mass units produces a peak at *m/e* 99 in the spectrum of N-propionylpyrrolidine, and this peak was quantitatively displaced to *m/e* 101 in the N-*n*-propionyl-2,2-d_2 derivative. This result is consistent with the formulation of this ion as *j* (*m/e* 99), its origin being analogous to that of the species *d* (*m/e* 85) in the spectrum of N-acetylpyrrolidine.



A peak at *m/e* 71 (M − 56) in the spectrum (Figure 2) of N-*n*-propionylpyrrolidine was quantitatively shifted

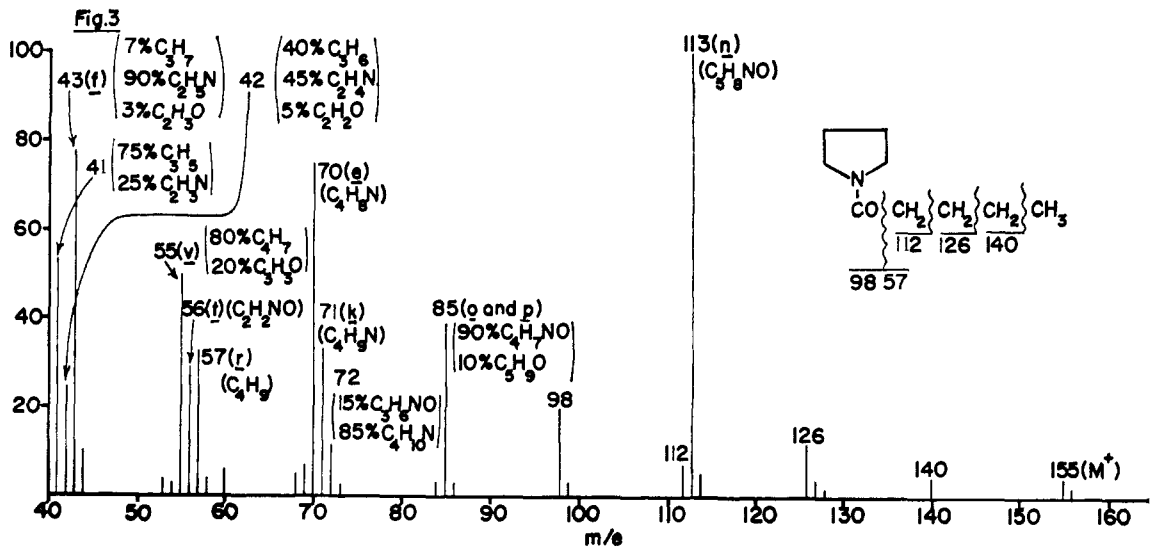
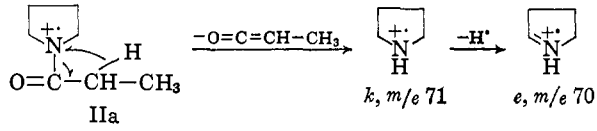


Figure 3. Mass spectrum of N-*n*-valerylpyrrolidine.

to *m/e* 72 in the 2,2-d_2-acyl derivative. This displacement is consistent with transfer of hydrogen from C-2 of the acyl chain in IIa to nitrogen with the concomitant expulsion of methylketene and production of the species *k* (*m/e* 71).



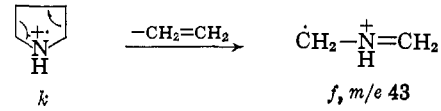
The base peak in the spectrum (Figure 2) of N-*n*-propionylpyrrolidine occurs at *m/e* 70 and is transferred in excess of 90% to *m/e* 71 in the spectrum of the 2,2-d_2-propionyl analog. This result is in harmony with the assignment of structure *e* (*m/e* 70) to this ion. Its genesis (IIa → *h* → *e*) may be identical with that described for the same fragment in N-acetylpyrrolidine (I) with the exception of the expelled neutral fragment.

A second origin for a portion of the ion yield at mass 70 was apparent by recognition of a metastable ion at *m/e* 69.1 ($70^2/71 = 69.0$) which testifies to the occurrence of the process *k* → *e* + H·. This decomposition is analogous to the formation of the M − 1 species in the mass spectrum of pyrrolidine which has been shown to involve loss of an α-hydrogen atom.[12]

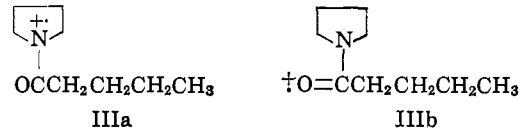
A peak at *m/e* 57 in the spectrum (Figure 2) of N-*n*-propionylpyrrolidine was quantitatively displaced to *m/e* 59 in the spectrum of the 2,2-d_2-acyl derivative. This behavior is consistent with the representation of this ion as the propionyl cation *m* ($CH_3CH_2C{\equiv}O^+$).

The relative abundances of the two peaks at *m/e* 55 and 56 were virtually identical in the spectra (Figures 2 and 3) of N-*n*-propionyl- and N-*n*-valerylpyrrolidine, and their derivation will be discussed in connection with the fragmentation of the valeryl homolog (see below).

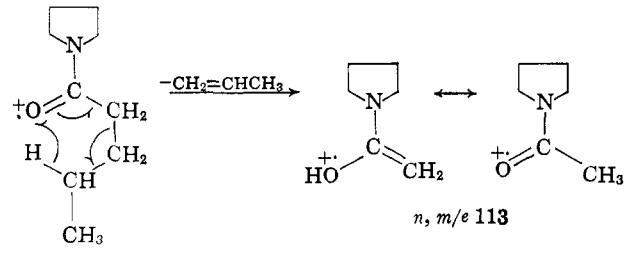
The intense peak at *m/e* 43 (M − 84) in the spectrum (Figure 2) of N-*n*-propionylpyrrolidine was completely transferred to *m/e* 44 in the spectrum of the 2,2-d_2-acyl analog. This displacement is compatible with this ion's representation as *f* (*m/e* 43) and its origin by a similar process as depicted by *d* → *f*. An alternative mode of formation for the species *f* is by expulsion of ethylene from the ion radical *k* (*m/e* 71). This process has been demonstrated[10] to yield the base peak in the spectrum of pyrrolidine.



N-n-Valerylpyrrolidine. The spectrum (Figure 3) of N-*n*-valerylpyrrolidine exhibits a weak molecular ion (IIIa and IIIb) while peaks at *m/e* 98, 112, 126, and 140 correspond to α, β, γ, and δ cleavage of the acyl chain (Table I) and require no additional comment.



The base peak in the spectrum (Figure 3) of N-*n*-valerylpyrrolidine occurs at *m/e* 113 and was completely shifted to *m/e* 115 in the spectrum of the 2,2-d_2-acyl analog. The source of the hydrogen atom transferred in the formation of this rearrangement ion was established from deuterium labeling (Table I) as C-4 of the side chain, thus demonstrating the operation of a McLafferty rearrangement[11] (IIIb → *n*).



An intense ion at mass 85 (M − 70) in the spectrum (Figure 3) of N-*n*-valerylpyrrolidine was displaced to

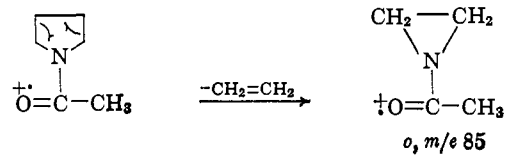
(11) F. W. McLafferty, *Anal. Chem.*, 31, 82 (1959); see also, C. Djerassi, G. von Mutzenbecher, J. Fajkos, D. H. Williams, and H. Budzikiewicz, *J. Am. Chem. Soc.*, 87, 817 (1965), and references cited therein.

Table I.[a] Principal Mass Spectral Peaks in N-*n*-Valerylpyrrolidine and Deuterated Analogs

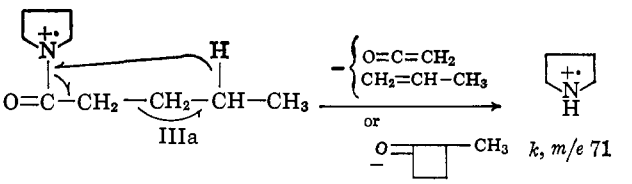
Compound	Isotopic purity	m/e										
		M+	M−15	M−29	M−42	M−43	M−57	M−70	M−84	M−85	M−98	M−99	M−100	M−112
R—$COCH_2CH_2CH_2CH_3$	..	155	140	126	113	112	98	85	71	70	57	56	55	43
									71 (75%)	70 (26%)				43 (26%)
R—$COCD_2CH_2CH_2CH_3$	97% d_2	157	142 (q)	128 (q)	115 (q)	114 (q)	98 (q)	87 (q)	72 (25%)	71 (74%)	59 (q)	56 (q)	55 (q)	44 (74%)
								85 (90%)	71 (95%)				
R—$COCH_2CD_2CH_2CH_3$	97% d_2	157	142 (q)	128 (q)	113 (q)	112 (q)	98 (q)	87 (10%)	72 (5%)	70 (95%)	59 (q)	56 (q)	55 (q)	43 (95%)
	95% d_2				113 (10%)			86 (85%)	71 (30%)	70 (80%)				43 (80%)
R—$COCH_2CH_2CD_2CH_3$	5% d_1	157	142 (q)	126 (q)	114 (90%)	112 (q)	98 (q)	87 (10%)	72 (70%)	71 (20%)	59 (q)	56 (q)	55 (q)	44 (20%)

[a] This table indicates the per cent shift of N-*n*-valerylpyrrolidine when specifically labeled with deuterium. The symbol (q) signifies a quantitative transfer (>95%) while the transfers quoted are considered to be accurate to ±5% for peaks in excess of 20% relative abundance. R = pyrrolylcarbonyl (C_4H_8NCO–).

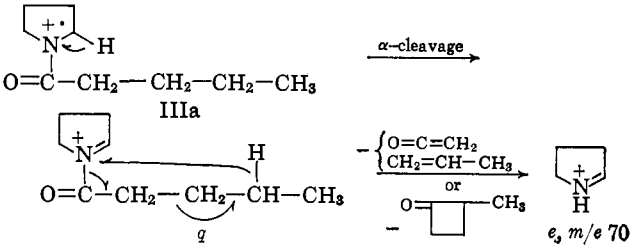
the extent of 85% to *m/e* 86 in the 4,4-d_2-acyl derivative. This observation, coupled with the recognition of a metastable ion at *m/e* 64.1 ($85^2/113$ = 63.9), is in agreement with this fragment's origin by loss of ethylene from *n* (*m/e* 113) and formulation as *o* (*m/e* 85). This assignment was supported by the results of high-resolution mass spectrometry[12] which showed (Figure 3) the peak at *m/e* 85 to represent the species $C_4H_7NO^+$ (90%) and $C_5H_9O^+$ (10%). The minor component of this peak can be assigned to the butyryl cation *p* ($C_3H_7C{\equiv}O^+$), and this assignment is supported by the results of deuterium labeling (Table I).



The peak at *m/e* 71 in the spectrum (Figure 3) of N-*n*-valerylpyrrolidine was homogeneous[12] and corresponded to $C_4H_9N^+$. The results obtained from deuterated analogs (Table I) are consistent with the major portion (70%) of the transferred hydrogen emanating from C-4 of the side chain with smaller contributions from positions C-2 (25%) and C-3 (5%) of the acyl chain. The major fragmentation process yielding the ion of mass 71 can be depicted by the process IIIa → *k* (*m/e* 71), the exact nature of the expelled neutral entity being unknown.



The intense ion of mass 70 (M − 85) in the spectrum (Figure 3) of N-*n*-valerylpyrrolidine was affected principally (74% transfer to *m/e* 71) in the 2,2-d_2-acyl analog, while the 4,4-d_2-acyl derivative registered a 20% transfer to *m/e* 71. High-resolution mass spectrometry[12] established the homogeneity and composition of this peak as $C_4H_8N^+$. The major mode of formation of this ion is thus analogous to that depicted by *a* → *e* (*m/e* 70), namely the loss of a neutral ketene molecule through a four-membered transition state. It is interesting to note, however, that a substantial contribution (20%) of the transferred hydrogen in the N-*n*-valeryl homolog emanates from C-4 of the side chain; a mechanism consistent with this observation is shown by IIIa → *q* → *e* (*m/e* 70).

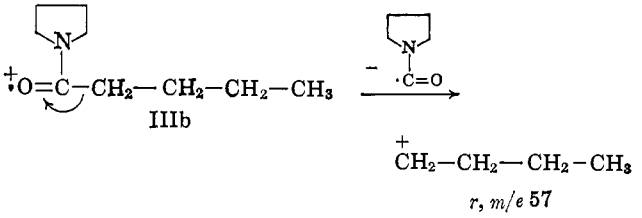


A portion of the ion yield present at *m/e* 70 in the spectrum of N-*n*-valerylpyrrolidine must have its

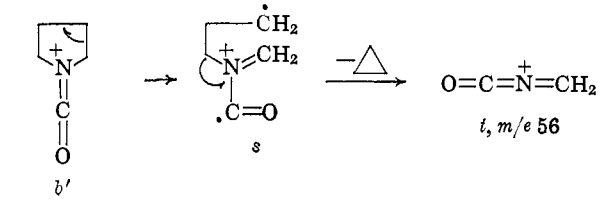
(12) Determined by Dr. L. Dolejš in this laboratory using an A.E.I. MS-9 double-focusing instrument.

origin according to the process $k \rightarrow e + H^{\cdot}$ since a metastable ion was recognized at *m/e* 69.1 ($70^2/71 = 69.0$) in the spectrum of this compound.

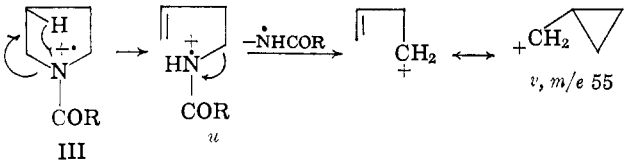
The peak at *m/e* 57 (M − 98) in the spectrum (Figure 3) of N-*n*-valerylpyrrolidine was quantitatively shifted to *m/e* 59 in each of the derivatives deuterated at C-2, C-3, and C-4 of the acyl chain (Table I). High-resolution mass spectrometry[12] determined the composition of this ion as $C_4H_9^+$ and its origin is consistent with the process IIIb → *r* (*m/e* 57).



The composition of the peak at *m/e* 56 in the spectrum (Figure 3) of N-*n*-valerylpyrrolidine was determined as $C_2H_2ON^+$ by high-resolution mass spectrometric measurements.[12] This peak was unaffected in those derivatives labeled on the acyl chain with deuterium (Table I), and a mechanism consistent with this result is shown by *b'* → *s* → *t* (*m/e* 56). By analogy, the ion of mass 56 in the spectrum (Figure 2) of N-*n*-propionylpyrrolidine (unaffected in the 2,2-d_2-acyl analog) is also assigned structure *t*.

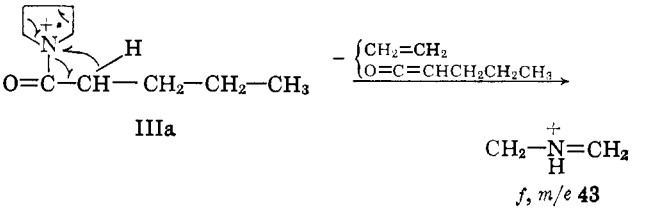


The abundant ion of mass 55 present in the spectra (Figures 2 and 3) of N-*n*-propionyl- and N-*n*-valerylpyrrolidine was unaffected in both compounds by deuteration of the acyl chain. High-resolution mass spectrometry[12] determined this ion's composition in the *n*-valeryl homolog (Figure 3) as $C_4H_7^+$ (80%) and $C_3H_3O^+$ (20%). A mechanism rationalizing the deuterium labeling results for the hydrocarbon fragment in both amides is depicted by III → *u* → *v* (*m/e* 55).

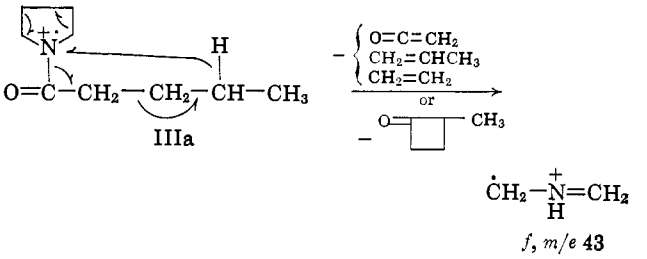


A peak present at *m/e* 43 (M − 112) in the spectrum (Figure 3) of N-*n*-valerylpyrrolidine was displaced (Table I) to *m/e* 44 to the extent of 74 and 20% in the 2,2-d_2- and 4,4-d_2-acyl derivatives, respectively. The major shift is compatible with hydrogen transfer from C-2 of the acyl chain to nitrogen with concomitant expulsion of propylketene and of ethylene from the β-carbon atoms of the pyrrolidine ring according to the sequence IIIa → *f* (*m/e* 43).[13]

(13) Loss of ethylene from expulsion of the β-carbon atoms of the pyrrolidine ring may equally well precede hydrogen transfer from and loss of the acyl chain.



It is noteworthy that the minor (20%) transfer of hydrogen occurs from C-4 of the acyl chain (Table I) and that a four-membered ring, although preferred, is not the only route since a six-membered intermediate can also intervene in the side-chain elimination.[13]



The above-described two routes to the ion *f* are supported by high-resolution mass spectrometry[12] (Figure 3) which demonstrated the composition $C_2H_5N^+$ (90%), $C_3H_7^+$ (7%), $C_2H_3O^+$ (3%) for the peak at *m/e* 43 in the spectrum of N-*n*-valerylpyrrolidine.

The preference for a six-membered transition state in the genesis of the ion (*k*) of mass 71 as compared to a four-membered one in the analogous acyl side-chain elimination leading to ions *e* (*m/e* 70) and *f* (*m/e* 43) raises an interesting problem, which has also been encountered recently in a study of ether and sulfide fragmentation processes.[14] It may be argued that a six-membered intermediate, when feasible, is preferred in primary reactions of the molecular ion, while intermediates of other ring sizes intervene in hydrogen-transfer reactions incident to further decompositions of fragment ions. Additional work is required to determine whether this view has any merit, but if correct, a corollary of this premise would be the suggestion that in the genesis of ion *f* in N-*n*-valerylpyrrolidine, the major (74%) path involving transfer of the C-2 hydrogen atom is represented by *first* ethylene expulsion from the pyrrolidine ring *followed by* acyl elimination-*cum*-hydrogen rearrangement, while the reverse sequence operates in the minor (20%) reaction in which the C-4 hydrogen transfer is implicated.

Experimental Section[15]

Deuterated N-Acylpyrrolidines. The appropriate deuteriated carboxylic acid[17] (200 mg.) and redistilled phosphorus trichloride (500 mg.) were heated for 30

(14) Unpublished experiments by C. Fenselau and S. Sample.

(15) All mass spectra, other than high-resolution spectra,[12] were obtained with a Consolidated Electrodynamics Corp. mass spectrometer Model No. 21-103C using an all-glass inlet system heated to 200°. The ionizing voltage was maintained at 70 e.v. and the ionizing current at 50 μa. Preparative vapor phase chromatography was carried out on a Wilkens Aerograph instrument using a 3-ft. polybutylene glycol column.[16]

(16) L. D. Quin, *J. Org. Chem.*, 24, 911 (1959).

(17) A. M. Duffield, R. Beugelmans, D. A. Lightner, H. Budzikiewicz, D. H. Williams, and C. Dierassi, *J. Am. Chem. Soc.*, 87, 805 (1965).

min. in a water bath maintained at 60–65°. The reaction mixture was cooled to room temperature and diluted with anhydrous ether (5 ml.); an excess of pyrrolidine (0.8 ml.) was added. After stirring at room temperature for 30 min. excess solvent was removed on the steam bath and the product isolated by preparative vapor phase chromatography.[15] The following retention times were observed: N-acetylpyrrolidine, 8 min.; N-*n*-propionylpyrrolidine, 9 min.; and N-*n*-valerylpyrrolidine, 23 min. using an oven temperature of 150° and helium pressure of 10 p.s.i. The isotopic purity of the products was at least 98% d_2 species.[17]

Mass Spectrometry in Structural and Stereochemical Problems. LXXV.[1] Occurrence of Alkyl Rearrangements in the Fragmentation of Some Formaldehyde Acetals[2]

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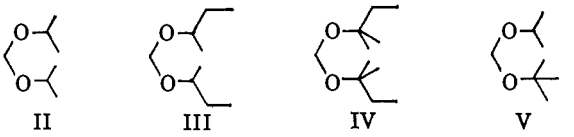
The mass spectra of a series of formaldehyde acetals of primary, secondary, and tertiary alcohols, and phenol, have been recorded. Deuterium labeling and high resolution mass spectrometry demonstrated the operation of three distinct alkyl rearrangement mechanisms, each involving elimination of formaldehyde. Plausible pathways for the formation of all other principal ions are presented.

Introduction

Although the mass spectra of a wide range of acyclic acetals are on record,[4,5] few attempts,[6,7] have been made to rationalize the fragmentations mechanistically. No studies on deuterium-labeled acetals have been reported at all, whereas ketals have received extensive scrutiny.[8] The first new spectrum obtained in this work, that (Figure 4) of di-*t*-butoxymethane (I), excited immediate interest owing to the presence of an appreciable (29% relative intensity) peak corresponding to the loss of 45 mass units. It was subsequently shown by a combination of deuterium labeling and high-resolution techniques that this fragment ion arose

I a

in a rearrangement involving alkyl migration,[9] resulting in expulsion of a formaldehyde molecule from the M − 15 α-cleavage product *a*. In view of the paucity of rigorously demonstrated alkyl rearrangements—in contrast to the virtually ubiquitous hydrogen rearrangements—induced by electron impact, it was deemed important to examine the scope and mechanism of the alkyl-transfer reaction noted in the acetal I. Indeed, completely analogous rearrangements were uncovered in other formaldehyde acetals of secondary and tertiary alcohols (compounds II–V). It is interesting



II III IV V

to note that neither the dithioacetal VI (Figure 16) nor the ether VII (Figure 17) showed any analogous M − (15 + 46) or M − (15 + 28) peaks, respectively. Two other groups of formaldehyde acetals could be

VI VII

classified, on the basis of direct loss of formaldehyde from the molecular ion. The first of these included the primary alcohol derivatives VIII, IX, and X, and the second, the half-acetals of phenol XI, XII, and XIII. In addition, other modes of fragmentation proposed[7] for acetals in general were confirmed by the deuterium-labeling results.

(1) Paper LXXIV: A. M. Duffield and C. Djerassi, *J. Am. Chem. Soc.*, 87, 4554 (1965).

(2) Financial assistance from the National Institutes of Health (Grant No. GM-06840 and AM-04257 to Stanford University) of the U. S. Public Health Service and Lucidol Divisions, Wallace and Tiernan, Inc., Buffalo, N. Y. (to Aarhus University), are gratefully acknowledged.

(3) Postdoctoral Research Fellow, 1964–1965.

(4) (a) W. H. McFadden J. Wasserman, J. Corse, R. E. Lundin, and R. Teranishi, *Anal. Chem.*, **36** 1031 (1964); (b) R. A. Friedel and A. G. Sharkey, *ibid.*, **28**, 940 (1956).

(5) "Catalog of Mass Spectral Data," American Petroleum Institute Research Project 44, Carnegie Institute of Technology, Pittsburgh, Pa., Spectra No. 1089–1101, 1111–1122.

(6) F. W. McLafferty, *Anal. Chem.*, **29**, 1782 (1957).

(7) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Interpretation of Mass Spectra of Organic Compounds," Holden-Day, Inc., San Francisco, Calif., 1964, Chapter 3.

(8) (a) Z. Pelah, D. H. Williams, H. Budzikiewicz, and C. Djerassi, *J. Am. Chem. Soc.*, **86**, 3727 (1964); (b) G. von Mutzenbecher, Z. Pelah, D. H. Williams, H. Budzikiewicz, and C. Djerassi, *Steroids*, 2, 475 (1963); (c) H. Audier, J. Bottin, A. Diara, M. Fétizon, P. Foy, M. Golfier, and W. Vetter, *Bull. soc. chim. France*, 2292 (1964); (d) H. Audier, A. Diara, M. de Durazo, M. Fétizon, P. Foy, and W. Vetter, *ibid.*, 2827 (1963); (e) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Structure Elucidation of Natural Products by Mass Spectrometry," Vol. 2, Holden-Day Inc., San Francisco, Calif., 1964, Chapter 18.

(9) For a recent and fully documented example of electron impact induced alkyl (methyl) migration, see F. Komitsky, Jr., J. E. Gurst, and C. Djerassi, *J. Am. Chem. Soc.*, 87, 1398 (1965).