tional aid. We are grateful to Mr. G. J. Boudreaux of the Southern Regional Research Laboratory, U. S. Department of Agriculture, for assistance with the nmr spectra, and to Professor A. I. Meyers of Colorado State University for the stimulating discussion which led to the initiation of this study.

Registry No.—**3a**, 51381-71-6; **3b**, 51381-73-8; **4g** picrate, 51381-81-8; **9**, 28912-93-8; **12**, 51464-55-2.

References and Notes

(1) (a) Arenediazonium Ions. II. For part I of this series see R. C. Petterson, A. DiMaggio, A. L. Hebert, T. J. Haley, J. P. Mykytka, and I. M. Sarkar, *J. Org. Chem.*, **36**, 631 (1971). (b) Preliminary accounts of this work were presented at the Mardi Gras Symposium in Organic Chemistry, Baton Rouge, La., Feb 1970, as a seminar at the University of Stuttgart, May 1970, and at the 164th National Meeting of the American Chemical Society, New York, N. Y., Aug 1972.

(2) Taken in part from the B. S. (Honors Program) theses of J. P. Mykytka and T. G. Troendle, Loyola University (New Orleans), 1968 and 1969, respectively.

(3) F. Klages and W. Grill, *Justus Liebigs Ann. Chem.*, **594**, 21 (1955).

(4) (a) H. Meerwein, P. Laasch, R. Mersch, and J. Spille, *Chem. Ber.*, **89**, 209 (1956); (b) H. Meerwein, P. Laasch, R. Mersch, and J. Nentwig, *ibid.*, **89**, 224 (1956).

(5) J. E. Gordon and G. C. Turrell, *J. Org. Chem.*, **24**, 269 (1959).

(6) G. A. Olah and T. E. Kiovsky, *J. Amer. Chem. Soc.*, **90**, 4666 (1968).

(7) E. V. Donkt, R. H. Martin, and F. Greerts-Evrard, *Tetrahedron*, **20**, 1493 (1964).

(8) H. Gilman and R. D. Nelson, *J. Amer. Chem. Soc.*, **70**, 3316 (1948).

(9) A. J. Nunn, K. Schofield, and R. S. Theobald, *J. Chem. Soc.*, 2797 (1952), and references cited therein.

(10) R. R. Schmidt, W. Schneider, J. Karg, and U. Burkert, *Chem Ber.*: **105**, 1634 (1972).

(11) D. C. Lankin and R. C. Petterson, unpublished results.

(12) Melting points were taken on a Fisher-Johns block unless otherwise stated and are uncorrected. Ir spectra were taken on a Perkin-Elmer Model 337 spectrometer. Nmr spectra were run on a Varian A-60 nmr spectrometer and are reported in parts per million downfield from tetramethylsilane internal standard. Nitriles were normally dried by distillation from phosphorus pentoxide just prior to use. Apparatus used in cyclization experiments was dried at 120° or above before assembly.

(13) G. Schiemann and W. Roselius, *Chem. Ber.*, **62**, 1805 (1929). We often used a variation of their method in which the only acid present was HBF_4.

(14) M. M. Coombs, *J. Chem. Soc.*, 3454 (1958).

(15) C. L. Arcus and E. A. Lucken, *J. Chem. Soc.*, 1634 (1955).

(16) A. Pictet and A. Hubert, *Ber.*, **29**, 1182 (1896).

(17) H. Gilman and J. Eisch, *J. Amer. Chem. Soc.*, **79**, 4423 (1957).

(18) C. L. Arcus and M. M. Coombs, *J. Chem. Soc.*, 4319 (1954).

(19) D. A. Peak and F. Stansfield, *J. Chem. Soc.*, 4067 (1952).

(20) H. A. Scarborough and W. A. Waters, *J. Chem. Soc.*, 89 (1927).

(21) J. V. Braun, *Chem. Ber.*, **43**, 2880 (1910).

Mass Spectroscopy of Indolo[2,3-*a*]quinolizidines. I. Fragmentation Patterns of C-3, C-4, C-6, C-7, and C-12b Deuterated Derivatives

Gordon W. Gribble*[1] and Randall B. Nelson[2]

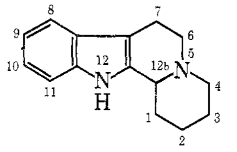
Department of Chemistry, Dartmouth College, Hanover, New Hampshire 03755

Received November 19, 1973

The mass spectra of the C-3, C-4, C-6, C-7, and C-12b deuterated derivatives of the indole alkaloid 1,2,3,4,6,7,12,12b-octahydroindolo[2,3-*a*]quinolizine (1). (*Dracontomelum mangiferum*) show that the P − 1 (base) peak at 70 eV is a mixture of four discrete ions, resulting from loss of C-4 H, C-6 H, C-7 H, and C-12b H. The labeling results show that the previously proposed structure for *m/e* 197 arising from a retro Diels–Alder reaction of *m/e* 225 only accounts for about 20% of *m/e* 197. The revised structure accounting for most of *m/e* 197 arises from a stepwise fragmentation from the parent ion (*m/e* 226). New fragmentation pathways and ion structures are also proposed and supported for the peaks at *m/e* 184, 156, 144, 97, 83, and 69.

Since its first application to indole alkaloids,[3] mass spectrometry has become a very important technique for the elucidation of the structure of alkaloids and other natural products.[4,5]

Although mass spectrometry has been applied to several members of the *Corynanthe-Yohimbe* family,[4-6] there is no consensus and little direct support for the various proposed fragmentation pathways for this class of indole alkaloids.[7] The indole alkaloid 1,2,3,4,6,7,12,12b-octahydroindolo[2,3-*a*]quinolizine (1)[8] is the simplest structure for which a mass spectral fragmentation pattern representative of the *Corynanthe-Yohimbe* class of indole alkaloids may be expected.[6] The mass spectrum of 1 has been previously published,[6] but without direct support for the proposed fragments. We now report a mass spectral study of selected deuterated derivatives of 1.



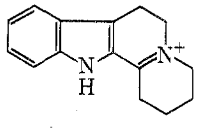
1

Results and Discussion

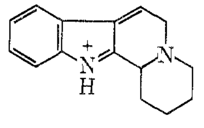
The 70-eV mass spectra of 1 is reproduced in Figure 1 and each of the main fragment clusters will be discussed in turn.

Parent Ion Cluster. It has been widely assumed[6,9-11] that the P − 1 (base) peak (*m/e* 225 for 1) observed in the mass spectra of *Corynanthe-Yohimbe* indole alkaloids and other tetrahydro-β-carboline alkaloids is due to the loss of C-12b H leading to 2. Only in systems where for steric reasons a C-12b iminium ion cannot form have alternate P − 1 ions been suggested.[12]

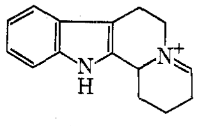
Our results (Table I) show that the P − 1 ion is a *mixture* of ions 2–5, arising by hydrogen loss from C-12b, C-7, C-4, and C-6, respectively. For example, P − 2 (*m/e* 225, loss of D) is intense in the spectrum of 1-*7*-d_2 and P − 1 (*m/e* 226, loss of H) is intense in the spectrum of 1-*12b*-d_1, both indicating the importance of other ions to P − 1. In contrast, 1-3-d_2 (statistically adjusted for isotopic inhomogeneity) shows complete retention of deuterium in the



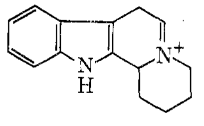
2 (*m/e* 225)



3 (*m/e* 225)



4 (*m/e* 225)



5 (*m/e* 225)

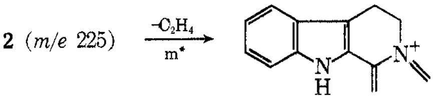
P − 1 ion. A quantitative analysis of the data, assuming 100% specific deuterium incorporation, gives the result that most of the P − 1 peak is comprised of **2** (37%) and **3** (32%), and the rest is due to **4** (13%) and **5** (19%) (see Sample Calculation).

Loss of C-7 H to give **3** has analogy in the mass spectrum of 3-methylindole,[13] where P − 1 is the base peak, arising from loss of a methyl hydrogen. Such ions have also been implicated in the solution chemistry of indoles.[14]

Loss of deuterium from C-4 in **1**-*4*-d_1 and **1**-*4*-d_2 is about the same (17% *vs.* 13%). We ascribe this to the trans-axial orientation of the deuterium and the nitrogen lone pair in **1**-*4*-d_1; this geometry is the much preferred one for loss of hydrogen (deuterium) (*i.e.*, in **1**-*4*-d_1 there is little preference for loss of hydrogen from C-4, even with an isotope effect working against deuterium loss). The axial deuterium in **1**-*4*-d_1 is so assigned because the 2040-cm^{-1} C-D stretch in the infrared spectrum[15] is a C-D "Bohlmann band."[16] By comparison, the infrared spectrum of **1**-*4*-d_2 with an axial and equatorial deuterium shows 2050 and 2190 cm^{-1} for the two C-D stretches, respectively.

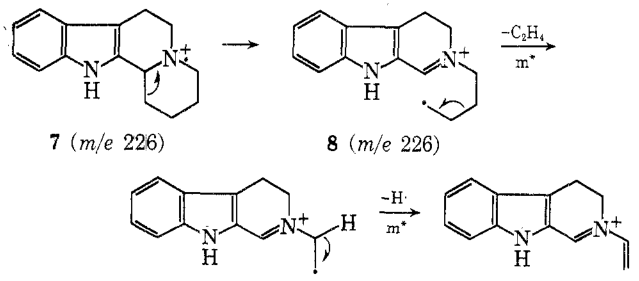
We conclude that the facile loss of one hydrogen from **1** is much less specific than previously believed, loss of hydrogen from C-12b, C-7, and C-4–C-6 each representing about one-third of the P − 1 peak.

m/e **197 Cluster.** The peak at *m/e* 197 (28%) in the mass spectrum of **1** and many other indole alkaloids has been assigned to **6** and is proposed to arise by a retro Diels–Alder loss of ethylene from **2**.[6] This pathway is also implicated in quinolizidine itself.[11] A high-resolution measurement shows *m/e* 197 to have a molecular formula due entirely to $C_{13}H_{13}N_2$.



6 (*m/e* 197)

Our results (Table II) require that an additional structure be written for *m/e* 197. This new species must retain hydrogen on C-12b and C-3, and one-half of the hydrogen on C-4. The precursor to this ion, at *m/e* 198 (8%) and previously unexplained, must retain *all* of the hydrogen on C-3, C-4, and C-12b. We propose **9** as the *m/e* 198 ion and **10** as the other *m/e* 197 ion, with the following sequence accounting for their formation.



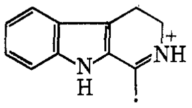
7 (*m/e* 226) **8** (*m/e* 226)

9 (*m/e* 198) **10** (*m/e* 197)

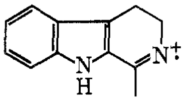
Metastables are found for both routes to *m/e* 197. In the deuterated derivatives the metastables corresponding to the stepwise process **7** → **10** are usually more pronounced than those for the retro Diels–Alder route.

The clusters observed for **1**-*3*-d_2 and **1**-*12b*-d_1 at *m/e* 197, 198, 199, and 200 were used to calculate the contributions of the pathways leading to *m/e* 197. In the **1**-*3*-d_2 spectrum the *m/e* 199 peak will uniquely reflect the contribution of **10** and *m/e* 197 will be the contribution from **6**. After correction for isotopic distribution the intensity of these two peaks relative to the total *m/e* (197 + 199) intensity is 20% for **6** and 80% for **10**. A similar analysis for **1**-*12b*-d_1 gives 16% for **6** and 84% for **10**.

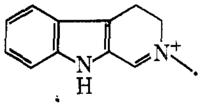
m/e **184 Cluster.** The cluster of three peaks at *m/e* 184 (7%), 183 (7%), and 182 (7%) has been ascribed[6,17,18] to two sets of ions, **11–12** or **13**, with the latter generally favored[17,18] and being supported by deuterium labelling (ajmalicine).[18] A high-resolution measurement shows *m/e* 184 to have a molecular formula due entirely to $C_{12}H_{12}N_2$.



11 (*m/e* 184)



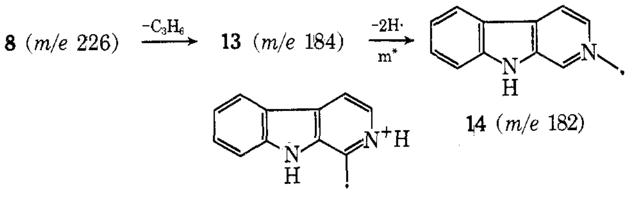
12 (*m/e* 184)



13 (*m/e* 184)

Our results (Table III) indicate that *both* sets of ions are contributors to the *m/e* 184 cluster. For **1**-*4*-d_2, the *m/e* 186 peak will be due primarily to fission of the C-12b–C-1 bond and subsequent loss of the carbon fragment (**13**). The *m/e* 184 peak will consist of ions from aromatization of *m/e* 186 (*i.e.*, loss of 2 H to give **14**) and **11–12**. Knowing the relative frequency of aromatization of both **11–12** and **13** in forming **15** and **14**, respectively, one can, by adjusting *m/e* 184 by the ratio *m/e* 184/182, determine the percentages to be 76% for **13** and 24% for **11–12**.

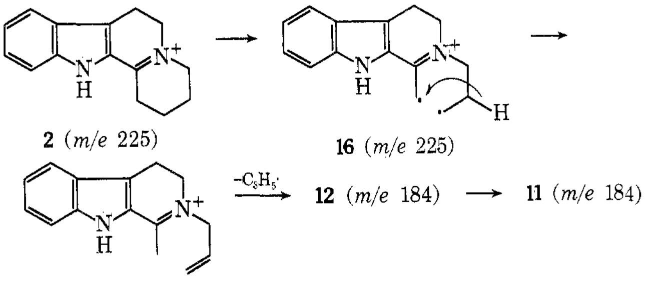
The formation of **13** and its cluster partners at *m/e* 183 and 182 can be viewed as arising from **8** with loss of cyclopropane or propene. Loss of C_3H_6 from the ion corresponding to **8** from quinolizidine itself is supported by a metastable peak.[11] We see a metastable for *m/e* 226 → 182 at 147.0 (calcd 146.6).



14 (*m/e* 182)

15 (*m/e* 182)

The formation of **11–12** might be visualized as involving C-1–C-2 cleavage followed by H migration and loss of allyl radical. The H migration from C-3 in **16** is supported by the increased peak at *m/e* 185 in **1**-*3*-d_2.



2 (*m/e* 225) **16** (*m/e* 225)

17 (*m/e* 225)

Such rearrangements are proposed to occur in the mass spectra of simple cyclic amines.[19,20]

At 20 eV *m/e* 183 and 182 are much less intense than at 70 eV (Table III), indicating that these fragments are formed from *m/e* 184 by successive hydrogen loss. At low ionization energy *m/e* 184 does not have enough residual energy to lose one or two hydrogens and it tends to accumulate.

m/e **170 Cluster.** The cluster of two peaks at *m/e* 170 (24%) and 169 (33%) has been previously assigned[17,18] to **18** and **19**, respectively, and these fragments are supported by a deuterium label at C-12b in ajmalicine, each being shifted to one higher mass unit.[18] The lesser peaks

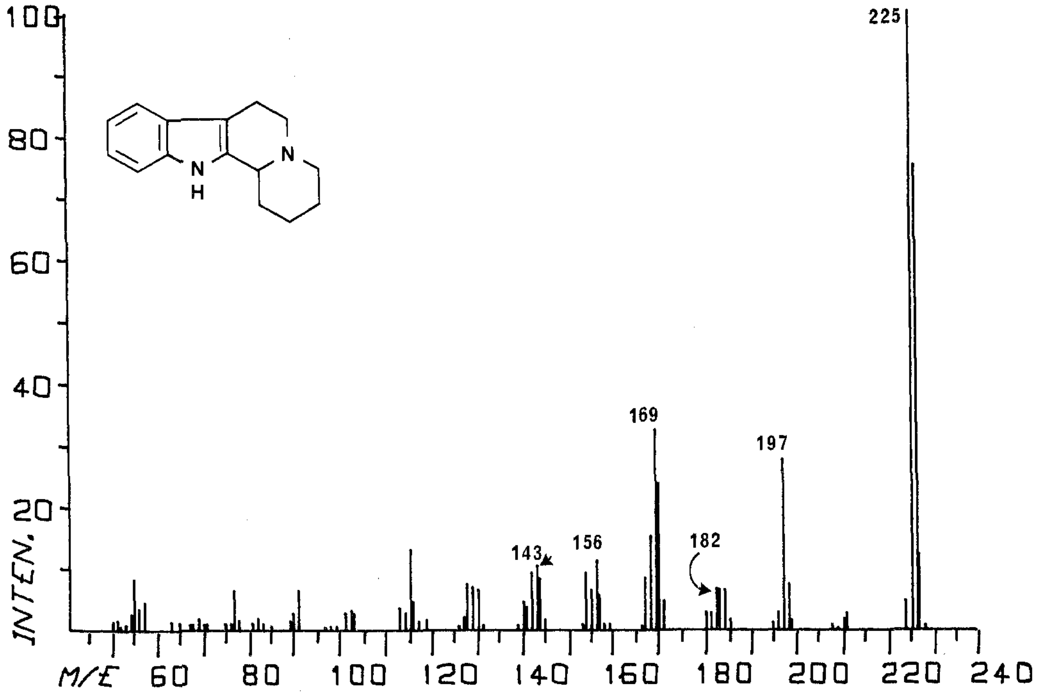
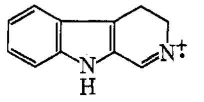
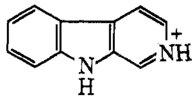


Figure 1. Mass spectrum (70 eV) of 1.

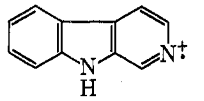
at *m/e* 168 (15%) and 171 (15%) are assigned to 20 and 21, respectively. A high-resolution measurement shows *m/e* 170 to have a molecular formula due entirely to $C_{11}H_{10}N_2$.



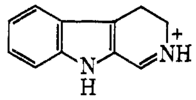
18 (*m/e* 170)



19 (*m/e* 169)



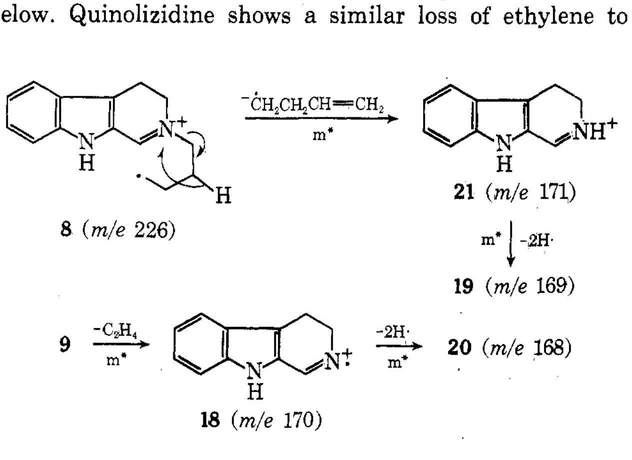
20 (*m/e* 168)



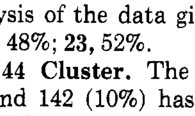
21 (*m/e* 171)

Our results (Table IV) support these assignments. As expected, the mass spectrum of 1-*3*-d_2 shows complete deuterium loss from this cluster. The increase by 20% in the *m/e* 170 peak in 1-*4*-d_2 may indicate that the origin of the hydrogen on N-5 in 19 and 21 is at least partly C-4. The spectrum of 1-*12b*-d_1 shows retention of deuterium in all four fragments (18–21). 1-*7*-d_2 shows a surprisingly large *m/e* 171 that may be due to 19 containing deuterium at both C-7 and N-5.

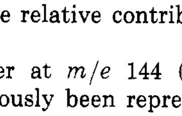
The formation of these fragments may proceed as shown below. Quinolizidine shows a similar loss of ethylene to give a fragment corresponding to *m/e* 170 (18), and is supported by a metastable.[11]



m/e **156 Cluster.** The peak at *m/e* 156 (12%) has been previously assigned both to 22 and 23. A high-resolution measurement shows *m/e* 156 to have a molecular formula due entirely to $C_{11}H_{10}N$.



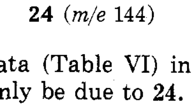
22 (*m/e* 156)



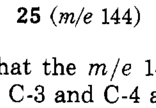
23 (*m/e* 156)

Our results (Table V) show that *both* 22 and 23 are present. The data for 1-*3*-d_2, 1-*4*-d_1, and 1-*4*-d_2 indicate clearly that C-3 and C-4 are not retained in the *m/e* 156 fragment. C-6 is retained but to a lesser extent than C-7 and C-12b, indicating a mixture of fragments 22 and 23. An analysis of the data gives the relative contributions of each: 22, 48%; 23, 52%.

m/e **144 Cluster.** The cluster at *m/e* 144 (9%), 143 (11%), and 142 (10%) has previously been represented as 24 (or 25) but this was in a study of oxindole alkaloids[18] and may not be the structure of the *m/e* 144 fragment from 1. A high-resolution measurement shows *m/e* 144 to have a molecular formula due entirely to $C_{10}H_{10}N$.



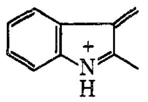
24 (*m/e* 144)



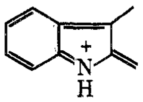
25 (*m/e* 144)

Our data (Table VI) indicate that the *m/e* 144 cluster cannot only be due to 24. Carbons C-3 and C-4 are clearly not present in the *m/e* 144–142 fragments, nor is hydrogen transferred from these carbons to the fragments. The data for 1-*3*-d_2, 1-*4*-d_1, and 1-*4*-d_2 are self-consistent, but the small increase in *m/e* 145 in these three spectra compared to that for 1 is difficult to rationalize. It is clear from the data that both hydrogens on C-7 are retained but that only one from C-6 is retained in the fragments. The hydrogen on C-12b is retained to the extent of about 75%.

This suggests that the *m/e* 144 peak is due both to **24–25** (55%) and **26–27** (45%).



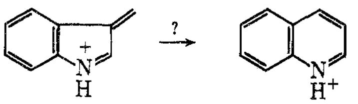
26 (*m/e* 144)



27 (*m/e* 144)

These ions have been proposed to occur in the fragmentation of quebrachamine.[21]

m/e **130 Cluster.** The cluster of four peaks at *m/e* 130 (7%), 129 (7%), 128 (8%), and 127 (2%) has previously been ascribed[18] to **28** and subsequent ions. A high-resolution measurement shows *m/e* 130 to have a molecular formula due entirely to C_9H_8N.

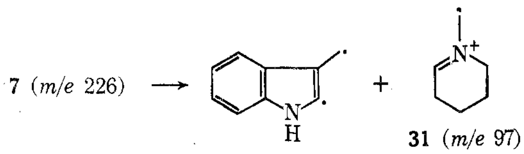


28 (*m/e* 130) **29** (*m/e* 130)

Fragment **28** is invariably found in the mass spectra of simple indoles,[13,18,22] but it is still not clear whether it has indole structure **28** or quinoline structure **29**,[23–25] even though ring expansion has been proposed to be significant in the fragmentation of 2-methylindole.[23,25]

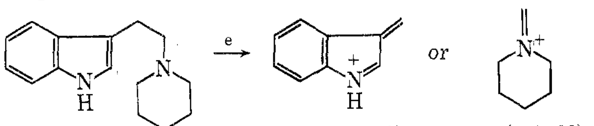
Our results (Table VII) show that C-3, C-4, and C-6 are not present in the *m/e* 130 fragment, as expected. Furthermore, it is clear that hydrogens from C-7 and C-12b are present in the fragment, supporting **28** (or **29**) as the *m/e* 130 structure. The *m/e* 129 and 128 fragments both appear to retain at least some hydrogen from C-7 and C-12b, but it is difficult to postulate appropriate structures.

The other ion formed in the fragmentation leading to *m/e* 130 appears at *m/e* 97 (1%). Our data (not tabulated) show that C-3, C-4, C-6 and C-12b, but not C-7, are retained in the ion. This is consistent with **7** → **30** + **31**.



30 **31** (*m/e* 97)

The tricyclic amine **32** shows in its mass spectrum the fragments **28** (3%) and **33** (100%),[26] indicating the facile cleavage of the "tryptamine bond."[22]



32 **28** (*m/e* 130) **33** (*m/e* 98)

Quinolizidine shows a very intense *m/e* 97 peak which has been assigned to **31**.[11]

Summary. It is clear that the mass spectral fragmentation pattern of indole alkaloid **1**, and probably most of the *Corynanthe-Yohimbe* alkaloids, is more complex than previously believed. All of the important high molecular weight fragments are shown to be mixtures of different ions. The main points of this work are summarized as follows.

(1) The P − 1 peak (*m/e* 225) consists of a mixture of four ions, **2–5**, arising from loss of hydrogen at C-12b, C-7, C-4, and C-6, respectively. Three of these ions result when ionization occurs at N-5, while the fourth (**3**) occurs when an electron is lost from the aromatic ring, presumably from N-12.

(2) The large molecular weight fragments at *m/e* 197, 184, and 170 arise principally from parent ion **7** by cleavage of the C-12b–C-1 bond and subsequent loss of two, three, and four carbons, respectively.

(3) The *m/e* 197 fragment is a mixture of two ions, **6** and **10**. The previously proposed retro Diels–Alder reaction from **2** (*m/e* 225) accounts for at most 20% of *m/e* 197 (**6**).

(4) The fragments that appear at *m/e* 184, 156, and 144 are each due to a mixture of at least two discrete ions (**11–13**, **22–23**, and **24–27**, respectively) arising from different fragmentation pathways.

(5) When hydrogen loss within a cluster at high ionization energy (70 eV) is important, at low ionization energy (≤ 20 eV) it is greatly retarded. This results in the accumulation of certain ions (*e.g.*, *m/e* 198, 171, 158, and 145) that are not easily seen at high ionization energy.

(6) Hydrogen loss from a carbon α to a nitrogen (*i.e.*, C-4, C-6, and C-12b in **1**) is more favorable when the hydrogen is trans diaxial to the nitrogen lone pair. This interesting observation, seen in the present work (*cf.* **1**-*4*-d_1 and **1**-*4*-d_2) and in our earlier work[16a] with the *cis*- and *trans*-2-*tert*-butyl derivatives of **1**, should be generally applicable to the problem of determining stereochemistry and ring fusion in *Corynanthe-Yohimbe* and other quinolizidine alkaloids.

Acknowledgment. We are grateful to the National Science Foundation (GP-13374), Eli Lilly, Merck Sharp and Dohme, and the National Institutes of Health (CA-14237) for their generous financial support of this work and our research program. We also thank Mr. Sunwen Chou for assistance with some of the computer work and Professor Jerome E. Gurst (University of West Florida) for comments on the manuscript.

Registry No.—**1**, 4802-79-3; **1**-*3*-d_2, 51263-49-1; **1**-*4*-d_2, 51263-50-4; **1**-*6*-d_2, 51263-51-5; **1**-*7*-d_2, 51263-52-6; **1**-*12b*-d_1, 34388-09-5.

Supplementary and Miniprint Material Available. The 70-eV mass spectra of the deuterated derivatives of **1** will appear following these pages in the microfilm edition of this volume of the journal. Photocopies of the supplementary material and full-sized photocopies of the miniprinted material from this paper only or microfiche (105 × 148 mm, 24× reduction, negatives) containing all of the miniprinted and supplementary material for the papers in this issue may be obtained from the Journals Department, American Chemical Society, 1155 16th St., N.W., Washington, D. C. 20036. Remit check or money order for $4.00 for photocopy or $2.00 for microfiche, referring to code number JOC-74-1845.

JOC-13-1

Table I. Relative Intensities for the Parent Ion Cluster at 70 eV[a]

Compound	*m/e* 224	225	226	227	228	229
1	5	100	75	12		
1-3d_2		4	16	100	70	11
1-4d_1	7	21	100	94	16	2
1-4d_2		6	15	100	93	19
1-6d_2	3	8	23	100	81	13
1-7d_2	6	11	47	100	92	17
1-12bd_1		58	100	97	16	
1[b]	3	29	100	17		
1[c]			100	17.6	1.4	

[a] uncorrected for isotopic composition
[b] at 20 eV
[c] Calculated isotopic abundance (^{13}C, ^{15}N)

JOC-13-2

Table II. Relative Intensities of the m/e 197 Cluster at 70 eV[a]

Compound	*m/e* 195	196	197	198	199	200
1	5	10	100	28	7	
1-3d_2	7	6	20	32	100	30
1-4d_1	8	13	58	100	32	5
1-4d_2	8	19	30	96	100	47
1-6d_2	8	12	39	37	100	23
1-7d_2	11	19	56	64	100	28
1-12bd_1	5	8	20	100	30	3
1[b]	13	10	100	56	7	
1[c]			100	15.3	1.1	

[a] uncorrected for isotopic composition
[b] at 20 eV
[c] calculated isotopic abundances (^{13}C, ^{15}N)

JOC-13-3

Table III. Relative Intensities of the m/e 184 Cluster at 70 eV[a]

Compound	*m/e* 180	181	182	183	184	185	186	187
1	42	42	100	99	97	28	3	
1-3d_2	15	29	46	71	100	43	30	5
1-4d_1	25	34	70	93	100	70	14	2
1-4d_2	17	21	49	44	100	48	59	13
1-6d_2	32	36	90	84	100	82	65	13
1-7d_2	28	52	80	80	80	80	100	35
1-12bd_1	16	35	55	95	100	85	17	3
1[b]			20	50	100	22		
1[c]					100	14.2	0.9	

[a] uncorrected for isotopic composition
[b] at 20 eV
[c] calculated isotopic abundance (^{13}C, ^{15}N)

Table IV. Relative Intensities for the m/e 170 Cluster at 70 eV[a]

Compound	167	168	169	m/e 170	171	172	173
1	26	47	100	74	15	2	
1-3d$_2$	21	39	100	85	22	9	2
1-4d$_1$	24	48	100	78	17	3	1
1-4d$_2$	17	41	100	93	18	8	2
1-6d$_2$	27	42	54	100	43	81	16
1-7d$_2$	18	29	47	70	100	76	18
1-12bd$_1$	12	24	46	100	72	12	2
1[b]	5	11	14	100	20	7	
1[c]				100	13.1	0.8	

[a] uncorrected for isotopic composition
[b] at 20 eV
[c] calculated isotopic abundance (^{13}C, ^{15}N)

Table V. Relative Intensities for m/e 156 Cluster at 70 eV[a]

Compound	154	155	156	m/e 157	158	159	160
1	83	58	100	50	10	10	
1-3d$_2$	62	46	100	60	19	8	
1-4d$_1$	60	48	100	62	22	8	
1-4d$_2$	51	44	100	58	28	12	
1-6d$_2$	61	60	100	53	60	39	10
1-7d$_2$	43	57	86	71	100	57	24
1-12bd$_1$	33	60	53	100	40	13	
1[b]		14	51	100	43		
1[c]			100	12.7	0.7		

[a] uncorrected for isotopic composition
[b] at 20 eV
[c] calculated isotopic abundance (^{13}C, ^{15}N)

Table VI. Relative Intensities for the m/e 144 Cluster at 70 eV[a]

Compound	141	142	m/e 143	144	145	146	147
1	36	90	100	81	18	2	
1-3d$_2$	28	78	100	86	41	16	8
1-4d$_1$	30	75	100	95	30	10	5
1-4d$_2$	29	73	100	82	39	15	11
1-6d$_2$	49	82	100	82	88	70	20
1-7d$_1$	55	82	73	100	100	91	37
1-12bd$_1$	26	27	86	100	50	14	5
1[b]		100	100	75	33		
1[c]				100	11.6	0.6	

[a] uncorrected for isotopic composition
[b] at 20 eV
[c] calculated isotopic abundance (^{13}C, ^{15}N)

Table VII. Relative Intensities for the m/e 130 Cluster at 70 eV[a]

Compound	127	128	129	m/e 130	131	132	133
1	30	100	94	88	13	6	4
1-3d$_2$	52	100	95	77	38	17	10
1-4d$_1$	57	100	87	57	39	14	7
1-4d$_2$	56	100	78	86	39	22	6
1-6d$_2$	50	92	100	75	42	22	20
1-7d$_2$	36	60	95	100	90	60	38
1-12bd$_1$	77	78	89	100	56	13	6
1[b]				100	10.4	0.5	

[a] uncorrected for isotopic composition
[b] calculated isotopic abundance (^{13}C, ^{15}N)

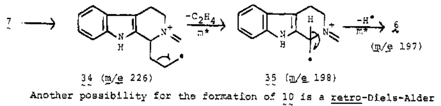
Table VIII. Calculation of Ion Distribution in the Parent Cluster for 1-12bd$_1$

m/e	observed relative intensities	expected P+1 contribution	corrected intensities
225	58	0	58
226	100	10	90
227	97	17	80
228	16	17	0

The percent total intensities for the uncorrected and corrected intensities are then calculated using the relationship: $\%X = X/(X+Y+Z)$ where X, Y, and Z represent the intensities of different peaks in a cluster. For example, the m/e 225 calculations for 1-12bd$_1$ using uncorrected and corrected values give 37% and 39%, respectively, for the percent of m/e 225 in the parent cluster. This difference of 2% is less than the 5% precision assumed to obtain in the mass spectral measurements.

Fragmentation Appendix

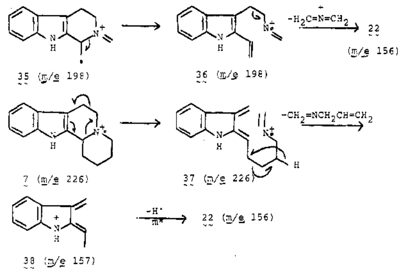
The cleavage of the C1-C12b bond has been suggested to occur in the fragmentation of ajmalicine and related alkaloids,[10] as well as quinolizidine itself.[11] A similar stepwise mechanism can account for 6 but its precursor ion 35 does not satisfy the requirement that m/e 198 retain hydrogen at C3 and C12b. In addition, fragment 34 does not benefit from the extra stability of 8 where the positive charge can be shared by both nitrogens.



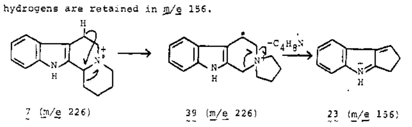
Another possibility for the formation of 10 is a *retro*-Diels-Alder loss of ethylene from 4 (m/e 225). Although our data cannot rule out the 4→10 pathway, the mass spectra at 20 eV show a more intense m/e 198 (56%) relative to m/e 197 (100%) than at 70 eV which suggests the importance of 9 in the formation of 10. One would expect an accumulation of m/e 198 relative to m/e 197 at low eV since less residual energy is available to be dissipated. It is not reasonable to suppose that the 4→10 pathway would be important when our results do show that the 2→6 pathway accounts for only 20% of m/e 197.

The much less intense peak at m/e 197 in the mass spectra of yohimbine and ajmalicine[6] compared to that in the mass spectrum of 1 supports the stepwise mechanism rather than the *retro*-Diels-Alder reaction as the main pathway for the formation of 6 (m/e 197).

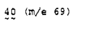
A possible scheme for the formation of the m/e 156 fragment (22) is depicted below.



The fragmentation leading to retention of C6 as in 23 is shown below and resembles the mechanism proposed by Coutts[7] for tetrahydro-β-carbolines. This pathway is consistent with the fact that both C7 hydrogens are retained in m/e 156.

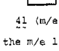


The other ion formed in m/e 226→157 (37→38) appears in a cluster of peaks at m/e 68, 69, and 70 (all <1%). A high resolution measurement shows m/e 69 to have a molecular formula due entirely to C_4H_7N. Our data (not tabulated) show that both 37→38 + 40 and 39→23 + 41 are operating since some loss of hydrogen from C6 is seen.



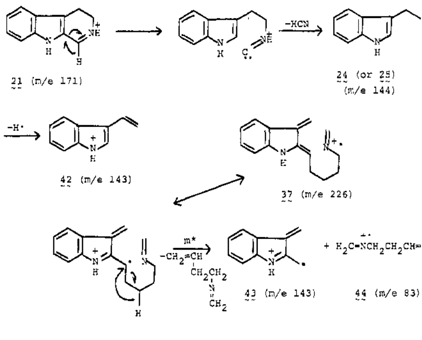
$CH_2{=}\overset{+\cdot}{N}{-}CH_2CH{=}CH_2$

40 (m/e 69)



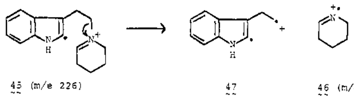
41 (m/e 70)

A possible scheme for the formation of the m/e 143 fragments is shown below.



Loss of HCN from 21 (m/e 171) has been proposed to occur in the fragmentation of tetrahydro-β-carbolines.[7]

The other ion formed in m/e 226→143 (37→43) appears in a cluster of peaks at m/e 82, 83, 84 and 85 (all <1%). A high resolution measurement shows m/e 83 to have a molecular formula due entirely to C_5H_9N. Our data (not tabulated) show that C3, C4, and some C6, but not C7, are retained in this ion. Therefore, both 37→43 + 44 and 45→46 + 47 are probably occurring.



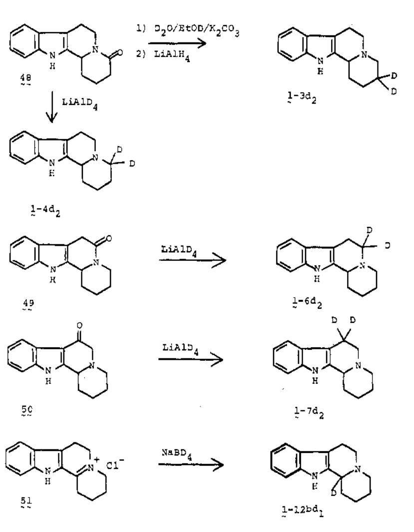
Experimental Section

Deuterated Compounds. - The synthesis of the deuterated compounds 1-3d$_2$, 1-4d$_2$, 1-6d$_2$, 1-7d$_2$ and 1-12bd$_1$ is summarized in Scheme I. Compounds 1-4d$_1$ and 1-12bd$_1$ have been previously described,[15] although in the present study iminium ion 51 was prepared according to the method of Martel and Costercusse.[27] Lactams 48[28] and 49,[29,30] and ketone 50[30,31] are known compounds.

The isotopic purity of 1-4d$_1$, 1-4d$_2$, 1-6d$_2$, 1-7d$_2$, and 1-12bd due to the method of preparation should reflect the purity of the metal deuteride reducing agent,[32] whereas the preparation of 1-3d$_2$ involving aqueous exchange and a metal hydride reduction could give material having a much lower deuterium content.[33]

Analysis of the parent-ion clusters at 20 eV and 9 eV using a computerized version of published "parent" and "parent-1" procedures[34] gave unreasonably low values of deuterium content, even though the (P+1)/P isotopic ratios (at 20 eV) indicated high isotopic purity. Additional measurements at 25 eV showed the parent cluster to have the same relative intensities as at 70 eV, indicating very facile P-1 processes. Nonetheless, the "parent-1" procedure[34] should have corrected for this facile P-1 fragmentation at low ionization potential. Failure to do so indicated that the underlying assumptions[34] of the program were not applicable in the present case.

Scheme I



Visual examination of the data revealed that more than one species was contributing to the P-1 peak. Indeed, loss of hydrogen (deuterium) from C4, C6, C7, and C12b occurs at low and high ionization potential, making the "parent" and "parent-1" procedures unusable. The analysis of 1-3d$_2$ is acceptable using this method, since deuterium loss from C3 is insignificant, and it gives an isotopic composition of 86% d$_2$, 11% d$_1$, and 3% d$_0$.

Mass Spectra. - The mass spectra were determined by Mr. H. A. Kirst, Mr. J. W. Suggs, and Mr. H. E. Ensley at Harvard University on an associated Electronics Industries MS9 mass spectrometer at source temperatures of 150-200°. For the exact mass determinations perfluorotri-*n*-butyl amine was the calibration standard, the minimum resolution was 90 ppm, and the precision was ±5 ppm.

3,3-Dideuterio-1,2,3,4,6,7,12,12b-octahydroindolo[2,3-a]quinolizine (1-3d$_2$). - A mixture of 2.0 g (0.0083 mol) of lactam 48,[28] 0.5 g of anhyd K_2CO_3, 15 ml of D_2O, and 32 ml of EtOD was refluxed. After one day an additional 20 ml of EtOD and 1.0 g of K_2CO_3 were added. After 3 days an additional 10 ml of EtOD and 0.5 g of K_2CO_3 were added. After 13 days of reflux the mixture was allowed to cool and the white solid was collected by filtration. The filtrate was diluted with H_2O and extracted with $CHCl_3$. This afforded, after H_2O washing and drying (K_2CO_3), on concentration *in vacuo* 0.27 g of white solid. This material was stirred with 0.4 g (0.0095 mol) $LiAlH_4$ in 75 ml of dry THF at 25° (after 1 hr at 0°) under N_2 for 10 hr and then refluxed for 48 hr. The cooled mixture was cautiously quenched with H_2O and diluted with 2N NaOH. The THF layer was separated, the salts were further extracted with Et_2O, and the combined extracts were water washed, dried (K_2CO_3), and concentrated *in vacuo* to give 0.27 g of 1-3d$_2$ as a white solid. Recrystallization from Et_2O-hexane gave tiny crystal clusters, mp 150-152°. The tlc behavior was identical to that of 1.

4,4-Dideuterio-1,2,3,4,6,7,12,12b-octahydroindolo[2,3-a]quinolizine (1-4d$_2$). - A mixture of 2.0 g (0.0083 mol) of lactam 48[28] and 2.0 g (0.048 mol) of $LiAlD_4$ in 150 ml of dry THF was stirred under N_2 at 25° (after 1 hr at 0°) for 24 hr and then refluxed for 68 hr.

The cooled mixture was cautiously quenched with water and diluted with 2N NaOH. The usual workup (*vide supra*) gave 1.64 g (86%) of 1-4d$_2$ as a white solid. Recrystallization from Et_2O-hexane gave tiny colorless crystals, mp 152-153.5°. The tlc behavior was identical to that of 1.

6,6-Dideuterio-1,2,3,4,6,7,12,12b-octahydroindolo[2,3-a]quinolizine (1-6d$_2$). - A mixture of 2.0 g (0.0083 mol) of lactam 49[29,30] and 1.0 g (0.024 mol) of $LiAlD_4$ in 50 ml of dry THF was stirred under N_2 at 25° (after 1 hr at 0°) for 22 hr and then refluxed for 3 hr. The usual workup gave a yellow solid. Chromatography over 60 g of activity III basic Woelm alumina gave, with benzene elution, 1.53 g (81%) of 1-6d$_2$ as a white solid, mp 151-153°. Recrystallization from ether gave pure material as colorless crystals. The tlc behavior was identical to that of 1.

7,7-Dideuterio-1,2,3,4,6,7,12,12b-octahydroindolo[2,3-a]quinolizine (1-7d$_2$). - A mixture of 0.26 g (0.0011 mol) of ketone 50[30,31] and 0.13 g (0.0031 mol) of $LiAlD_4$ in 50 ml of dry THF was stirred under nitrogen at 25° (after 1 hr at 0°) for 20 hr and then refluxed for 1 hr. The usual workup and chromatography gave 0.082 g (33%) of 1-7d$_2$ as a white solid, mp 149-151°. The tlc behavior was identical to that of 1.

12b-Deuterio-1,2,3,4,6,7,12,12b-octahydroindolo[2,3-a]quinolizine (1-12bd$_1$). - To a solution of 0.20 g (0.0048 mol) of $NaBD_4$ in 20 ml of abs EtOH was added 1.2 g (0.0046 mol) of iminium chloride 51.[27] After 15 min the mixture was concentrated *in vacuo* and diluted with benzene. Chromatography over activity III basic Woelm alumina gave, with benzene elution, 0.93 g (89%) of 1-12bd$_1$ as an off-white solid. The tlc behavior was identical to that of 1.

Sample Calculation. To calculate the true intensities of peaks, the observed intensities are scaled for the most intense peak to 100%. The expected P+1 contributions are calculated by multiplying the peak intensity of, for example, m/e 225, 226, and 227 in succession by 17.6 (the calculated ((P+1)/P)100 for m/e 225, 226, and 227 using 1.107% ^{13}C, 0.366% ^{15}N, and 0.015% ^{2}H) to get the expected P+1 contributions of each peak. The expected P+1 contributions are then subtracted from the observed relative intensities of the peak to which they contribute to obtain the corrected values (Table VIII).

References and Notes

(1) Recipient of a Public Health Service Research Career Development Award (1KO4-GM-23756) from the National Institute of General Medical Sciences, 1971–1976.

(2) NDEA Predoctoral Fellow, 1971–1973.

(3) K. Biemann, *Tetrahedron Lett.*, **No. 15**, 9 (1960).

(4) K. Biemann, *Progr. Chem. Org. Natur. Prod.*, **24**, 1 (1966).

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

(6) L. D. Antonaccio, N. A. Pereira, B. Gilbert, H. Vorbrueggen, H. Budzikiewicz, J. M. Wilson, L. J. Durham, and C. Djerassi, *J. Amer. Chem. Soc.*, **84**, 2161 (1962).

(7) Only one rigorous study of any tetrahydro-β-carbolines has been reported: R. T. Coutts, R. A. Locock, and G. W. A. Slywka, *Org. Mass Spectrom.*, **3**, 879 (1970).

(8) S. R. Johns, J. A. Lamberton, and J. L. Occolowitz, *Chem. Commun.*, 421 (1966); *Aust. J. Chem.*, **19**, 1951 (1966).

(9) Reference 4, p 41.

(10) Reference 5, Chapter 5.

(11) M. Hussain, J. S. Robertson, and T. R. Watson, *Aust. J. Chem.*, **23**, 773 (1970).

(12) As in the sarpagine alkaloid ring system: K. Biemann, *J. Amer. Chem. Soc.*, **83**, 4301 (1961).

(13) J. H. Beynon, "Mass Spectrometry and Its Applications to Organic Chemistry," American Elsevier, New York, N. Y., 1960, pp 397–403.

(14) L. J. Dolby and G. W. Gribble, *Tetrahedron*, **24**, 6377 (1968).

(15) G. W. Gribble, *J. Org. Chem.*, **37**, 1833 (1972).

(16) (a) G. W. Gribble and R. B. Nelson, *J. Org. Chem.*, **38**, 2831 (1973); (b) J. Skolik, P. J. Krueger, and M. Wiewiorowski, *Tetrahedron*, **24**, 5439 (1968).

(17) G. Spiteller and M. Spiteller-Friedmann, *Monatsh. Chem.*, **93**, 795 (1962).

(18) B. Gilbert, J. A. Brissolese, N. Finch, W. I. Taylor, H. Budzikiewicz, J. M. Wilson, and C. Djerassi, *J. Amer. Chem. Soc.*, **85**, 1523 (1963).

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

(20) Q. N. Porter and J. Baldas, "Mass Spectrometry of Heterocyclic Compounds," Wiley-Interscience, New York, N. Y., 1971, Chapter 11.

(21) Reference 5, p 46.

(22) Reference 5, pp 49–51.

(23) M. Marx and C. Djerassi, *J. Amer. Chem. Soc.*, **90**, 678 (1968).

(24) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Mass Spectrometry of Organic Compounds," Holden-Day, San Francisco, Calif., 1967, p 611.

(25) S. Safe, W. D. Jamieson, and O. Hutzinger, *Org. Mass Spectrom.* **6**, 33 (1972).

(26) Unpublished results.

(27) J. Martel and G. Costerousse, *Chem. Abstr.*, **77**, 152432v (1972).

(28) R. B. Nelson and G. W. Gribble, *Org. Prep. Proced.*, **5**, 55 (1973).

(29) E. Ochiai and M. Takahashi, *Chem. Pharm. Bull.*, **13**, 618 (1965).

(30) We wish to thank Professor L. J. Dolby (University of Oregon) for a sample of this material.

(31) D. C. Tompkins, Ph.D. Thesis, University of Oregon, 1968, p 60.

(32) For the preparation of 98% d_2-labeled amines by reduction of lactams with lithium aluminum deuteride, see A. M. Duffield, H. Budzikiewicz, D. H. Williams, and C. Djerassi, *J. Amer. Chem. Soc.*, **87**, 816 (1965).

(33) For the preparation of 84–95% d_2-labeled amines from lactams by base-catalyzed exchange and lithium aluminum hydride reduction, see ref 32 and A. M. Duffield, H. Budzikiewicz, and C. Djerassi, *J. Amer. Chem. Soc.*, **86**, 5541 (1964).

(34) K. Biemann, "Mass Spectrometry," McGraw-Hill, New York, N. Y., 1962, Chapter 5.

Photochemistry of Polycyclic 5-Acylnorbornenes[1]

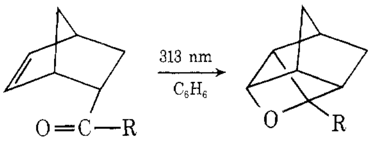
Ronald R. Sauers* and Thomas R. Henderson

School of Chemistry, Rutgers University, New Brunswick, New Jersey 08903

Received January 24, 1974

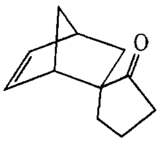
Ketones **3X**, **3N**, **4X**, and **4N** were synthesized and irradiated with ultraviolet light. Compounds **3X** and **3N** gave products, enal **6** and oxetane **5**, respectively, which are believed to have been formed from n,π* states of the carbonyl groups. Ketones **4X** and **4N** gave products, **8** and **7**, respectively, which were probably formed from π,π* states of the double bonds.

Earlier studies of the photochemistry of simple *endo*-5-acylnorbornenes[2,3] (**1**) have revealed a photocycloaddition reaction of significant synthetic versatility as well as one which involves intriguing mechanistic subtleties. It has been shown[4] that oxetanes of structure **2** are formed from **1** with quantum efficiencies ranging from 0.10 to 0.22 and that essentially no other products are produced. In particular, type I and type II cleavages were not competitive even in favorable cases, *e.g.*, R = *t*-C_4H_9, *i*-C_5H_{11}.[4] Preliminary studies with *exo*-5-acylnorbornenes did not yield well-defined product mixtures, on the other hand. Thus, these results raised several questions concerning the factors which control the efficiency of oxetane formation and the general structural limitations of this reaction. In addition, the behavior of the exo systems was perplexing and a more detailed investigation was clearly of interest in view of the paucity of data on the behavior of constrained γ,δ-unsaturated ketones.[5]



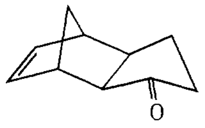
1 2

To these ends, an investigation of the synthesis and photochemistry of the following four ketones was initiated: **3X**, **3N**, **4X**, and **4N**.

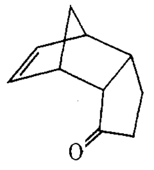


3X

3N

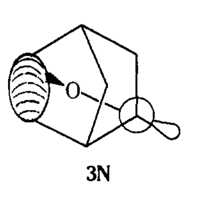


4X

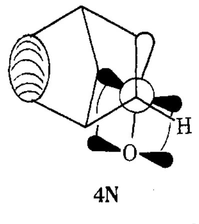


4N

The choice of these systems was governed by the relatively fixed geometrical orientations of the chromophores. From the drawings shown below, it can be seen that only in **3N** is the n orbital of the carbonyl group suitably positioned with respect to the double bond to permit the mode of interaction proposed for exciplex formation in the



3N



4N