Nonbenzenoid Aromatic Systems. IX. Aryl Participation in Mass Spectrometry. Mechanisms and Comparisons with Solvolytic Data for Some Azulene, Pyridine, and Benzene Derivatives[1]

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The nitrogen atom in 2-substituted pyridines participates in unique fragmentation reactions (formally simple δ- and ε-bond cleavages) which are analogous to those involving C_3 in 4-substituted azulenes. Free-radical character of the ring atom appears to be involved in these and other bond-forming reactions, none of which occur in benzene derivatives. 3-Pyridylpropanols, acetates, and tosylates apparently form pyridylethylenonium ions, but phenonium (phenylethylenonium) ions are of no more than minor importance in 2-phenylethanols and their acetates and tosylates. Close relationships between electron impact and solvolytic phenomena are demonstrated in all three ring systems and particularly in the azulenes.

While concepts borrowed from solution chemistry have aided enormously in the development of organic mass spectrometry, the reverse process is only now beginning to develop. Previously we compared and contrasted the solvolytic and electron impact induced behavior of azulylethanols and their esters and made predictions concerning the solvolysis of 3-(4-azulyl)-propyl tosylate based on mass-spectral results.[3] Here we report mass-spectral data for the 3-(azulyl)-1-propanol derivatives and compare it with solvolytic data for this system.[4] In addition, we have sought a better understanding of aryl participation in the mass spectrometer by studying (i) benzene derivatives and (ii) alkylpyridines, where the heteroatom might be involved, and by comparing these systems with the azulene compounds.

Pyridine Derivatives.—Important features of the mass spectra of the 3-(pyridyl)-1-propanols (**1–3**), -propyl acetates (**4–6**), and -propyl tosylates (**7–9**), as well as the 2-(pyridyl)ethanols (**10** and **11**), appear in Table I. Nomenclature for bond cleavage is standard, *i.e.*, for the propyl tosylates

$$\mathrm{Py}\overset{\alpha}{-}\mathrm{CH_2}\overset{\beta}{-}\mathrm{CH_2}\overset{\gamma}{-}\mathrm{CH_2}\overset{\delta}{-}\mathrm{O}\overset{\epsilon}{-}\mathrm{Ts}$$

where Py = pyridyl and Ts = *p*-toluenesulfonyl. Fragment ion abundances appear in Table I under the type of bond cleavage by which, formally, the ions arise. We are primarily concerned with processes which cannot be accounted for as simple bond cleavages and for which aryl-participation mechanisms are therefore possible.[3] These processes are γ, δ, and ε cleavage in the propanol series and γ and δ cleavage in the ethanols. While analogous fragmentations appear to occur in the alcohols, acetates, and tosylates, it is significant to note that H· loss from the alcohols (**1–3** and **10** and **11**) does not correspond, mechanistically, to Ac· and Ts· loss. This is shown by the observation that the O-deuterated analogs of both **1** and **10** lose predominantly H· rather than D·. The low efficiency of H· loss relative to loss of the more stable radicals, Ac· and Ts·, has been noted previously in connection with aryl-participation reactions in 4-substituted azulenes.[3]

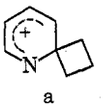
TABLE I
PARTIAL MASS SPECTRA OF SOME PYRIDINE DERIVATIVES[a]

		Bond cleavage				
Compd	M^+	ε	δ	γ	β	β + H
1, 3-(2-Py)-1-PrOH	0.2	1.8[b]	8	20	6	100
2, 3-(3-Py)-1-PrOH	37	1[b]	0	17	44	22
3, 3-(4-Py)-1-PrOH	42	1[b]	0	23	33	98
4, 3-(2-Py)-1-PrOAc	≪0.1	18	24	18	6	100
5, 3-(3-Py)-1-PrOAc	15	3	0	42	32	13
6, 3-(4-Py)-1-PrOAc	0.5	6	2	25	30	15
7,[c] 3-(2-Py)-1-PrOTs	≪0.1	19	77	63	70	94
8,[c] 3-(3-Py)-1-PrOTs	20	4	9	67	52	21
9,[c] 3-(4-Py)-1-PrOTs	100	3	15	11	19	14
10, 2-(2-Py)EtOH	16		23[b]	67	14	99
11, 2-(4-Py)EtOH	41		1[b]	19[d]	14	99

[a] All data are corrected for ^{13}C contributions and expressed relative to the base peak in the uncorrected spectrum. [b] Hydrogen atom loss; see text. [c] The tosylates were difficult to purify (see Experimental Section) and some variation was observed in their spectra. [d] Shown by metastable analysis to arise from low abundance impurity ion (*m/e* 134) as well as the molecular ion.

The results of Table I indicate that the ionized 2-substituted pyridines **1**, **4**, and **7** are much more reactive than their isomers; their molecular ion abundances do not exceed 0.2% and they yield abundant ions due to γ, δ, and ε cleavages (with the qualification regarding H· loss from alcohols noted above). Of these processes only γ cleavage occurs with facility in the 3- and 4-substituted pyridines. The contrast between the 2- and the 3- and 4-substituted compounds is also evident in such normal fragmentations as loss of acetic acid from the acetates. The sequence $M\cdot^+ - AcOH - H\cdot$ gives the base peak in the 3- and 4-pyridyl acetates, **5** and **6**, but an ion of only 9% abundance in the 2-pyridyl compound **4**.

The mechanisms involved in the interesting δ- and ε-bond scissions can now be explored in more detail. These reactions are, to a high degree, specific to the 2-substituted pyridines. This is best seen by comparing daughter ion–molecular ion abundance ratios. For example, for *p*-toluenesulfonyl radical loss these ratios are >190 (**7**), 0.2 (**8**), and 0.03 (**9**). The specificity, which is generally rather more marked for δ than for ε cleavage, implies that the spiro type ions a and b (and



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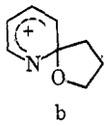

b

(1) For part VIII, see ref 4.

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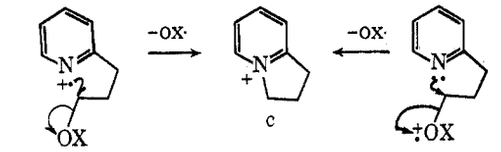
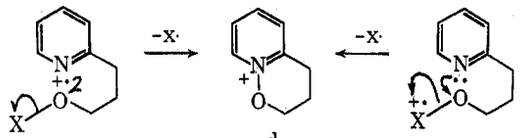
(3) R. G. Cooks, N. L. Wolfe, J. R. Curtis, H. E. Petty, and R. N. McDonald, *J. Org. Chem.*, **35**, 4048 (1970).

(4) R. N. McDonald, N. L. Wolfe, and H. E. Petty, *ibid.*, **38**, 1006 (1973).

their meta and para isomers) are not formed as the major products of δ and ϵ eleavage, respectively.

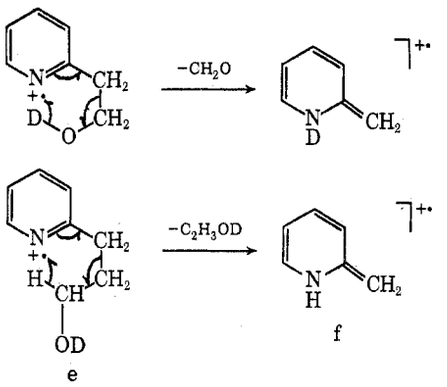
It is, therefore, apparent that the nitrogen atom plays a direct role in these fragmentation mechanisms, just as was noted for the C_3 carbon atom in the fragmentation of 2-(4-azulyl)ethanol and its derivatives.[3] These results also demonstrate that, in the most general sense, the aryl group participates in the fragmentation of the substituents. If the analogy with the participation reactions observed in the azulenes[3] holds, δ cleavage in the propyl pyridine series will yield ion c and ϵ cleavage ion d. Note that, in illustrating the formation of ions c



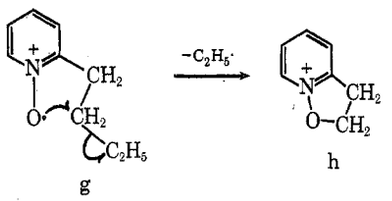


and d, reactants ionized on the pyridine ring, as well as those ionized in the substituent, have been considered. Analogous possibilities existed for the participation mechanism in the 2-(4-azulyl)ethanol derivatives and appearance potential data favored the substituent ionization mechanism.[3] More recently, Shapiro and coworkers[5] have interpreted their results on anchimeric assistance in the fragmentation of homoallylic systems in terms of participation with expulsion of the leaving group once it begins to bear charge. In spite of these precedents for substituent ionization in other systems, there is considerable evidence that the ring ionization mechanism may be involved in the pyridines.

First, the appearance potential of the δ-cleavage ion in 2-(2-pyridyl)ethyl tosylate (10.2 eV) is considerably larger than both the IP of ethyl tosylate (8.4 eV) and the IP expected for an alkylpyridine (approximately 9.0 eV[6]). The thermochemical data therefore do not correspond to those observed in the earlier studies, although they do not allow a definitive choice between ring and substituent ionization. Second, many other reactions of the pyridine derivatives appear to be initiated by an ionized nitrogen atom. For example, the alcohols **10** and **1** both undergo the specific six-membered hydrogen transfers shown below. It is also interesting that 3-phenylpropyl bromide shows reciprocal hydrogen transfer between the ortho and C_1 positions in the molecular ion.[7] This supports the suggested e → f sequence. Third, the observed loss of $C_2H_5\cdot$ from 2-*n*-butylpyridine *N*-oxide, but not from its isomers,[8] is also best explained as proceeding from a ring-ionized rather than a side-chain ionized form of the molecular ion.

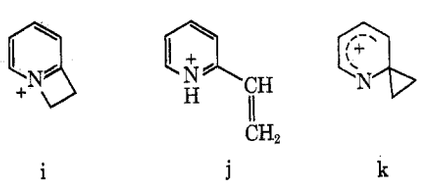


Representation of *N*-oxide molecular ions in the oxy-radical form (*e.g.*, g) helps explain many aspects of their spectra; for example the rearrangements of nitrones, and the relationship between their mass spectra and photochemistry, is rationalized.[9] The sequence g → h may be responsible for $C_2H_5\cdot$ loss.



In summary, the major bond-forming reactions in the pyridine derivatives **1–11** (δ and ϵ cleavage, and β cleavage with hydrogen migration) appear to involve a form of the molecular ion in which a nitrogen lone-pair electron has been removed.

The remaining reaction of interest, γ cleavage, does not show the specificity to the 2 isomer shown by δ and ϵ cleavage. Hence, while it will be readily accepted that the reaction does not merely involve simple cleavage, participation by the nitrogen atom is not demanded. Similar conclusions apply to the alkylpyridines whose spectra are given in Table II.[10,11] While it is true that 2-alkylpyridines do show more γ cleavage (measured in terms of fragment ion–molecular ion abundance ratios) than their isomers, the differences are not particularly large. Hence, γ-cleavage mechanisms which involve cyclization to nitrogen, to give ion i, or hydrogen abstraction by nitrogen, to give ion j, are not indicated. Rather, formation of a spiro phenonium type ion k is



probably involved, both in the alkylpyridines and in compounds **1–11**. It is interesting to note from Table II that δ cleavage in the butylpyridines is specific to 2-*n*-butylpyridine, suggesting the formation of ion c rather than the unstable spiro (5.4) system a.

(5) K. B. Tomer, J. Turk, and R. H. Shapiro, *Org. Mass Spectrom.*, **6**, 235 (1972).

(6) J. L. Franklin, J. G. Dillard, H. M. Rosenstock, J. T. Herron, K. Draxl, and F. H. Field, "Ionization Potentials, Appearance Potentials, and Heats of Formation of Gaseous Positive Ions," NSRDS-NBS 26, U. S. Government Printing Office, Washington, D. C., 1969, p 101.

(7) N. M. M. Nibbering and T. J. deBoer, *Tetrahedron*, **24**, 1427 (1968).

(8) D. A. Lightner, R. Nicoletti, G. B. Quistad, and E. Irwin, *Org. Mass Spectrom.*, **4**, 571 (1970).

(9) B. S. Larsen, G. Schroll, S. O. Lawesson, J. H. Bowie, and R. G. Cooks, *Tetrahedron*, **24**, 5193 (1968); R. G. Cooks, *Org. Mass Spectrom.*, **2**, 481 (1969).

(10) J. H. Beynon, "Mass Spectrometry and its Applications to Organic Chemistry," Elsevier, Amsterdam, 1960, p 403.

(11) S. D. Sample, D. A. Lightner, O. Buchardt, and C. Djerassi, *J. Org. Chem.*, **32**, 997 (1967).

TABLE II
PARTIAL MASS SPECTRA OF SOME ALKYLPYRIDINES[a]

		Bond cleavage				
Compd	Ref	M+	δ	γ	β	β + H
2-*n*-Butylpyridine	8	3	12	33	12	100
3-*n*-Butylpyridine	8	63	1.5	13	100	84
4-*n*-Butylpyridine	8	49	0	10	12	100
2-*n*-Propylpyridine	10	3	14	27	14	99
4-*n*-Propylpyridine	11	90	15	42	57	96

[a] See footnote *a*, Table I.

Benzene Derivatives.—The apparent formation of phenonium-ion analogs k from substituted pyridines reopens the question of mass spectral phenonium-ion formation in benzene derivatives. This question has previously been studied using ω-phenylalkyl bromides with disputed results.[12] In Table III some literature

TABLE III
PARTIAL MASS SPECTRA OF SOME BENZENE DERIVATIVES[a]

		Bond cleavage			
Compd	Ref	M+	ε	δ	γ
$Ph(CH_2)_2Br$	13	33			46
$Ph(CH_2)_3Br$	7	19		2	2
$Ph(CH_2)_4Br$	12		5	2	11
$Ph(CH_2)_2OH$	14	16		0	2
$Ph(CH_2)_3OH$	15	15	0	0	14
$Ph(CH_2)_3ONO$	16	0	49	0	56
$Ph(CH_2)_3CO_2Me$	17	51	31	0	31

[a] See footnote *a*, Table I.

data[12-17] on other alkylbenzene derivatives are collected. Although differences in bond strengths and radical stabilities must be considered, these results clearly demonstrate the preference for γ *vs.* δ cleavage. This does not prove aryl participation but it is certainly consistent with the formation of spiro-fused product ions.[18]

We have examined 2-phenylethyl tosylate (**12**) and nosylate (**13**) and the corresponding *p*-methoxy (**14** and **15**) and *p*-nitro arenesulfonates (**16** and **17**). The unsubstituted and *p*-methoxy tosylates and the *p*-methoxy nosylate undergo γ cleavage, albeit to give ions of low abundance (2–4%).[20] The other compounds do not undergo γ cleavage, nor does the 2-(*p*-nitrophenyl)-ethanol (**18**), while the process gives an ion of 2% relative abundance from 2-phenylethanol.[14] The substituent effect evident in these results suggests that γ cleavage is accompanied by phenonium-ion formation but does not prove this,[21] and the multiple ion compositions contributing to a single mass peak make energy measurements impossible. Besides the question of $C_8H_9^+$ ion structure, it is interesting that the γ-cleavage ions in compounds **12–18** have such low abundances relative to their 3-(2-pyridyl)propanol counterparts. Some role for the lone pair ionized form of the pyridine molecular ion is indicated but substantial mechanistic questions remain. The complete absence of $M\cdot^+ - Ts\cdot$, $M\cdot^+ - Ns\cdot$, and $M\cdot^+ - H\cdot$ ions in compounds **12–18** is, on the other hand, completely in line with expectations based on the pyridine data.

Azulene Derivatives.—Major features of the mass spectra of 3-(4-azulyl)-1-propyl tosylate (**19**) and its 6-azulyl isomer (**20**) appear in Table IV. The former

TABLE IV
PARTIAL MASS SPECTRA OF SOME AZULENE DERIVATIVES[a]

Compd	M+	ε	δ	γ	β	β + H	M+ − XOH[c]
3-(4-Az)-1-PrOTs, **19**	2	33	10	17[b]	55	0	17
3-(6-Az)-1-PrOTs, **20**	100	2	1	15[b]	23	6	45
3-(4-Az)-1-PrOH, **21**	19	0.5	1.5	18	48	94	6
3-(6-Az)-1-PrOH, **22**	52	0.8	1	25	70	92	4
3-(1-Az)-1-PrOH, **23**	25	0	0	12	100	0	0.7

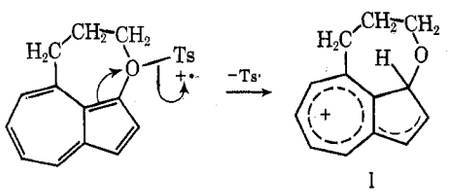
[a] See footnote *a*, Table I. [b] Includes contributions from Ts^+. [c] X = Ts (**19**, **20**); X = H (**21–23**).

compound undergoes δ- and ε-bond cleavages, in complete analogy with the γ- and δ-bond cleavages observed in its ethyl analog.[3] The absence of these unusual modes of fragmentation in compound **20**, the observation of a metastable peak linking the molecular ion of compound **19** and the ε-cleavage daughter ion, and the energetics of ε-bond cleavage (IP, 7.3 eV; AP, ε-cleavage, 10.2 eV) all emphasize the similarity between the aryl participation reactions occurring in **19** and 2-(4-azulyl)ethyl tosylate (IP, 7.3 eV; AP, δ cleavage, 10.5 eV).[3]

In discussing the 2-(4-azulyl)ethanol derivatives, we suggested[3] that the unique reactivity of C_3 was responsible for the unexpected mass spectrometric reactions. This reactivity could either be due to the high electron density at C_3 or to the fact that C_3 is the position of greatest spin density in the molecular ion.[23] The latter possibility, involving a form of the molecular ion ionized in the azulene system, was considered less likely than a side-chain ionization mechanism, partly because of the energetics involved. Either mechanism implies that the δ- and ε-cleavage products in the propyl tosylate (**19**) should have structures l and m, respectively. They are illustrated as being formed from side chain ionized forms of the molecular ion.

A metastable peak was observed for loss of water from the ε-cleavage product ion in compound **19**. This requires that the ring in ion l be opened in those ions having sufficient energy to undergo further frag-

(12) Compare R. H. Shapiro and T. F. Jenkins, *Org. Mass Spectrom.*, **2**, 771 (1969), with H. F. Grützmacher, *ibid.*, **3**, 131 (1970).
(13) N. M. M. Nibbering and T. J. deBoer, *ibid.*, **2**, 157 (1969).
(14) N. M. M. Nibbering and T. J. deBoer, *ibid.*, **1**, 365 (1968).
(15) N. M. M. Nibbering and T. J. deBoer, *Tetrahedron*, **24**, 1415 (1968).
(16) N. M. M. Nibbering and T. J. deBoer, *Org. Mass Spectrom.*, **3**, 487 (1970).
(17) I. Howe, D. H. Williams, D. G. I. Kingston, and H. P. Tannenbaum, *J. Chem. Soc. B*, 439 (1969). Compare D. H. Williams and I. Howe, *Arch. Mass Spectral Data*, **1**, 122 (1970).
(18) An exceptional case, where δ cleavage occurs with some facility, is provided by 4-phenylbutylamine.[19]
(19) D. A. Lightner, F. W. Sunderman, L. Hurtado, and E. Thommen, *Org. Mass Spectrom.*, **3**, 1325 (1970).
(20) These ions occur at the same nominal mass as the ^{13}C isotope peaks of the $M\cdot^+ - TsOH$ (NsOH) fragment ions. High resolution (30,000) was employed to establish the presence of the γ-cleavage ion in compound **14**: required for $C_9H_{11}O^+$, 135.0810; found, 135.0812.
(21) Arguments based on substituent effects have appeared several times in discussions of phenonium-type ion formation in the mass spectrometer. Shapiro and Jenkins[12] employed this argument in their study on 2-arylethyl bromides, and a σ^0, but not a σ^+ or σ, correlation in the ethylenediamines $ArN(Me)CH_2CH_2N(Me)Ph$ has been suggested[22] as evidence against phenonium-type ion formation. The caution necessary in using such arguments is well illustrated by the behavior of methyl 4-arylbutyrates, where electron donation repressed the γ-cleavage process.[15]
(22) H. Giezendanner, M. Hesse, and H. Schmidt, *Org. Mass Spectrom.*, **4**, 405 (1970).
(23) I. C. Lewis and L. S. Singer, *J. Chem. Phys.*, **43**, 2712 (1965).



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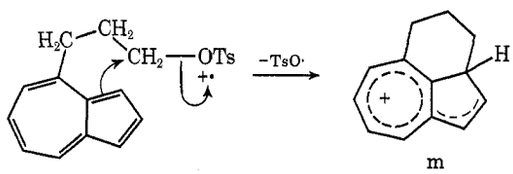
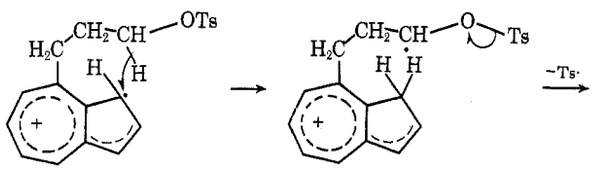
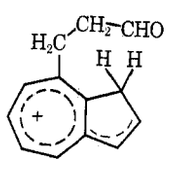


m

mentations or, alternatively, it suggests that ϵ cleavage occurs in these higher energy ions by an alternative mechanism which does not give a cyclized product. The formation of the protonated β-azulylalkanal (n)





n

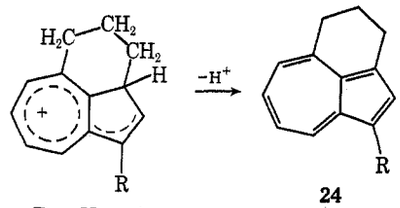
is possible, since it invokes the unique reactivity of C_3 in allowing fragmentation only in the 4-substituted azulene. (In 4-azulylacetic acids hydrogen transfer to a C_3 radical site was previously suggested.[3])

This type of mechanism involves participation by the aryl group, but only in the sense that the radical site on the ring abstracts a hydrogen atom from the substituent and so causes its fragmentation. It should also be noted that this general mechanism can be considered as an alternative to the direct participation mechanisms so far proposed for the pyridine as well as the azulene series.

There is no direct evidence on whether δ cleavage in compound **19** (*i.e.*, loss of TsO·) involves hydrogen transfer or direct aryl participation to give ion m, although solvolytic data (*vide infra*) support the latter view. It is also noteworthy that TsO· loss is relatively much more important in **19** than in its ethyl analog, a fact which can be simply explained as a result of aryl participation with formation of a six- rather than a five-membered cyclic product. The appearance potential for δ cleavage could not be determined, since the ^{13}C isotope of the low AP $M\cdot^+ - TsOH$ process interfered.

The 3-(4- and 3-(6-azulyl)-1-propanols (**21** and **22**) together with the 1-azulyl isomer (**23**)[24] have also been studied. This latter compound, **23**, shows the expected dominance of simple β cleavage, but γ cleavage also occurs. Aryl participation with formation of an ethyleneazulenium ion, so important in solution,[25] may be involved.[26] The spectra of alcohols **21** and **22** are surprisingly similar; both show very low abundance $M\cdot^+ - H\cdot$ and $M\cdot^+ - HO\cdot$ ions and rather more abundant $M\cdot^+ - \cdot CH_2OH$ ions. Radical stability differences account for the dissimilar behavior of **21** and its tosylate, **19**, while the similarity between **21** and **22** continues a trend noted and commented upon in the ethanols.[3]

Relationships to Solution Chemistry.—Buffered acetolysis of 3-(4-azulyl)-1-propyl nosylate (**19**) yields the 4,5-dihydro-3*H*-benz[*cd*]azulene (**24**, R = H) in 72%



R = H or Ac

24

yield, and $\Delta S^{\pm} = -1.0 \pm 1.3$ eu for this solvolysis.[4] These results indicate that solvolysis proceeds by participation of the 3 position of the azulene ring, in complete analogy to the δ-cleavage process in the mass spectrometer. This solvolysis behavior was previously predicted after a consideration of the mass spectra of the azulylethyl tosylates.[3] The mass spectrum of the 3-acetyl solvolysis product (**24**, R = $COCH_3$), obtained in ~1% yield, shows $M\cdot^+$ (30%), $M\cdot^+ - H\cdot$ (30%), $M\cdot^+ - Me\cdot$ (100%).

ω-Pyridylalkyl tosylates have not been solvolyzed, but the mass spectral results lead one to predict that in the propyl series the 2-substituted pyridyl tosylate will show an important k_Δ process. Significantly, this was by far the least stable of the three isomeric pyridyl-1-propyl tosylates, decomposing in 1–2 days in carbon tetrachloride solution at room temperature.

The contrast between β-(*p*-nitrophenyl)ethyl tosylate (**16**), which shows no aryl participation, and β-(*p*-anisyl)ethyl tosylate (**14**), which does undergo γ cleavage, presumably due to aryl participation, also has its parallels in solvolytic processes.[27] Thus the *p*-methoxy tosylate undergoes mainly a k_Δ process while the *p*-nitro tosylate reacts, almost exclusively, by the k_s route.

Conclusions.—The mechanistic threads common to the different aromatic systems studied here and the promise offered that there exist important relationships between neighboring group participation in the mass spectrometer and in solution constitute the most important results of this study. An extended investigation of aryl participation upon electron impact would appear to be warranted on the following grounds.

(1) Mass spectrometry might find use as a means of quickly surveying systems of potential interest for solvolytic studies.

(2) Fresh insights into solvent effects and a separation of k_Δ from k_s routes might be suggested by comparison of the results of the two methods.

(3) This type of comparative investigation seems to yield valuable information on gaseous ion structures and

(24) R. N. McDonald and H. E. Petty, *J. Org. Chem.*, **37**, 2957 (1972).

(25) R. N. McDonald and J. R. Curtis, *J. Amer. Chem. Soc.*, **93**, 2530 (1971).

(26) γ cleavage was not observed at all in 1-azulylethanol.[3] This appears to be an instance of a quite general phenomenon (see Table III) associated with the reluctance to cleave a C–O bond and liberate HO·.

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it may serve as a probe of transition-state geometry in solution.

(4) Useful information on the relative importance of participating groups, preferred ring sizes, and relative radical stabilities can be obtained.

Experimental Section

Pyridyl-1-propanols **1–3** were commercial samples (Aldrich Chemical Co.) and were redistilled before use. The acetate **4** was prepared by acetylation of the alcohol with acetyl chloride in the presence of pyridine at −10 to 10°, and the product was fractionally distilled, bp 59–62° (0.08 mm). Acetates **5** and **6** were prepared by the same method, but in the absence of pyridine, to give products, bp 113–114° (2.5 mm) and 42° (0.75 mm), respectively. Tosylates **7–9** were prepared by Wiberg's method[28] using as reactant a suspension of powdered KOH in ether; products were extracted and chromatographed on alumina but could not be crystallized. Alcohols **10** and **11** were prepared from the corresponding picolines and paraformaldehyde;[29,30a] the products had bp 87–89° (2 mm) [lit.[29] bp 114–116° (9 mm)] and 121–122° (2 mm) [lit.[30a] 151–152° (13–14 mm)], respectively. 2-Phenethyl tosylate (**12**) and *p*-anisylethyl tosylate (**14**) were prepared by the method of Wiberg.[28] Nosylates **13**, **15**, and **17** were prepared by adding an ether solution of the corresponding alcohols to an ether solution of methyllithium (1 molar equiv) and adding an equivalent amount of *p*-nitrobenzenesulfonyl chloride.[4] Alcohol **18** was prepared by the sequence phenylacetonitrile → *p*-nitrophenylacetonitrile, mp 116° (lit.[30b] mp 116–117°), → *p*-nitrophenylacetic acid, mp 151–153° (lit.[31] mp 151–152°), → 2-(*p*-nitrophenyl)-ethanol. The corresponding tosylate (**16**) was prepared by Wiberg's method.[28] The preparation of the azulylpropanols and tosylates is detailed elsewhere[4,24] (the methylazulenes were converted to the carbanions and allowed to react with ethylene oxide to form the alcohols). 2-(2-Pyridyl)ethyl tosylate was a gift from Dr. G. Jones, University of Keele. The purity of all compounds was checked by nmr and in the few cases among the tosylates where impurities were present these did not contribute to the peaks of interest in the mass spectra.

Mass spectra were obtained by direct insertion for the tosylates and nosylates and by use of the heated introduction system in other cases. Spectra were obtained at 70 eV, 100 μA, and 8 kV on an AEI MS9 mass spectrometer. Ionization and appearance potentials were measured against benzene as internal standard using the semilog plot technique.

Registry No.—**1**, 2859-68-9; **2**, 2859-67-8; **3**, 2629-72-3; **4**, 38456-23-4; **5**, 38456-24-5; **6**, 38456-25-6; **7**, 38456-26-7; **8**, 38456-27-8; **9**, 38456-28-9; **10**, 103-74-2; **11**, 5344-27-4; **19**, 38456-31-4; **20**, 38456-32-5; **21**, 38305-10-1; **22**, 38456-34-7; **23**, 35046-09-4.

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The Study and Characterization of Nucleosides by Mass Spectrometry. III. Comparison between the Mass Spectra of Trimethylsilyl Derivatives of Purine 2′- and 3′-Linked Anhydro, Thioanhydro, and Aminoanhydro Nucleosides

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The mass spectra of trimethylsilyl derivatives of several purine O, S, and NH linked anhydro nucleosides were studied in order to determine the positional effects of 8,2′ *vs.* 8,3′ linkage of base to sugar. Principal ions in the spectra were common to both series of anhydro nucleosides but variations in intensity could be used to distinguish between them. These variations could be related to the anticipated ease of formation of the basic ion type from the skeleton of the molecule.

Cyclonucleosides are important analogs of natural nucleosides. They are characterized by having, in addition to the *N*-glycoside linkage, a covalent linkage, either directly or *via* bridging atoms, between the 2′, 3′, or 5′ carbons of the sugar and a carbon or nitrogen atom (other than the nitrogen of the glycoside bond) of the purine or pyrimidine ring. Anhydro nucleosides are cyclonucleosides in which the extra covalent linkage is *via* bridging atoms. Acid or base hydrolysis of the anhydro linkage normally leads to ribo, arabino, or xylo nucleosides.[1] Nucleophilic displacement of the anhydro linkage leads to nucleosides modified on the sugar moiety[1–3] and sometimes on the base moiety.[1,4–6] Chemical conversion of anhydro nucleosides has led to the synthesis of modified nucleosides such as the antitumor drug arabinocytidine[7,8] and the antibiotic cordycepin.[6] They have been used as model substrates for studies of enzyme activity[9,10] and as intermediates in the chemical synthesis of nucleotides.[11–13] Recently, the synthesis and properties of the dinucleoside monophosphate A^spA^s and its conversion to dApdA have been described.[14] In conjunction with our synthetic objectives it was necessary to develop methods of identifying small quantities of specific anhydro nucleosides and to estimate their purity. We have found mass

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