The Reaction of a 10-Methylacridinium Salt with Tertiary Amines

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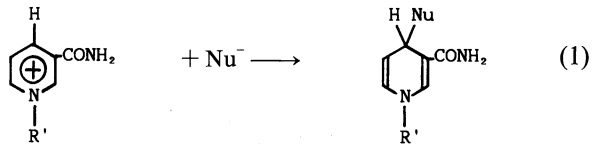
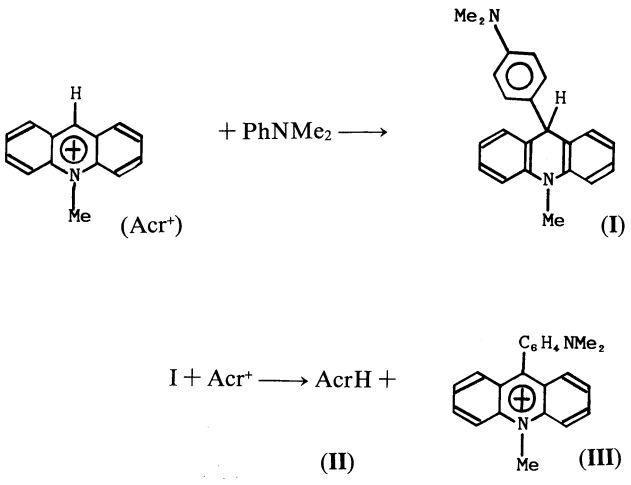
The reaction of 10-methylacridinium perchlorate with a variety of *N,N*-disubstituted alkylamines or aralkylamines was investigated in the presence or absence of air. In all cases studied, 10-methyl-9,10-dihydroacridine was produced in approximately 50% yield or more. In addition, either 10-methyl-9(10*H*)-acridinone or 9-(dialkylamino)-10-methylacridinium perchlorate or both were isolated, each yield being greatly dependent on the bulkiness of alkyl groups on the amines. In the blanket of air, significant amounts of aldehyde was detected. The mechanism was discussed.

The $NAD^+/NADH$ system is one of the most important redox couples in biological reactions,[1] and the reaction of NAD^+ or its related models, e.g., 1-benzylnicotinamide (NABH) and 10-methylacridinium ion (designated hereafter as Acr^+), with certain nucleophiles has found attraction in view of its resemblance to the $NAD^+/NADH$ transformation;[2] for example, addition of nucleophiles such as cyanide,[3] enolate,[4] *N,N*-dimethylaniline,[5] sulfite,[6] sulfoxylate,[7] and thiols[8] to the 4-position of the model pyridinium system has been well-recognized and extensively investigated. It was reported previously that Acr^+ reacts with *N,N*-dimethylaniline to give 10-methyl-9,10-dihydroacridine (hereafter abbreviated as 10-methylacridan or AcrH, **II**) and 9-(*p*-dimethylaminophenyl)-10-methylacridium salt (**III**). The following mechanism was proposed, which



(1)

involves the formation of a dihydropyridine analog, 9-(*p*-dimethylaminophenyl)-10-methyl-9,10-dihydroacridine (**I**), as the first intermediate, followed by the subsequent hydride transfer (Scheme 1).[9] The Pictet–Patry disproportionation of Acr^+ by OH^- is also deeply associated with such a reaction.[10] In this work we have mechanistically investigated the reaction of Acr^+ with a variety of tertiary amines and have found that the reaction features were different from those of arylamines and depend on the nature of tertiary alkylamines. To our knowledge there has been no literature precedent on such a reaction.



Scheme 1.

Experimental

Materials. Acetonitrile was distilled from P_4O_{10}. $Acr^+ ClO_4^-$ was prepared from acridine by methylation with methyl iodide in acetonitrile and then exchange of the counter anion by treatment of the iodide salt with the five-fold excess of $Mg(ClO_4)_2$ in water to give a precipitate as an orange solid, which was dried in vacuo at 80 °C for 48 h. Trimethyl-, triethyl-, tributylamine, and *N,N*-dimethylbenzylamine were purchased from Wako Pure Chemical Industry (Japan) and distilled before use. The other tertiary amines employed in this work were synthesized in good to moderate yields by treating the corresponding halides with excess dialkylamines. The amines thus obtained were purified by distillation under reduced pressure and were all NMR-pure. $PhCD_2NMe_2$ and $PhCDMeNEt_2$ were prepared according to the conventional procedures: $LiAlD_4$ (98% D, Aldrich) reduction of ethyl benzoate or acetophenone to the corresponding alcohols, followed by chlorination with $SOCl_2$ and subsequent amination with dialkylamines. $PhCD_2MeN(c\text{-}C_6H_{11})$ was synthesized by reducing the corresponding $PhCONMe(c\text{-}C_6H_{11})$ with $LiAlD_4$–$AlCl_3$.[11] The deuterium content was of more than the NMR detection limit (>98%).

Product Analysis. The reactions of $Acr^+ClO_4^-$ (100 mg, 0.34 mmol) with two equiv of amines were carried out in acetonitrile at 50 °C for 48 h under air or in a degassed sealed tube. The yield of benzaldehyde and acetophenone was determined by HPLC analysis of the reaction mixture. To evaluate the yields of 10-methylacridan and 10-methyl-9(10*H*)-acridinone and the aminoacridinium perchlorate, the reaction mixture was subjected to preparative TLC separation on Kieselgel G_{254} (Merck) using $CHCl_3/MeOH=10$ as the developing solvent. The yield of the first two compounds was determined by using UV-vis, and that of the aminoacridinium perchlorate was the isolated yield. Attempt to examine a material balance on amines was not made because of the complexity of products derived therefrom.

V_a (R,R′=Et, $PhCH_2$): Mp 130—133 °C; UV (MeCN) 528 nm (ε 39000 M^{-1} cm^{-1}) (1M=1mol dm^{-3}); IR (KBr) 1570 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.38 (3H,broad t, CH_3), 3.46—4.20 (2H, q, CH_2N^+), 3.79 (3H, s, Me-N), 4.69 (2H, s, $PhCH_2$), 6.64—8.19 (13H, m, aromatic). Elemental Anal. Calcd for $C_{23}H_{23}N_2O_4Cl$: C, 64.71; H, 5.43; N, 6.56%. Found: C, 64.41; H, 5.56; N, 6.86%.

V_b (R,R′=Et, PhCHMe): Mp 82—84 °C; UV (MeCN) 527 nm (ε 38000); IR (KBr) 1560 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.43 (3H, t, Me), 1.70 (3H, d, Me), 3.85 (3H, s, MeN), 3.46—4.12 (2H, q, CH_2N^+), 4.98 (H, q, CH), 7.20 (5H, s, Ph), 6.43—8.0 (8H, m, aromatic). Elemental Anal. Calcd for $C_{24}H_{25}N_2O_4Cl$: C,65.40; H, 5.74; N, 5.67%. Found: C, 65.12; H, 5.68; N, 5.64%.

V_c (R,R′=Et, PhCDMe) ^1H NMR ($CDCl_3$) δ=1.42 (3H, t, Me), 1.70 (3H, s, Me), 3.85 (3H, s, MeN), 3.5—4.2 (2H, m, CH_2N^+), 7.20 (5H, s, Ph), 6.4—8.0 (8H, m, aromatic).

V_d (R,R′=Et, Et): Mp 103—105 °C; UV (MeCN) 521 (ε 14000); ^1H NMR ($CDCl_3$) δ=1.44 (6H, q, Me), 3.6—3.8 (4H, m, CH_2N^+), 3.94 (3H, s, N-Me), 7.4—8.3 (8H, m, aromatic). Elemental Anal. Calcd for $C_{18}H_{21}N_2O_4Cl$: C, 59.25; H, 5.80%; N, 7.68%. Found: C, 59.12;H, 5.99; N, 7.83%.

V_e (R,R′=CH_2Ph, $CH_2CH_2CH_2CH_2CH_2OH$): Mp 91—93 °C, UV (MeCN) 512 (ε 22000); IR (KBr) 1570 cm^{-1}, no C=O group; ^1H NMR ($CDCl_3$) δ=1.82 (6H, m, $(CH_2)_3$), 2.82 (2H, broad t, CH_2-O), 3.60 (3H, s, N-Me), 3.60 (2H, broad t, CH_2N^+), 4.71 (2H, s, CH_2Ph), 6.68—7.73 (13H, m, aromatic). Elemental Anal. Calcd for $C_{26}H_{29}N_2O_5Cl$: C, 64.40; H, 5.99; N, 5.78%. Found: C, 64.60; H, 5.48; N, 5.73%.

V_f (R,R′=$(CH_2)_4$): ^1H NMR ($CDCl_3$) δ=1.5—3.7 (8H, m, $(CH_2)_4$), 6.7—7.8 (8H, m, aromatic). This compound could not be purified by TLC because it decomposed on silica gel.

V_g (R,R′=Me, $PHCH_2$): ^1H NMR ($CDCl_3$) δ=3.35 (3H, s, $^+$N-Me), 3.80 (3H, s, N-Me), 4.72 (2H, s, CH_2Ph), 6.96—8.01 (13H, m, aromatic).

V_h (R,R′=Me,Et): ^1H NMR ($CDCl_3$) δ=1.20 (3H, t, Me), 3.37 (3H, $^+$N-Me), 3.63 (2H, q, $^+$N-CH_2), 6.96—8.01 (13H, m, aromatic).

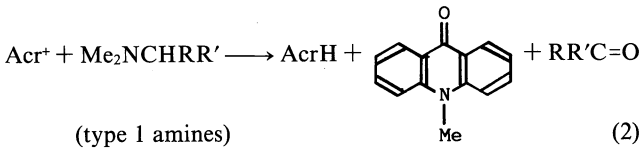
V_g and V_h could not be separated by using TLC.

V_j (R,R′=$PhCH_2$, $PhCH_2$): ^1H NMR ($CDCl_3$) δ=3.91 (3H, s, MeN), 4.91 (4H, s, Ph-CH_2), 6.36—8.06 (18H, m, aromatic). The analytically pure sample could not be obtained even by repeated TLC putification.

V_k (R,R′=$PhCH_2$, *i*-Pr): ^1H NMR ($CDCl_3$) δ=1.49, 1.60 (6H, d, Me), 3.96 (3H, s, Me-N), 4.40—5.10 (1H, m, C-H), 5.12 (2H, s, Ph-CH_2), 6.60—7.83 (13H, m, aromatic).

Results and Discussion

Reaction Products. Reactions between acridinium perchrolate and tertiary amines were carried out in acetonitrile at 50 °C in the presence or absence of air, the period of reaction being 48 h in every case. The miscellaneous data were listed in Tables 1 and 2. In almost all cases 10-methylacridan (**II**) was isolated in approximately 50% yields or more independent of the nature of the used amine. However, the formation of 10-methyl-9(10H)-acridinone (**IV**) was greately affected by the bulkiness of the used amine; with a series of *N*-substituted dimethylamines examined here such as trimethyl-, *N*,*N*-dimethylbenzyl-, *N*,*N*-dimethyl-1-phenylethylamine, and *N*,*N*-dimethylcyclohexylamine (referred to herein as type 1 amines), the acridinone was isolated in 30—45% yields (Eq. 2) as would be anticipated from a disproportionation of the acridinium cation in which the theoretical yields of the acridane **II** and the acridinone **IV** should be 50% each. (Table 1). In the presence of air, appreciable amounts of benzaldehyde and acetophenone were



(type 1 amines) (II) (IV) (2)

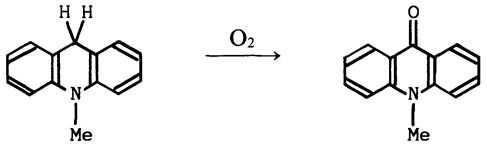
Table 1. Product Yields for Reaction of Acridinium Ion with Type 1 Amines

Amine	Reaction atmosphere	Product yield/%[a]		
		Acridan[b] (±3%)	Acridione[c] (±3%)	RhRC=O[d] (±1%)
None	A	0	0	0
Me_3N	A	54	46	e)
$C_6H_{11}NMe_2$	A	56	24	e)
$PhCH_2NMe_2$	A	48	37	13.8[f]
	Pure-O_2	47	34	16.0
	B	48	38	3.3
	B(+H_2O)[g]	43	34	2.3
	B(+D_2O)[g]	48	40	3.6
$PhCD_2NMe_2$[h]	A	49	27	15.4
$PhCHMeNMe_2$	A	51	30	40.2[f]
	B	44	39	0.5

Conditions: 10-Methylacridinium perchlorate, 0.34 mmol; amine, 1.70 mmol; MeCN, 10 mL; 48 h; room temp. A: aerobic, B: anaerobic. a) Almost all the reported data are an average of two runs. b) Determined by NMR after TLC isolation. c) Determined using UV method after TLC isolation. d) PhRC=O (R=H, Me) yields determined by HPLC analysis. e) Not determined. f) The formation of the corresponding alcohol was not recognized within HPLC detection limit. g) In the presence of 100 mg of water. h) Ca. 4% (±1) of the available deuterium was transferred to the acridan.

produced with the reaction of *N*,*N*-dimethylbenzyl- and *N*,*N*-dimethyl-1-phenylethylamine, respectively, suggesting that the cleavage of the N–C (aralkyl) bond must be involved during the course of the reaction.

Meanwhile, the product feature for bulkier amines (referred to as type 2 amines) differs much from that for type 1 amines; the acridinone was produced only in small amounts (less than 5%). A separate experiment shows that formation of such a small amount of the acridinone is attributed primarily to the spontaneous air-oxidation of the product AcrH during the period of the reaction and/or the TLC treatment of the reaction mixture on silica gel (Eq. 3). Moreover, trapping of the acridinyl radical (an intermediate in Scheme 2 mentioned later) may account for part of the acridinone formation.[12]



(3)

Instead of acridinone, considerable production of a red solid was observed. As displayed in Table 2, triethyl-, *N*,*N*-diethylbenzyl-, *N*,*N*-diethyl-1-phenylethyl-, and *N*-allyl-*N*-methylbenzylamine, *N*-benzylpyrrolidine, *N*-benzylpiperidine, and *N*-(1-phenylethyl)pyrrolidine belong to this class of amine. The reaction with, particularly, *N*,*N*-diethylbenzylamine under an air atmosphere will be taken here as a typical example; TLC separation of the reaction mixture afforded the red-colored solid ($\mathbf{V_a}$) in 29% isolated yield together with 54% of the 10-methylacridan (Eq. 4). The yields of these two products were almost identical with those under degassed conditions. The structure of the isolated red solid was identified as 9-(*N*-ethylbenzylamino)-10-methylacridinium perchlorate by NMR (λ_{max} 525 nm in MeCN) and elemental analysis. The aminoacridinium ions have a very characteristic UV–visible absorption at around 528 nm and afford a strong IR stretching vibration at 1570 cm^{-1}.

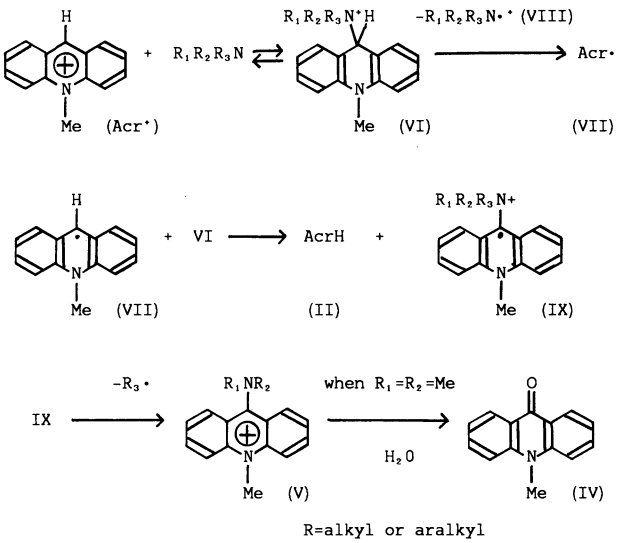
(4)

Rational Reaction Mechanisms. In order to explain these results, we propose at first the following sequence for the major part of the reaction (Scheme 2): The reaction would initially form an Acr^+–amine adduct (**VI**), which dissociates to give the acridinyl radical (Acr·, **VII**) and an aminium cation radical (**VIII**). The rapid hydrogen-atom transfer from **VI** to **VII** would lead to yielding the cation radical **IX** and the product acridan (**II**). Subsequent release of one of the substituents (R_3=alkyl or arakyl) as a free radical from the cation

Table 2. Product Yields for Reaction of Acridinium Ion with Type 2 Amines

	Reaction atmosphere	Product yield/%[a]			
		Acridan (±3%)	Acridinone (±1%)	PhCR=O[b] (±1%)	Aminoacridinium (±2%) (R,R')
Et_3N	A	53	5.0	—	15 (Et, Et)
	B	56	3.2	—	17 (Et, Et)
$PhCH_2NMeEt$	A	58	4.9	4.0	18 ($PhCH_2$, Me) 9 (Et, Me)
$PhCH_2NEt_2$	A	55	3.9[c]	3.5	29 ($PhCH_2$, Et)
$PhCH_2NMe$ (allyl)	A	58	6.2	10.2	36 ($PhCH_2$, Me)
$(PhCH_2)_2NEt$	A	57	1.9	7.1	10 ($2PhCH_2$)[d]
$PhCH_2NC_4H_8$[e]	A	60	4.3[c]	28.3	26 ($(CH_2)_4$)
$PhCH_2NC_5H_{10}$[f]	A	56	8.3, 9.1[c]	1.6	34 ($PHCH_2$, $(CH_2)_5OH$)
$PhCHMeNEt_2$	A	51	2.3[c]	2.8[g]	34 (PhMeCH, Et)
	B	49	1.1[c]	2.8[g]	40 (PhMeCH, Et)
	A(+H_2O)[h]	50	15.6[c]	3.6[g]	22 (PhMeCH, Et)
$PhCDMeNEt_2$	A	53[i]	0.8[c]	4.0[g]	31 (PhMeCD, Et)
$PhCHMeNC_4H_8$	A	50	3.9[c]	42.8[g]	j)
$PhCH_2N$ (*i*-Pr)$_2$	A	73	2.1[c]	14.6	13 ($PhCH_2$, *i*-Pr)
$PhCD_2NMe$ (*c*-C_6H_{11})	A	82[k]	2.9[c]	11.0	Trace
	B	76	1.2	9.8	Trace

Conditions: 10-methylacridinium perchlorate, 0.34 mmol; amine, 1.70 mmol; MeCN, 10 mL; 24 h; room temp. A: aerobic, B: anaerobic. a) Almost all the reported data are an average of two or more runs. b) Benzaldehyde yields determined by HPLC analysis. c) Determined using UV method after TLC isolation. d) 9-(*N*-ethylbenzylamino)acridinium (4%) was produced. e) *N*-Benzylpyrrolidine. f) *N*-Benzylpiperidine. g) PhRC=O yield determined by HPLC. h) In the presence of 100 mg of water. No deuterium-labelled acridan was produced upon addition of D_2O. i) The acridan contains 3.5% (±1) deuterium in its methylene group. j) Not determined owing to being unable to purify the product. k) The acridan contains 11% deuterium in its methylene group.



Scheme 2.

radical **IX** furnishes the aminoacridinium ion (**V**) which is then hydrolyzed to the acridinone (**IV**) when an amine is of type 1.

It has been well-documented that an alkyl radical under oxygen gives the peroxyl radical by being rapidly scavenged with oxygen and then would suffer further transformations;[13] a peroxy radical disproportionates to form a pair of a ketone and an alcohol (Eq. 5), and a certain radical, $MeCH(OMe)OCH_2O_2\cdot$, will react with its like with formation of the formic ester and H_2O_2 (Eq. 6).[14] However, the fact that

$$2\,ArRCHOO\cdot \longrightarrow ArRC{=}O + ArRCH_2OH \qquad (5)$$

$$2\,ArRCHOO\cdot \longrightarrow ArRC{=}O + H_2O_2 \qquad (6)$$

(R=H, Me)

the reaction with *N,N*-dimethylbenzylamine gave benzaldehyde but no formation of benzyl alcohol was recognized by HPLC analysis rules out the possibility of disproportionation of benzyl peroxyl radical. The reaction of Eq. 6 accounts for benzaldehyde production, but may not be generally accepted with benzyl peroxyl radical. The most probable mechanism for aldehyde formation involves the radical coupling between a peroxyl radical and an aminium radical (**VIII**) to form the adduct (**X**), which would decompose to give the aldehyde and the N-oxide (Eq. 7). However, further studies are required to understand the benzaldehyde formation, since the present reaction system is quite complex.

$$ArRCHOO\cdot + R_1R_2R_3N^+\cdot\,(\mathbf{VIII}) \longrightarrow$$

$$\longrightarrow ArRC{=}O + O^-{-}N^+R_1R_2R_3 \qquad (7)$$

On the other hand, a small but recognizable amount of benzaldehyde (<5%) was produced even under O_2-depleted conditions, strongly suggesting that an alternative minor pathway, including the formation of the acridinyl radical (**VII**) and the aminium cation radical (**VIII**) followed by hydrogen-atom transfer affording 10-methylacridan and a benzilideneiminium cation (**XI**) (Scheme 3), may also be operative, where benzaldehyde would form through facile hydrolysis of

$$Acr^+ + PhRCHNMe_2 \rightleftharpoons \mathbf{VI} \longrightarrow Acr\cdot + PhRCH\dot{\overset{+}{N}}Me_2$$

(R=H, Me)

$$\longrightarrow AcrH + PhRC{=}\overset{+}{N}Me_2 \xrightarrow{H_2O} PhRC{=}O$$

(**XI**)

Scheme 3.

the iminium cation (**XI**) by the moisture present in the reaction system rather than through the oxidation of a benzyl radical with residual O_2. In accordance with this inference, use of the deuterium-labelled $PhCD_2NMe_2$ led to small, but significant incorporation (ca. 8%) of deuterium in the product acridan, and the extent of the deuterium transfer was nearly identical for $PhCD_2NMe_2$ (a type 1 amine) and $PhCDMeNEt_2$ (a type 2 amine), implying that part of the reaction for these type 1 and 2 amines proceeds via the deuterium transfer process according to Scheme 3. The proportion of the deuterium-transfer process increased to 22% when more bulky *N*-benzyl-*N*-methylcyclohexylamine (the benzyl methylene was deuterium-labeled) was employed. Consistent with this obsevation, the considerable quantity of the acridan as high as 70—80% was produced with bulky amines such as the above amine and *N,N*-diisopropylbenzylamine. Significant amounts of benzaldehyde (ca. 10%) could be detected even in the absence of air. Thus, it becomes now clear that the reaction pathway via the hydrogen-atom transfer from the aminium cation (**VIII**) to the acridinyl radical (**VII**) yielding 10-methylacridan is taking place as a minor pathway. At the initial stage of the reaction sequence, the acridinyl radical (**VII**) might be formed via the dissociation of the adduct **VI** and/or via the one-electron transfer between Acr^+ and the amine.

Thermodynamically Unfavorable Bond Cleavage. As careful inspection of Tables 1 and 2 reveals, in the case of a series of alkyl and aralkyl-mixed amines the yield of benzaldehyde (or acetophenone) is a function of the nature of alkyl substituents of the used amine. Namely, extrusion of alkyl and aralkyl radicals from **IX** competes with each other; for instance, the acetophenone yield was as high as 40% with *N,N*-dimethyl-1-phenylethylamine.

On the other hand, the acetophenone yield was quite low (2.8%) with the corresponding *N*,*N*-diethylamine (Eq. 2), but the yield of the phenylethyl group-maintaining aminoacridinium product was noticeably high (Eq. 3), demonstrating that the thermodynamically unfavorable dissociation of the N–C (ethyl) rather than the N–C (aralkyl) bond exclusively takes place with this type of amines. It is concluded unequivocally that such an unexpected release of an ethyl vs aralkyl radical should be a consequence of steric crowding in the hypothetical radical intermediate (**IX**). Thus, in order to properly explain observed product features for the type 1 and 2 amines, the following two assumptions must be made here concerning the radical **IX**: (1) Except the case of trimethylamine of a small size, interconversion of the acridine ring between two boat-like shapes, similar to the boat form of cyclohexane, is absolutely fixed in one boat form, in which the 9-amino moiety occupies the axial position to the ring, the localized unpaired electron at the 9-position occupies the equatorial position, and the 10-methyl group prefers the equatorial to axial position owing to its steric interaction with the bulky amino group lying on the acridine ring; (2) a C–N σ-bond being cis or nearly cis to the unpaired electron at the adjacent carbon is cleaved off. It is well-documented that a radical prefers a syn to anti attack toward an electron pair, since a half-filled orbital, unlike a filled orbital, is virtually electron-deficient and hence electrophilic in nature.

Consideration of Corey–Pauling–Koltun space-filling molecular models (CPK) shows that, in the intermediate **IX** derived from all the *N*,*N*-dimethyl-substituted amines (type 1), the axially-oriented amino moiety can rotate almost freely about the C(9)–N σ-bond, and then a reacting conformation depicted in Fig. 1a is attained in which eclipsing occurs between the benzyl group and the unpaired-electron orbital to result in formation of 9-(dimethylamino)acridinium followed by its facile hydroysis. The same argument as above will hold for the corresponding 1-phenylethylamine; the only favorite rotamer can be depicted as in Fig. 1b, which would release mainly 1-phenylethyl free radical, then providing acetophenone, as was observed.

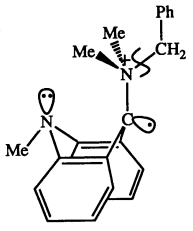


Fig. 1a.

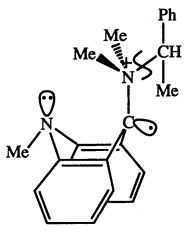


Fig. 1b.

Proposed structures for intermediate **IX**.

On the other hand, with slightly more congested amines like *N*,*N*-diethylbenzylamine (type 2), the rotation about the axial C(9)–N bond is rather restricted, but only narrowly allowed; thus, four different inflexible conformations are realizable (Figs. 2a, 2b, 2c, and 2d), but the last two are not of prime importance for **IX** because of occurrence of substantial steric repulsion between the phenyl group and the ethyl group lying on the fused ring. Therefore, the selective breakage of the N–C (ethyl) bond would occur through either of conformers a and b.

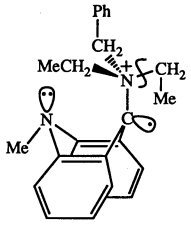


Fig. 2a.

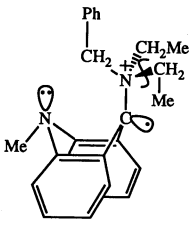


Fig. 2b.

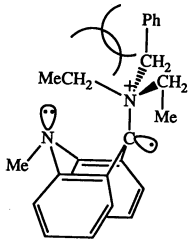


Fig. 2c.

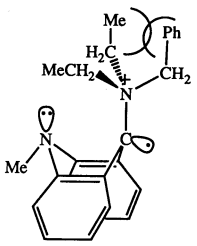


Fig. 2d.

In a similar manner, the preferable orientation of the rotating amino moiety in the hypothetical intermediate (**IX**) can well rationalize the product features for other amines such as *N*-ethyl-*N*-methylbenzylamine, *N*,*N*-dibenzylethylamine, and *N*-allyl-*N*-methylbenzylamine.

Incidentally, consideration of the possible conformations of **IX** bearing 5- and 6-membered rings appears to be instructive because the features of their C–N bond cleavage were markedly different from one another; the reaction with *N*-benzylpyrrolidine (a 5-membered cyclic amine) had lost the benzyl group in the aminoacridinium product, while that of *N*-benzylpiperidine (a 6-membered cyclic amine) gave predominant production of the ring-opening product over the benzyl-cleavaged product. These findings could also be verified with use of CPK models; the possible free rotation of the 5-membered cyclic amino axial-moiety in **VIII** about the C(9)–N bond would lead to the formation of the benzyl-group lacking product (Fig. 3a). Meanwhile, the favoring of ring opening for the corresponding 6-membered one can also be easily understood; the only feasible conformation would be the one having the benzyl group placed in the trans position to the unpaired electron (Fig. 3b), which conformation would lead to exclusive formation of the ring-opening product. An alternative interpretation might be possible; when an exocyclic C(9)=N^+ (partial) double bond is to be formed, the increasing internal-

angle strain seems to play an important role in determining which of the C–N bonds is cleaved because it is well known that a 6-membered vs 5-membered ring suffers more severe internal-angle strain in exocyclic double-bond formations;[15] it appears evident, however, that this interpretation is not necessarily needed now for the proper understanding of the observed results.

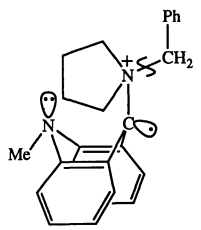


Fig. 3a.

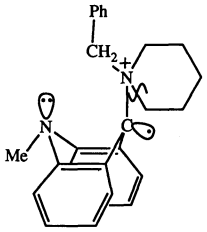


Fig. 3b.

Possible reacting conformations for **IX** having 5- and 6-membered cyclic amino moieties axial.

The aminoacridinium salts thus formed are generally quite stable toward strong mineral acids or under the reaction conditions. However, the aminoacridiniums derived from the series of *N*-substituted dimethylamines appear to be exceptional; those may undergo facile hydrolysis to the acridinone even by the moisture present in the reaction solvent, while [*N*,*N*-diethyl- or more bulky alkyl-substituted amino]acridinium is hydrolyzed only partly with added water during the course of the reaction (see Run 11 in Table 2), and they are hydrolyzed slowly to the corresponding acridinone in an alkaline medium in a fairly good yield, demonstrating that the 9-(diethylamino)acridinium is much more resistant to hydrolysis than is the methyl counterpart probably because the ethyl group provides higher steric hindrance to nucleophilic attacking than does the methyl group.

References

1) C.-I. Brändén, H. Jörnvall, H. E. Eklund, and B. Furugren, "Alcohol Dehydrogenases," in "The Enzymes," ed by P. D. Boyer, Academic Press, New York (1975), Vol. 2; C. Williams, Jr., "The Redox Chemistry of 1,4-Dihydronicotinic Acid Derivatives," in "The Enzymes," ed by P. D. Boyer, Academic Press, New York (1976), Vol. 13.

2) M. M. Kreevoy and A. T. Kotchevar, *J. Am. Chem. Soc.*, **112**, 3579 (1990); D. Ostvic, R. M. G. Roberts, and M. M. Kreevoy, *ibid.*, **105**, 7629 (1983); P. Hapiot, J. Moiroux, and J. -M. Saveant, *ibid.*, **112**, 1337 (1990).

3) J. F. J. Engbersen, A. Koudijs, H. M. Sleiderince, and M. C. R. Fransen, *J. Chem. Soc., Perkin Trans. 2*, **1990**, 79; R. N. Lindquist and E. N. Cordes, *J. Am. Chem. Soc.*, **90**, 1269 (1968); O. Meyerhof, P. Ohlmeyer, and W. Möhle, *Biochem. Z.*, **297**, 113 (1938); S. P. Colowich, N. O. Kaplan, and M. M. Ciotti, *J. Biol. Chem.*, **191**, 447 (1951); A. San Pietro, *J. Biol. Chem.*, **217**, 579, 589 (1955).

4) W. von E. Doering and W. E. McEwen, Jr., *J. Am. Chem. Soc.*, **73**, 2104 (1951); R. M. Burton, A. San Pietyro, and N. O. Kaplan, *Arch. Biochem. Biophys.*, **70**, 87 (1957).

5) E. Koenings, E. Ruppelt, *Ann.*, **509**, 142 (1961); W. E. McEwen, R. H. Terss, and I. W. Elliot, *J. Am. Chem. Soc.*, **74**, 3605 (1952).

6) G. Pfleiderer, E. Sann, and A. Stock, *Chem. Ber.*, **93**, 3083 (1960).

7) M. B. Yarmolinsky and S. P. Colowick, *Biochim. Biophys. Acta*, **20**, 177 (1956).

8) J. van Eys and N. O. Kaplan, *J. Biol. Chem.*, **228**, 305 (1957).

9) R. E. Ballard, J. Jones, and E. Sutherland, *Tetrahedron Lett.*, **23**, (36), 3677 (1982).

10) A. Albert and G. Catterall, *J. Chem. Soc.*, **1965**, 4653; A. Pictet and E. Patry, *Chem. Ber.*, **35**, 2534 (1902); J. Clark and M. Bakavoli, *J. Chem. Soc., Perkin Trans. 1*, **1977**, 1966.

11) K. T. Patts and D. R. Liljegren, *J. Org. Chem.*, **28**, 3202 (1963).

12) S. Fukuzumi, M. Ishikawa, and T. Tanaka, *J. Chem. Soc., Perkin Trans. 2*, **1989**, 1038.

13) E. G. Jansen, P. H. Krygsman, D. A. Lindsay, and D. L. Haire, *J. Chem. Soc., Perkin Trans. 2*, **112**, 8279 (1990); J. E. Bennett, D. M. Brown, and B. Mile, *Trans. Faraday Soc.*, **66**, 397 (1970); K.U. Ingold, *Acc. Chem. Res.*, **2**, 129 (1969); K. Adamic, J. A. Howard, and K. U. Ingold, *Can. J. Chem.*, **47**, 3803 (1969); T. Mill and R. S. Stringham, *J. Am. Chem. Soc.*, **90**, 1062 (1968); J. E. Bartlett and G. Guaraldi, *ibid.*, **89**, 4799 (1967)

14) M. N. Schuchmann, H.-P. Schuchmann, and C. von Sontag, *J. Am. Chem. Soc.*, **112**, 403 (1990); E. Bothe, D. Schulte-Frohlinde, *Z. Naturforsch. B: Anorg. Chem., Org. Chem.*, **33B**, 786 (1978).

15) H. C. Brown, J. H. Brewster, and H. Shechter, *J. Am. Chem. Soc.*, **76**, 467 (1954); O.H. Wheeler, *Chem. Ind.*, **1954**, 900; M. S. Newman, "Steric Effects in Organic Chemistry," John Wiley & Sons, Inc., New York (1956), p. 598.