ELECTROCYCLIC REACTIONS OF AZIRIDINES

by

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Abstract

Temperature dependent nmr spectra have been observed for a series of para-substituted 1-aryl-3,3-dimethyltriazenes . The temperature dependence has been interpreted in terms of restricted internal rotation about the N_2,N_3 bond of these triazenes and activation parameters $\Delta F^{\ddagger}$, $\Delta H^{\ddagger}$, and $\Delta S^{\ddagger}$ have been calculated from the spectral data. The origin of the rotational barrier is considered to lie in partial double bond formation between N_2 and N_3 due to the contribution of 1,3-dipolar resonance hybrids to the ground states of these triazenes. This interpretation is supported by a sizable substituent effect $\rho = -2{\cdot}1$ for the rotational process in the series studied. Chemical shift data at low temperatures indicates a stereospecific association of benzene with the triazenes studied which places the benzene ring closer to the trans N-Me group in the 1,3-dipolar resonance hybrid.

The thermal decomposition of N-arylazoaziridines follows two routes; one giving arylazide and alkene (stereospecifically) and the other giving products typical of homolysis of the azo-linkage. The products of the homolytic route in benzene solvent are aziridines, biaryls and arenes. Both the rate and extent of azide and alkene formation are favoured by increasing the electronegativity of substituents in the aryl ring and performing the reaction in more polar solvent ($CHCl_3$). Pyrolysis and photolysis of N-arylazo derivatives of larger cyclic amines proceeds via homolysis of the azo linkage to the exclusion of fragmentation of azide and unsaturate.

The thermal reaction of N-aryl-2,3-diphenyl aziridines with activated alkenes such as dimethyl maleate and dimethyl fumarate has been shown to yield 2,5-diphenyl-3,4-dicarboalkoxy pyrollidines. The reaction is stereospecific with respect to the alkene reactant. Kinetic investigation of the reaction revealed a two step reaction. The first step is considered to be rate determining conrotatory ring opening via C-C bond cleavage. A Hammett reaction constant of $\rho = -0.8$ was determined for the N-substituents in this step. The second step is the concerted 1,3-dipolar cycloaddition of the ring opened aziridine of the alkenes. The reaction of 7-aryl-6a,7a-dihydro-acenaphtha-[1,2-b] - aziridines with alkenes proceeds via slow disrotatory ring opening via C-C bond cleavage ($\rho = +0.74$) with subsequent stereospecific 1,3-addition to alkenes.

TO MY PARENTS

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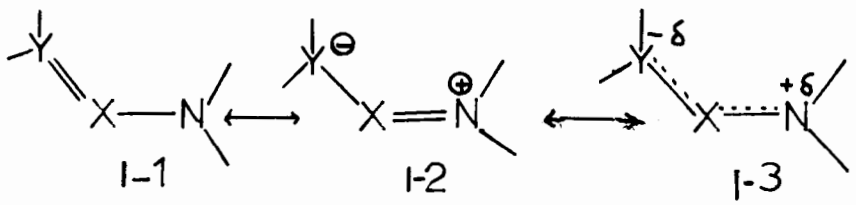
CHAPTER I

NMR STUDY OF HINDERED ROTATION IN 1-ARYL-3,3-DIMETHYLTRIAZENES

Introduction

In order to lay a foundation on which to base the study of the fragmentation of N-arylazoaziridines described in chapter II. We studied the variable temperature nmr spectra exhibited by 1-aryl-3,3-dimethyltriazenes.

In general, amine derivatives which possess π-conjugative systems directly attached to nitrogen, I-1, exist partially as the 1,3-dipolar resonance structures, I-2, and may be represented as I-3.

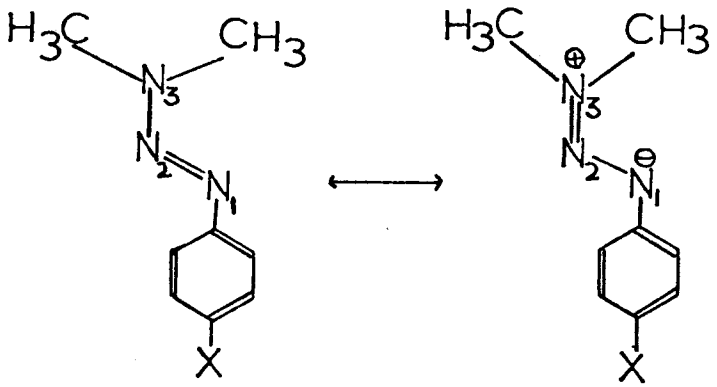


An observable effect of such resonance hybridisation is an increase in the effective barrier to rotation about X-N bond. This occurs to an appreciable extent in derivatives in which the dipolar resonance structures I-2 are stabilized by the presence of electronegative substituents at the Y position. Amine derivatives such as amides[1] (X=C, Y=O), nitrosoamines[2] (X=N, Y=O), enamines[3] (X=Y=C), hydrazones[3] (X=N, Y=C), amidines[4] (X=C, Y=N), thioamides[5] (X=C, Y=S), and selenamide[6] (X=C, Y=Se), exist to a sufficient extent in the 1,3-dipolar structure, I-2, to cause the barrier (7-23 Kcal) to rotation about the X-N bond to be measurable by nmr techniques.

We have found thet 1-aryl-3,3-dimethyltriazenes I-4 produced upon the coupling of aryl diazonium salts with dimethylamine[7] are excellent models for the study of the I-1 ⟷ I-2 resonance hybridization.

Results

Each of the para substituted triazenes listed in Table I exhibited temperature variable nmr spectra which were interpretable in terms of hindered internal rotation about the N_2,N_3 bond of I-4. The N-methyl signals in the nmr spectra of the triazenes studied (see Table I) appeared as a single peak at room temperature. At lower temperatures the signals broadened and eventually emerged as two distinct



I-4 I-5

signals of equal intensity. This type of temperature dependence may be described, vide infra, as a case of hydrogen exchange between two sites with equal populations and lifetimes. The temperature dependence was examined by the line width method above and below the coalesence temperatures. The rates of the exchange process were estimated above the coalesence temperatures using equation 1.[2,8] In this equation

$$k = \pi \Delta \nu^{2}/2W \qquad (1)$$

$\Delta\nu$ is the seperation of the N-methyl signals when the rate process is slow and $\underline{W}$ is the exchange broadening, i.e., the width of the methyl signals at half height. When it was apparent that the seperation of the methyl signals varied with temperature, $\Delta\nu$ was plotted as a function of temperature and k was obtained at each temperature from the plot. The observed exchange broadening was corrected from natural line width by substracting from it the line width of the tetramethylsilane signal at the same temperature. At the coalesence temperatures the rates of exchange were calculated from equation 2 and below the coalesence temperature k was calculated using equation 3.[2,8] The exchange broadening term $\underline{W}$ in equation 3 was corrected as described for high temperature determinations. Although this method of obtaining exchange rates from the nmr spectra is not as accurate as complete line-shape matching, we feel the rates obtained by this method are sufficiently precise for the present study.

$$k = \pi\Delta\nu / \sqrt{2} \qquad (2)$$

$$k = \pi W \qquad (3)$$

If the present N-methyl interchange is treated as a typical rate process, the temperature dependence of the rate constant, k for the interchange may be expressed by the Eyring rate equation 4.

$$k = \frac{KfT}{h} e^{-\Delta F^{\ddagger}/RT} \qquad (4)$$

where, K = Boltzman constant, f = transmission coefficient.

The transmission coefficient f in this equation is assumed to be unity.[8] The transition state for the interconversion represents the conformation about the N_2,N_3 bond in which any p-orbital overlap between these atoms is minimal. This conformation thus represents the energy maximum in the potential energy curve for the N_2-N_3 rotation.[9,10] Substitution of numerical constants and f = 1 into equation 4 followed by rearrangement gives equation 5. Since $\Delta F^{\ddagger} = \Delta H^{\ddagger} - T\Delta S^{\ddagger}$, equation 4 may be expanded to equation 6. For the purposes

$$\Delta F = 4.58T(10.32 + \log_{10} \frac{T}{k}) \qquad (5)$$

$$\log_{10} \frac{k}{T} = 10.32 + \frac{\Delta S^{\ddagger}}{2.3R} - \frac{\Delta H^{\ddagger}}{2.3RT} \qquad (6)$$

of comparison of different triazenes the free energy of activation ($\Delta F^{\ddagger}$) was calculated (eq. 5) at a single tempearture (298°A) for all triazenes. Plots of log k/T vs 1/T yielded straight lines (Fig. 1) from which the activation entropy ($\Delta S^{\ddagger}$) were calculated (eq. 6). Errors in these determinations were estimated by drawing lines of maximum and minimum slope containing between them all the experimental points. The values for $\Delta F^{\ddagger}$, $\Delta H^{\ddagger}$, and $\Delta S^{\ddagger}$ reported in Table II are the means of the values calculated in this manner.

TABLE I. CHEMICAL SHIFTS AND COALESENCE TEMPERATURES OF TRIAZENE N-METHYL HYDROGENS

Para Substituent	Tc_{CHCl_3}	δvs TMS Room Temperature (37°) $CDCl_3$	C_2D_5OD	C_6H_6	δvs TMS (-56°) $CDCl_3$	C_2D_5OD	C_6H_6
OCH_3	-44°	192.0	192	172	207.5	201	
					188	184	
CH_3	-31.5	192.0	192	172	205.5	200.5	
					186.5	189.5	
H	-23.5	193	190	170	206	198.5	
					187	181.5	
Cl	-13	195	193	169	208.5	208[a]	168.5[b]
					188.5	191[a]	163.5[b]
NO_2	+37	205	214	166	216[c]		165.8[d]
					196[c]		158.5[d]

[a] At -20°.
[b] At -3.5° (signals not well resolved).
[c] At -5°.
[d] At 6°.

TABLE II. ACTIVATION PARAMETERS FROM LINE MEASUREMENTS

Para Substituent	$CDCl_3$ $\Delta F^{\ddagger}_{298}$ (kcal/mol)	$CDCl_3$ $\Delta H^{\ddagger}$ (kcal/mol)	$CDCl_3$ $\Delta S^{\ddagger}$(eu)	C_2D_5OD $\Delta F^{\ddagger}_{298}$ (kcal/mol)	C_2D_5OD $\Delta H^{\ddagger}$ (kcal/mol)	C_2D_5OD $\Delta S^{\ddagger}$(eu)	C_6H_6 $\Delta F^{\ddagger}_{298}$ (kcal/mol)	C_6H_6 $\Delta H^{\ddagger}$ (kcal/mol)	C_6H_6 $\Delta S^{\ddagger}$(eu)
OCH_3	12.7 ± 0.4	7.4 ± 0.5	-16.1 ± 2.3	13.1 ± 0.3	6.5 ± 0.5	-21.6 ± 2.5			
CH_3	13.0 ± 0.3	9.4 ± 0.5	-11.5 ± 2.3						
H	13.7 ± 0.3	8.7 ± 0.5	-16.8 ± 2.3	13.6 ± 0.4	9.7 ± 0.7	-12.2 ± 4.6			
Cl	13.9 ± 0.2	7.8 ± 0.5	-21.2 ± 2.8	14.6 ± 0.2	10.4 ± 0.9	-14.0 ± 3.7			
NO_2	15.7 ± 0.2	11.7 ± 1.1	-12.7 ± 4.1				16.1 ± 0.3	13.1 ± 0.9	-9.4 ± 1.6

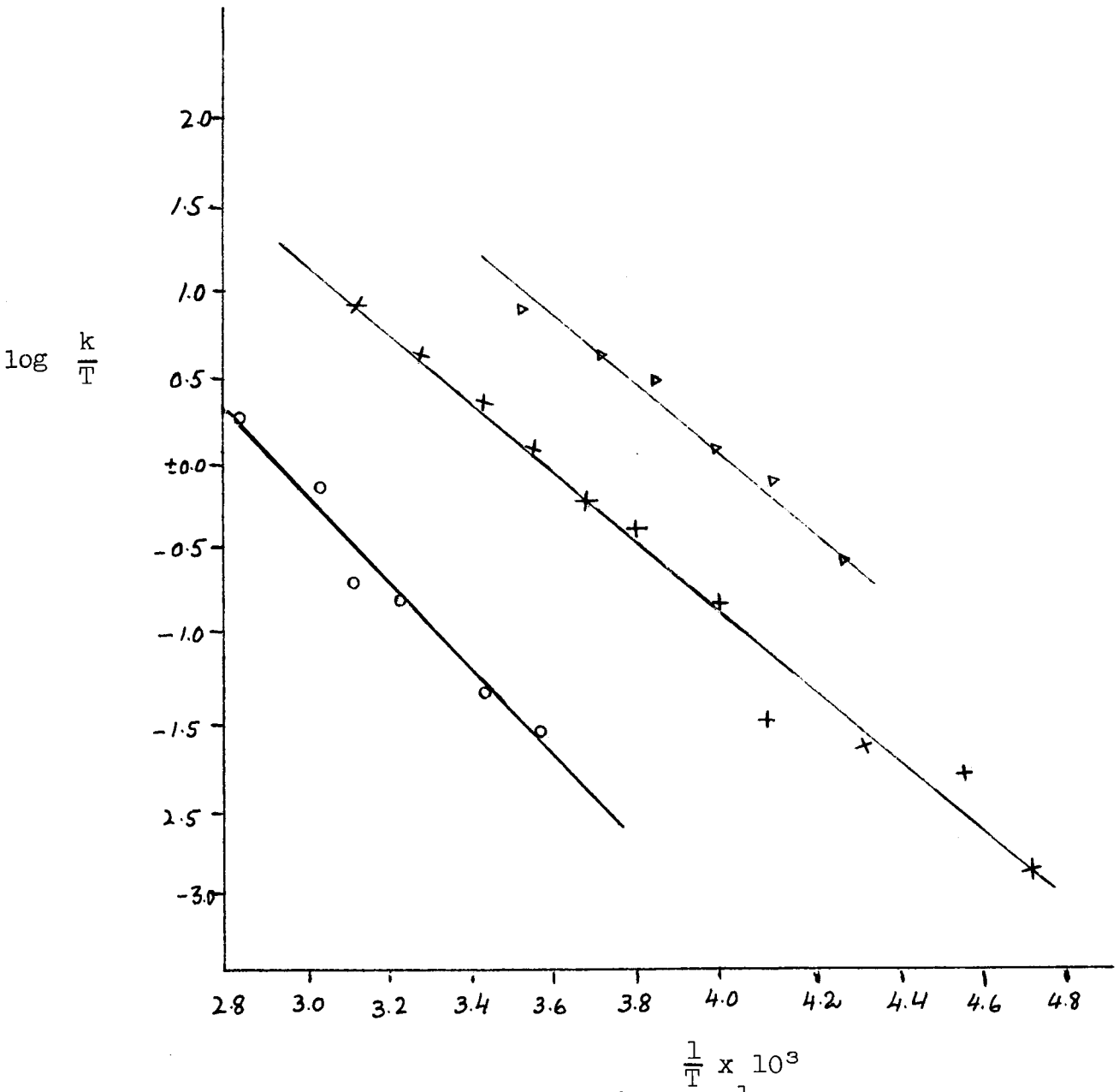


Figure 1 : Plots of $\log \frac{k}{T}$ vs. $\frac{1}{T}$ for I-4, x = NO_2 (O), x = H (+) and x = OCH_3 (Δ) $CDCl_3$ solution.

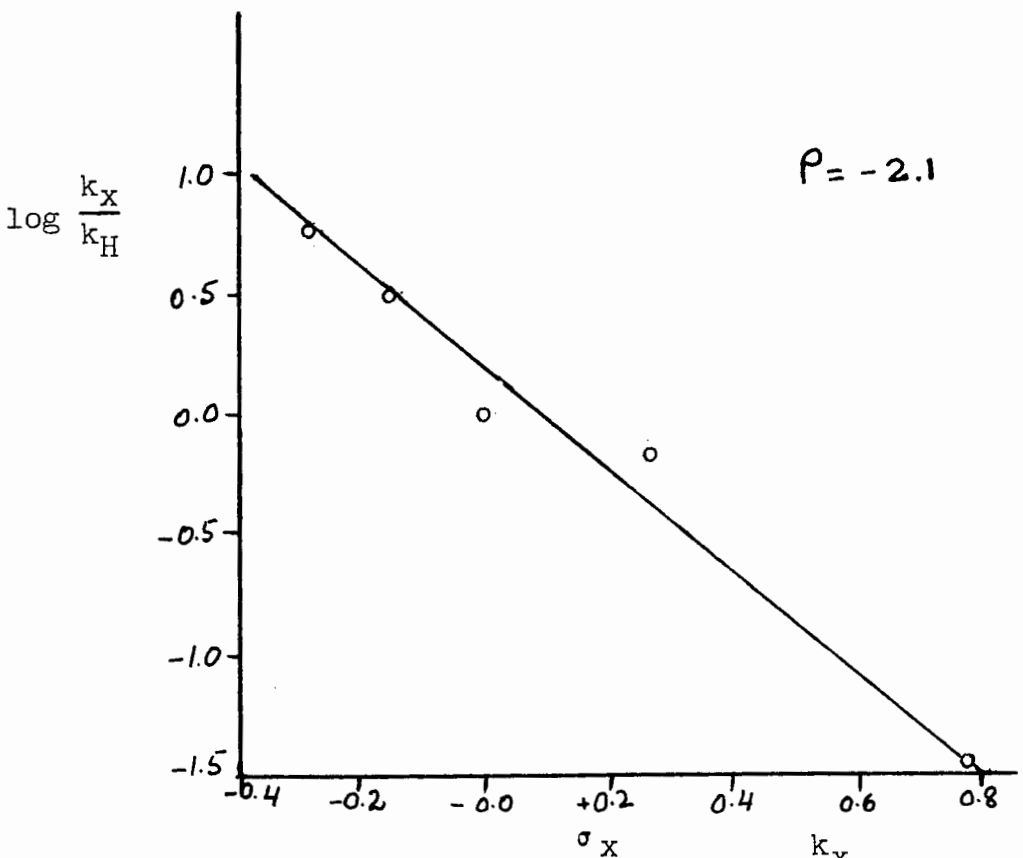


Figure 2: Correlation of log $\frac{k_X}{k_H}$ and σ_X for the N-methyl interchange in triazenes of type I-4.

Discussion

Triazenes of type I-4 are azo derivatives and as such may undergo cis-trans isomerization about the azo linkage. This process would produce nmr spectra in which the N-methyl hydrogens resonated at different magnetic fields. Furthermore, this process would be expected to be temperature dependent. We feel that this process is not the origin of the temperature dependence in the nmr spectra of triazenes because the exchange process which is observed involves exchange of the N-methyl hydrogens between two equally probable sites with equal lifetimes. This would not be the case if cis-trans isomerization of I-4 were being observed since the sterically less hindered trans isomers of I-4 (shown) are the more stable.[11] In support of this conclusion are X-ray crystallographic studies of p,p'-dibromodiazoaminobenzene which show it to be trans in the solid state.[12] Finally, the observation that the signals due to the aromatic hydrogens are not temperature dependent indicates the rate process is not cis-trans isomerization about the azo linkage.

The observed temperature dependence of the nmr spectra of the triazenes studied is most easily interpreted in terms of hindered internal rotation about the N_2, N_3 bonds of these compounds. This process would give rise to temperature dependent spectra resulting from variation in the rate of transposition of the N-methyls about the azo

linkage of I-5. Furthermore, this process would be expected to involve interchange of the N-methyl hydrogens between two equally probable sites with equal lifetimes as was observed.

At a given temperature the observed differences in the rates of internal rotation about the N_2, N_3 bonds of the para substituted triazenes studied are interpreted in terms of the ability of the para substituents to stabilize the 1,3-dipolar form I-5 of these compounds.* This form represents the ground state for the rotation process whereas the transition state is represented by the conformation about the N_2, N_3 bond in which the p-orbitals on these atoms are perpendicular and they are thus singly bonded. The chemical shift of the N-methyl signals of the substituted triazenes when rotation is fast (room temp.) gives an indication of the transmission of inductive effects of the substituents through the N_2,N_3 single bond. The data in Table I reveals these effects to be rather small.

Transition state theory considers the transition state in a rate process as being in equilibrium with the ground state. Thus estimates of rate constants in the present case are equivalent to estimates of free energy differences between the various species considered above.

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*The dipole moments of the triazenes studied increases markedly as the aryl ring is substituted with electron withdrawing groups. This increase has also been ascribed to the increased contribution of the 1,3-dipolar form I-5 to the ground state of these compounds upon such substitution (Ref. 11)

Accordingly the present rate process exhibits a linear Hammett relationship with a clear retardation of the process by electron-withdrawing substituents (Fig. 2).[13] The entropy of activation for the rotational process would be expected to be near zero. The highly negative values reported are considered to be due to the approximate nature of the method used for determination of the activation parameters from the line measurements. References to detailed discussions of the sources of error in this method can be found in Ref. 8.

The N-methyl hydrogens which resonate at higher magnetic field in each of the substituted triazenes studied are assigned to the position in the 1,3-dipolar form I-5 cis to the nitrogen atom bearing the negative charge.[14] These hydrogens appear about 0.3 ppm higher field than those N-methyl hydrogens trans to this nitrogen when the low temperature spectra are observed in deuterochloroform (Table I). Dilution of deuterochloroform solutions of the p-nitrophenyl and p-chlorophenyl triazenes with benzene caused the resonances assigned to the trans N-methyl hydrogens to shift to higher field more rapidly than those of the corresponding cis (Fig. 3). The high coalescence temperature of the p-nitrophenyl triazene allowed determination of the chemical shift difference between the two N-methyl signals in benzene solution. Inspection of the nmr spectrum of this derivative in benzene solution at 0° revealed the trans-N-methyl hydrogens shifted upfield by 0.9 ppm whereas the cis-N-methyl hydrogens were shifted by

0.6 ppm. Such a change is consistent with stereospecific association of benzene with the triazenes in such a manner as to place the benzene ring closer to the trans than to the cis hydrogens. Such a situation is depicted in I-6 and has been elegantly employed by Karabatsos and Taller to account for analogous solvent shifts in the nmr spectra of N,N-dialkyl nitrosamines.[14] Similar effects have been observed in the nmr spectra of amides.[15]

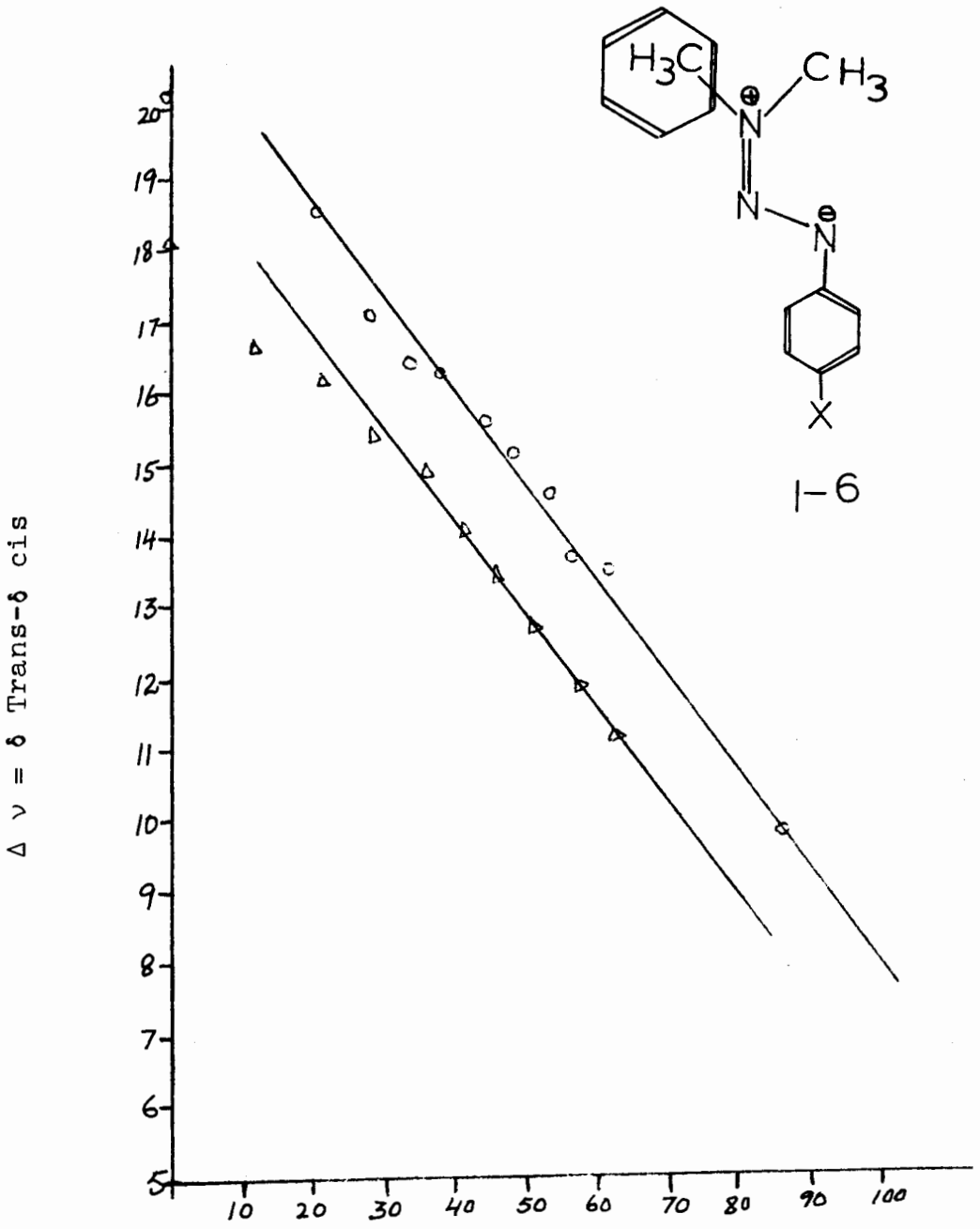


Figure 3: Plot of Δ ν for the N-methyl signals of I-4, x = NO_2 (O) at 0°C and x = Cl (Δ) at -28°C, as function of mole percent C_6H_6 in $CDCl_3$.

Experimental

Preparation of 1-aryl-3,3-dimethyl triazenes.

The 1-aryl-3,3-dimethyl triazenes studied were prepared by coupling variously substituted aryl diazonium salts with dimethyl amine in buffered aqueous solution according to Procedure F of reference 7. The yield in these coupling reactions ranged from 75-90%. Each triazene was extracted in ether solution and purified according to its properties, i.e., distillation under vacuum or crystallization from ether-petroleum ether solution. Relevant data are recorded below in Table III.

The n.m.r. spectra were recorded at the temperatures indicated ($\pm$ 1°) using a sweep width of 100 c.p.s. and a sweep time of 500 sec.

TABLE III. PROPERTIES OF TRIAZENES Ar-N=N-N$\begin{matrix}CH_3\\CH_3\end{matrix}$

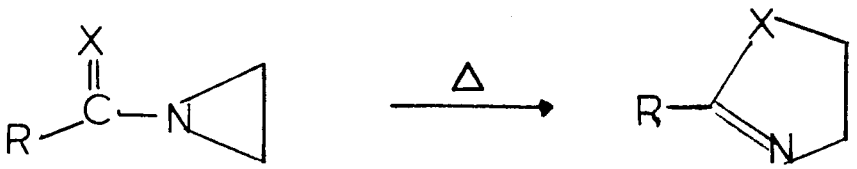
Ar	MP (bp/mm)	λ max($\log_{10}$)hexane λ Lit.[11] max($\log_{10}$) ethanol	Formula	Analyses Calcd. C	Calcd. H	Found C	Found H
p-Anisyl	(59/0.75)	286(4.24), 322(4.17)					
	Lit.[11] (174-177/29)	288(4.12), 324(4.17)	$C_9H_{13}N_3O$	60.32	7.31	59.74	7.37
p-Tolyl	46.5-47.5°	286(4.17), 322(4.17)					
	Lit.[16] 50-51°	285(4.15), 324(4.07)	$C_9H_{13}N_3$	66.23	8.03	66.55	8.39
Phenyl	(125°/8)	286(4.15), 303(4.11)					
	Lit.[17] (125-127/19)	285(4.14), 308(4.11)	$C_8H_{11}N_3$	64.40	7.43	63.60	7.46
p-Chloro-	55-56°	286(4.18), 311(4.10)					
phenyl	Lit.[11] (164-166/27)	287(4.18), 314(4.15)	$C_8H_{10}ClN_3$	52.26	5.49	52.49	5.83
p-Nitro-	143-144°						
phenyl	Lit.[17] 144-145°		$C_8H_{10}N_4O_2$	49.48	5.19	49.46	5.30

CHAPTER II

DECOMPOSITION OF N-ARYLAZOAZIRIDINES AND RELATED CYCLOAMINES

Introduction

Thermally induced rearrangements of aziridines possessing π-conjugative groups attached to the nitrogen usually result in enlargement of the aziridine ring or expulsion of the aziridine nitrogen with concomitant alkene formation. Thus, thermolysis of the N-acylaziridine[18] (II-1) and the sulfur containing analog[19] give ring expanded products (II-2) in good yield.



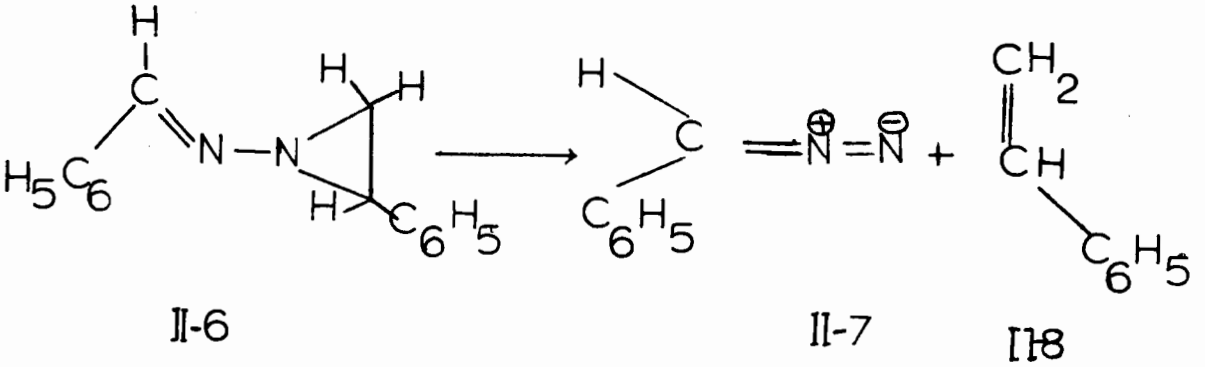
II-1a, X=O; R=C_6H_5
b, X=S, R=NHC_6H_5

II-2a, X=O, R=C_6H_5
b, X=S R=NHC_6H_5

By contrast thermolysis of N-nitrosoaziridines (II-3) yield nitrous oxide (II-4) and alkenes (II-5)[20]. The elimination is highly stereospecific yielding substituted alkenes which posses the same stereochemistry as the aziridine from which they are derived. The thermal decomposition of N-phenyliminoaziridine (II-6) has been reported

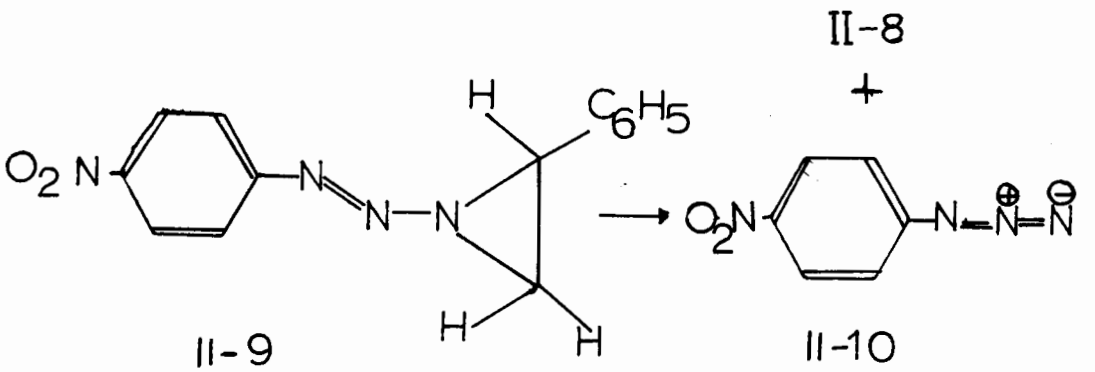
II-3 II-4 II-5

to follow a similar course yielding phenyldiazomethane (II-7) and styrene (II-8)[21].



II-6 II-7 II-8

Likewise, Huisgen[21] et al. found that N-aryl-azoaziridine, II-9, underwent smooth thermal fragmentation to p-nitrophenyl azide (II-10) and II-8.



II-9 II-10

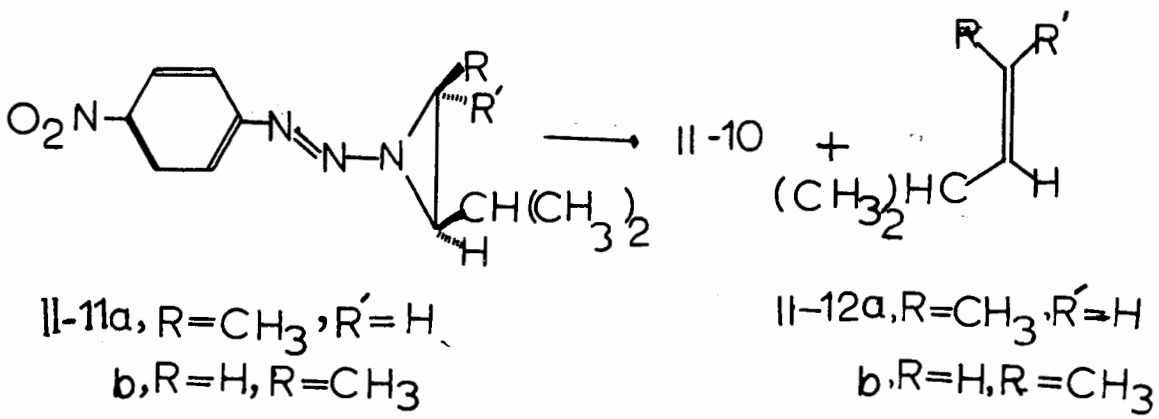
This observation supports the report by Rondestvedt and Davis[7] of the formation of aryl azides upon the dry distillation of impure N-arylazoaziridines.

The cycloeliminations of N-nitroso, N-imino, and N-azo aziridines are apparent examples of electrocyclic reactions. In an effort to determine the applicability of the Woodward-Hoffmann orbital symmetry theory[22] to the pre-

diction of the stereospecificity of nitrogen elimination from the heterocyclic ring in these cycloeliminations[23] and to determine the extent to which cycloelimination would occur in larger cyclic amine derivatives we have investigated the thermal and photochemical decomposition of several N-aryl-azoamines. The choice of the N-arylazoamine system was based on the ease with which the electronic nature of the triazo-group could be changed by proper substitution.

Results

The N-arylazoaziridines studied were prepared by coupling variously substituted aryl diazonium salts with the appropriate aziridine in buffered aqueous solution according to the procedure of Rondestvedt and Davis[7]. Because of the thermal instability of the triazenes studied, elemental analyses were not attempted. The triazenes studies were characterized by nmr, ir and UV spectra and by their ready rearrangement into 1,2,3,-Δ^2-triazolines by iodide ion in acetone[24]. The aziridines used were either commercially available or were synthesized by well established procedures and were known stereochemistry[25]. In agreement with earlier reports[7,21] the N-p-nitrophenylazoaziridines were found to undergo facile thermal decomposition. Thermolysis of cis and trans-2-isopropyl-3-methyl-N-p-nitrophenylazo-aziridines, II-11a, and, II-11b, at 80° in benzene gave a 78-82% yield of p-nitrophenyl azide (II-10) and 67-71% yield 4-methyl-2-pentenes, II-12a and II-12b, which were of the same configuration as the N-arylazoaziridine from which they were derived.

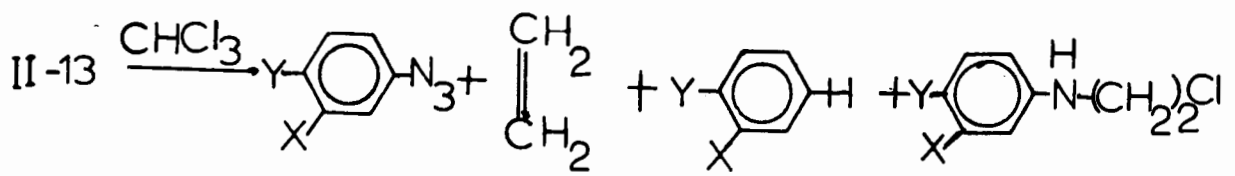


II-11a, R=CH_3, R'=H
b, R=H, R=CH_3

II-12a, R=CH_3, R'=H
b, R=H, R=CH_3

The thermolysis of N-arylazoaziridines II-13a-c in refluxing benzene (Table IV) gave aryl azides (II-14), ethylenimine (II-15), substituted biphenyls (II-16), and substituted arenes (II-18) (Scheme I). A glpc search for biphenyl, N-arylethylenimine and symmetrically substituted biphenyls in these reaction mixtures was negative. The limits of experimental detection of these possible products was 2-3%. Each of these possible products was stable in refluxing benzene.

When the thermolyses of N-arylazoaziridines II-13a,d-e were carried out in chloroform, aryl azides (II-14), substituted arenes (II-18) and N-(2-chloroethyl) anilines (II-19) were formed (Table IV.)



II-14 II-18 II-19

A glpc search for N-arylethylenimines in these reaction mixtures was negative. In separate experiments it was determined that N-arylethylenimines were stable in refluxing chloroform. The structures of the N-2-chloroethyl anilines were determined by synthesis from the corresponding 1,2,3-Δ^2-triazolines (II-20)[24].

SCHEME I

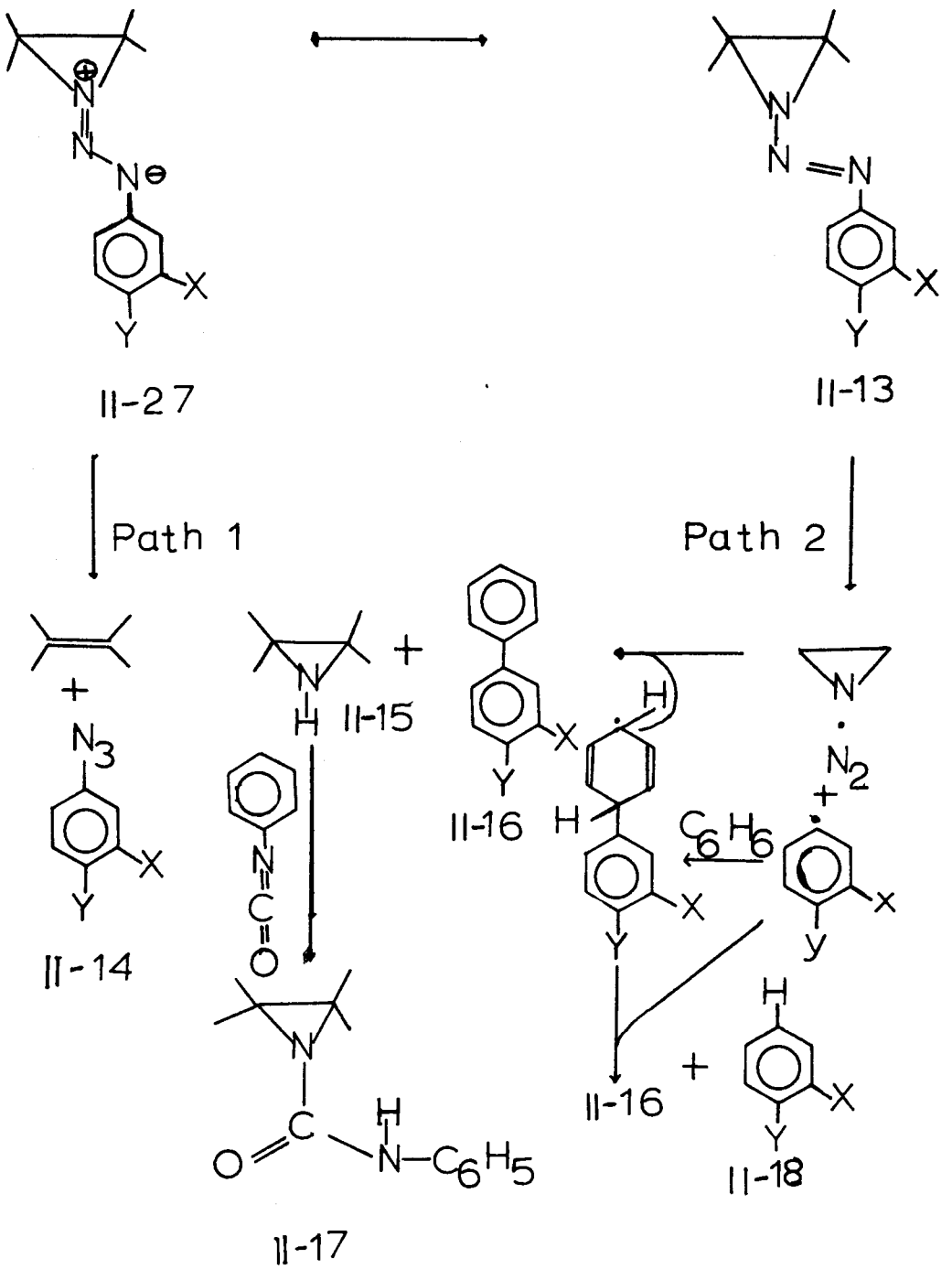


TABLE IV.

PRODUCTS OF DECOMPOSITION OF N-ARYLAZOAZIRIDINES IN BENZENE AND CHLOROFORM

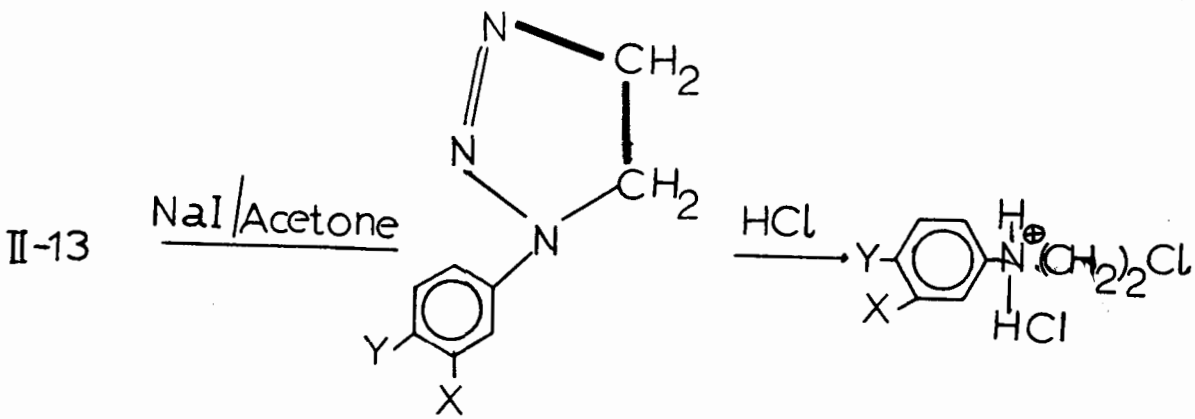
N-Arylazoaziridine	Solvent	Aryl azide[b] II-14	Ethylenimine as II-17	Biphenyl deriv. II-16	Benzene deriv. II-18	N-2-Chloroethyl deriv. II-19
II-13a, x=H, y=Cl	C_6H_6	a	84	92	3-4	-
	$C_6H_6(h\nu)$	-	-	57	17	28[c]
	$CHCl_3$	30			50	10
b, x=H, y=Br	C_6H_6	a	63	84	6	-
c, x=H, y=NO_2	C_6H_6	89				
d, x=NO_2, y=CH_3	C_6H_6	9	53	77	10	-
	$CHCl_3$	52			28	12
e, x=y=Cl	C_6H_6	13	50	71	9	-
	$CHCl_3$	68			14	9

a) Azide not detected by infrared analysis of reaction mixture.

b) Ethylene is presumed to be formed also but was not sought.

c) N-p-chlorophenylethylenimine

The thermal decomposition of II-13b in cyclohexene solution gave bromobenzene (34%), 3,3'-biscyclohexenyl (50%), ethylenimine (20%) and N-(p-bromophenyl) ethylenimine (40%). The photolysis of II-13b in this solvent gave very nearly the same product distribution. The N-(p-bromophenyl) ethylenimine was identified by comparison with an authentic sample obtained by photodecomposition of triazoline, II-20b[24,26].



II-20

The rate of azide formation from the N-arylazoaziridines II-13 was determined by ir analysis. The reaction followed good first order kinetics in benzene and chloroform as long as the reaction was run in a non-pressured vessel. If the sealed tube technique was used as the method of performing the reaction the apparent rate of azide formation decreased steadily from initial values as the reaction progressed.

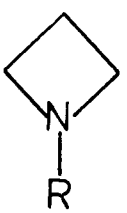
TABLE V.

RATES OF ARYL AZIDE FORMATION FROM N-ARYLAZOAZIRIDINES IN BENZENE AND CHLOROFORM

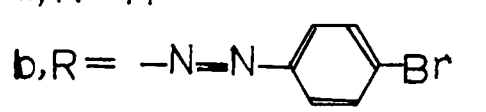
N-Arylazoaziridine	Solvent	Temp.	$k_1 \times 10^6$ sec^{-1}
II-13a, x=H, y=Cl	$CHCl_3$	51 ± 0.05°	36 ± 2.5
c, x=H, y=NO_2	C_6H_6	80 ± 0.05°	140 ± 7.3
	C_6H_6	70 ± 0.05°	45 ± 2.1
	C_6H_6	60 ± 0.05°	13 ± 1.5
	C_6H_6	50 ± 0.05°	3.8 ± 0.7
d, x=NO_2, y=CH_3	C_6H_6	80 ± 0.05°	4.5 ± 0.7
	$CHCl_3$	50 ± 0.05°	50.7 ± 3.4
e, x=y=Cl	C_6H_6	80 ± 0.05°	7.1 ± 1.2
	C_6H_6	70 ± 0.05°	1.5 ± 0.6
	$CHCl_3$	50 ± 0.05°	79 ± 1.3

That this was due to the reaction of the azide with ethylene formed in the decomposition and trapped in the sealed tube was indicated by performing the reaction under a nitrogen blanket, at atmospheric pressure, conditions which should allow the ethylene to escape into the vapour phase. Under these conditions the reaction of II-13 to give azide followed first order kinetics. As shown in Table V the rate of azide formation from N-arylazoaziridines (II-13) is much faster in chloroform than it is in benzene. It is also obvious that the rate of azide formation from II-13 increases as the electronegativity of the aryl substituent increases.

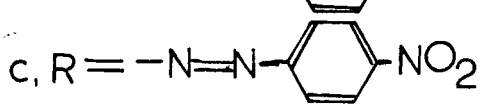
In an attempt to extend this azide elimination reaction to other N-arylazocycloamines the N-arylazo-derivatives of azetidine, II-21a, Δ^3-pyrroline, II-22a, 2,3-dihydro-1H-benz-(de) isoquinoline, II-23a, and 2,7-dihydro-3,4,5,7-dibenzazepine, II-24a, were prepared by coupling the free amine with the appropriate aryl diazonium salt in buffered aqueous solution.



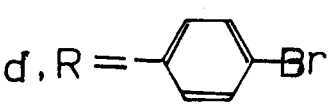
II-21a, R=H



b, R = –N=N–Br

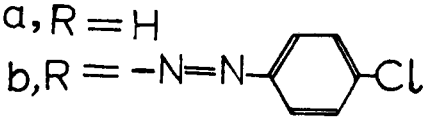


c, R = –N=N–NO$_2$

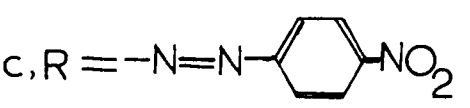


d, R = –Br

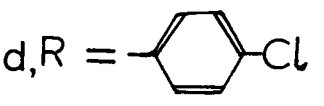
II-22a, R = H



b, R = –N=N–Cl



c, R = –N=N–NO$_2$



d, R = –Cl

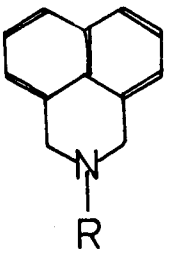
TABLE VI.

PRODUCT DISTRIBUTION FROM PYROLYSIS AND PHOTOLYSIS OF N-ARYLAZOCYCLOAMINES IN BENZENE SOLUTION

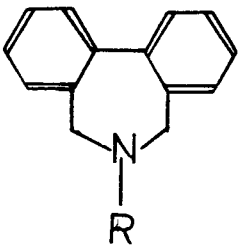
(% YIELD)

N-arylazo derivative	Conditions	Amine	Biphenyl derivative[b]	Benzene derivative[b]	N-arylamine	Subst. aniline[b]
II-21b	200°/12 hr.	42(II-21a)	45(II-16b)	28(II-18b)	12(II-21d)	4(II-25b)
	hν	30(II-21a)	41(II-16b)	20(II-18b)	25(II-21d)	3-5(II-25b)
II-22b	170°/12 hr.	12(II-22a)	45(II-16a)	21(II-18a)	5(II-22d)	3(II-25a)
	hν	16(II-22a)	49(II-16a)	18(II-18a)	14(II-22d)	3(II-25a)
II-23b	170°/12 hr.	53(II-23a)	55[c]	a	16(II-23d)	3[d]
	hν	49(II-23a)	60	a	16(II-23d)	
II-24b	170°/8 hr.	41(II-23a)	44(II-16a)	16(II-18a)	13(II-24c)	4(II-25a)
	hν	47(II-23b)	53(II-16a)	13(II-18a)	20(II-24c)	3(II-25a)

a) Benzene. b) Letter in the parenthesis refers to substituent as evident from Table IV.
c) Biphenyl d) Aniline.



II-23a, R=H



II-24a, R=H

b, R = -N=N-

c, R = -N=N-NO_2

d, R =

e, R = -NO

b, R = -N=N-Cl

c, R = -Cl

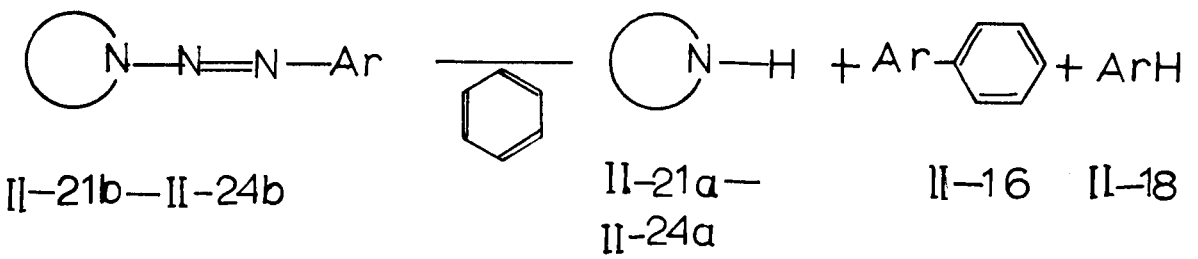
d, R = -NO

In addition the known N-nitroso derivatives II-23e and II-24d were studied.

The rates of thermal decomposition of the N-arylazoderivatives of II-21a-II24a were much slower than those of the N-arylazoaziridines studied. Thus in refluxing benzene or chloroform II-21b,c-II-23b,c and II-24c were unchanged after 34 hrs. Heating II-21b,c-II-23b,c and II-24b, in benzene solution in a sealed tube at 170°-200° for twelve hours resulted in loss of nitrogen and formation of the several products shown below (Scheme II).

The product distribution observed in the photo-decomposition differed very little from that observed in the pyrolysis as can be seen from Table VI. The small amounts of substituted anilines II-25 which were observed

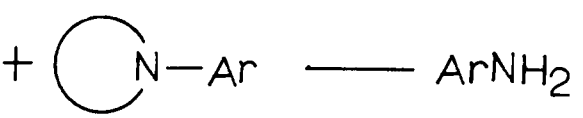
by glpc were found to arise from thermal decomposition of the N-arylamines in the injection port of the gas chromatograph. This interesting observation is under further study. Although the product distribution from the thermolysis of II-21c-II23c was not investigated in detail the absence (< 2%) of p-nitrophenyl azide and its thermal decomposition products (e.g. p-nitroaniline) was indicated by glpc and tlc. A search for acenaphthene in the pyrolysate and photolysate of both II-23c and II-23d was negative.



II-21b—II-24b

II-21a—II-24a

II-16 II-18



II-21c,
II-22c,
II-23d
II-24c

II-25

The thermolysis of the N-nitrosoderivatives II-23e and II-24d in o-xylene at reflux for two days produced no acenaphthene or 9,10-dihydrophenanthrene. High yields of starting material were obtained from these thermolyses.

Discussion

The thermal decomposition of N-arylazoaziridines takes two paths (Scheme I). The competition between these two paths depends primarily on the aryl substituent. When electron withdrawing substituents are present in the aryl ring a cycloelimination occurs (Path 1) to give alkene and aryl azide. When no electron withdrawing group is present thermal fragmentation occurs (Path 2) to give nitrogen, ethyleneimine, and products arising from reactions with the solvent. This latter path (Path 2) leads to production of ethylenimine (II-15), biphenyls (II-16), and substituted arenes (II-18) in benzene and is considered to involve homolytic expulsion of nitrogen to give aziridinyl and aryl radicals[28-31] and was not of primary interest in the present investigation, the mechanistic complications such as the sequence of cleavage of the two bonds to the departing nitrogen and the possibility of radical induced reactions were not investigated. The absence of biphenyl in the pyrolysis mixture is noteworthy since this indicates that ethylenimine is not formed by the abstraction of hydrogen from the benzene solvent. Such a reaction would yield phenyl radicals which would readily couple[30]. The proposed sequence readily explains the observation that the yield of ethylenimine II-15 is greater than the aryl derivative II-18 and the total yield of II-15 and II-18 is not greater than that of the

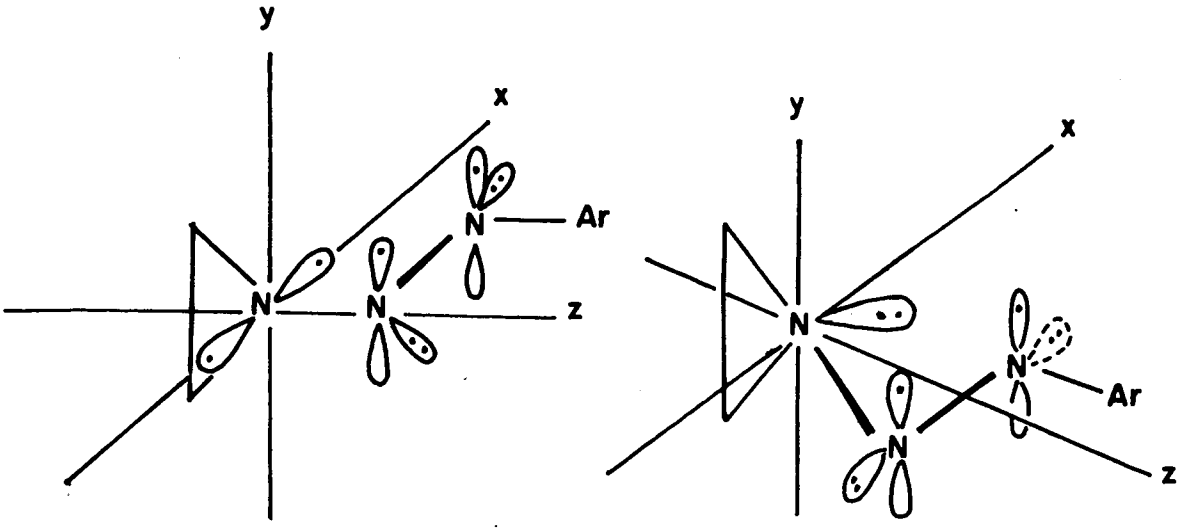
biphenyl derivative (II-16). A radical mechanism is also indicated by the formation of high yields of 3,3'-biscyclohexenyl when II-13b is thermally or photochemically decomposed in cyclohexene.

The origin of the N-2-chloroethylanilines (II-19) from N-arylazoaziridines (II-13) in chloroform solution is unclear. These products (II-19) as well as the substituted arenes (II-18) detected are undoubtedly formed via homolytic cleavage of the N-arylazoaziridine as discussed above. In chloroform the aryl and aziridinyl radicals thus formed would be expected to couple as well as abstract hydrogen from the solvent. While the latter process explains the origin of the substituted arenes, the former would yield N-arylaziridines which were stable in refluxing chloroform. Furthermore, in the presence of benzoyl peroxide in refluxing chloroform we found that N-arylaziridine remained unchanged after one day. The possibility of their formation via N-arylazoaziridine to triazoline isomerization followed by decomposition of the latter was also ruled out since the triazolines in question were stable in refluxing chloroform.

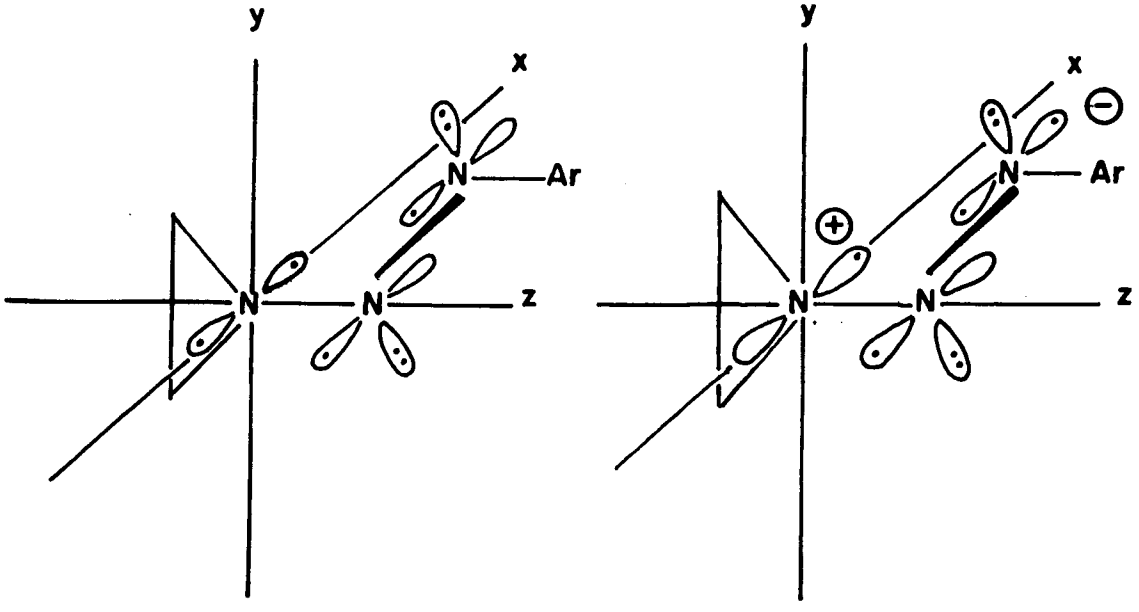
Competing with azo type homolysis of N-arylazoaziridines is cycloelimination to give aryl azide and alkene. The high degree of stereospecificity observed in the cycloelimination of N-arylazoaziridines II-11a and II-11b strongly suggests that both aziridinyl C-N bonds are broken

simultaneously. Indeed the ease with which the thermal cycloelimination of azide, nitrous oxide[20] and isoelectronic species[21] occurs from appropriately N-substituted aziridines indicates a general reaction type. The cycloelimination of aryl azide from N-arylazoaziridines is symmetry allowed ($_{\sigma}{}^{2}s+_{\sigma}{}^{2}a$)[32] from either the conformation of the N-arylazoaziridine in which the plane of the π-bond is not favorably oriented for overlap with the lone pair on the aziridinyl nitrogen II-26 (aziridine ring in yz plane and the azo linkage in xz plane) or the conformation in which the aziridinyl lone pair is in the same plane as the azo π-bond (yz plane) and can be delocalized into the arylazo system as in II-27.

We have determined that the proportion of cycloelimination obtained increases with increasing π-overlap between N_2 and N_3 of the reacting arylazoaziridine. This trend suggests very strongly that conformation II-27 is the preferred conformation in the cycloelimination reaction. Recent studies[33] in this laboratory have shown that there is appreciable π-overlap between N_2 and N_3 of N-arylazoamines such as I-4. This π-overlap increases with increasing electronegativity of the aryl substituent since the dipolar resonance hybrids of these N-azoamines are stabilized. Although placing the amino nitrogen in the three membered ring such as in the N-arylazoaziridines, II-13, would be

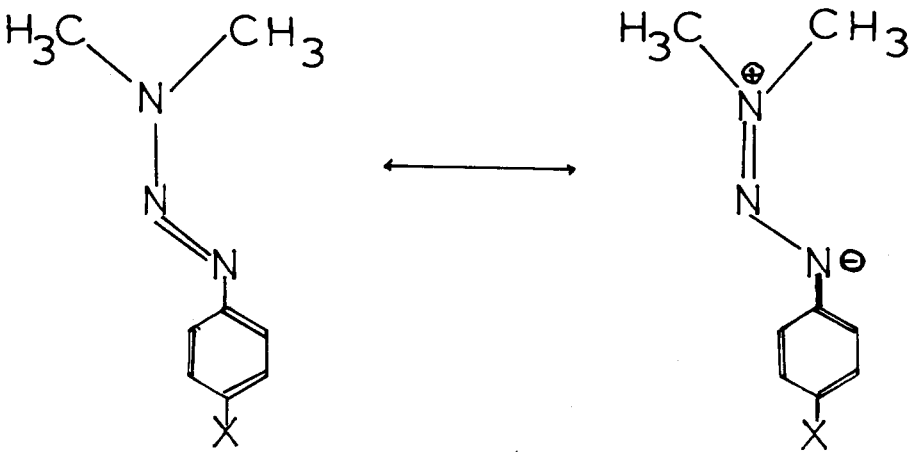


II-26



II-27

expected to decrease N_2-N_3 π-overlap appreciably, any



I-4

trends in amount of π-overlap between these two nitrogens would be expected to be in the same direction*.

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* In agreement with this the coalescence temperature of the aziridinyl hydrogens of II-13c was observed to be -57± 1° and that of II-13a below 60°. Although we suspect the origin of the temperature dependence in this system is restricted N_2-N_3 rotation we have not yet ruled out the possibility of slow aziridinyl nitrogen inversion.

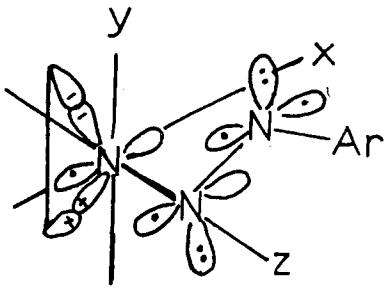
The thermolysis (Table IV) of those N-arylazoaziridines expected to have the larger degree of N_2-N_3 π -overlap II-13 x =NO_2, y=H, x=y=Cl) gave proportionally more cycloelimination and at a faster rate (Table V). Thermolysis of those N-arylazoaziridines expected to have the lowest amount of N_2-N_3 π-overlap (II-13, x=Br, Cl; y=H) resulted in cleavage of the azo linkage (Path 1) at the expense of cycloelimination.

As N_2-N_3 π character increases in the N-arylazoaziridines the triazo group becomes dipolar in character, the 1,3-dipolar resonance hybrid being represented by II-27 (Scheme I). The increased rate of azide formation as well as the increased yield of azide from N-arylazoaziridines II-13d and II-13e in chloroform as compared to benzene (Table IV and V) are readily interpretable in terms of a dipolar transition state in the cycloelimination which is stabilized in the more polar solvent. It is noteworthy that the rate of cycloelimination of nitrous oxide from N-nitrosoaziridines is also increased by increasing solvent polarity[20].

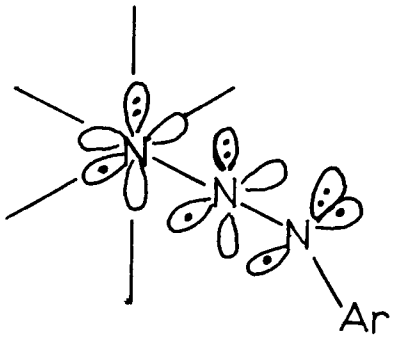
Woodward and Hoffmann have recently[32] pointed out that cycloeliminations which involve concerted cleavage of two σ bonds terminating at a single atom have definite symmetry requirements. In the case of cycloelimination of aryl azide from N-arylazoaziridines the electrons in the

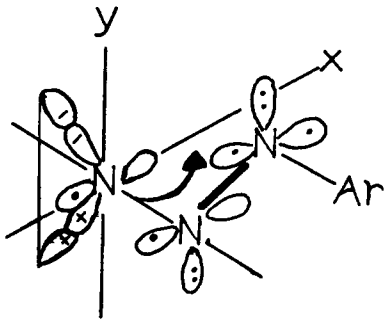
symmetric aziridinyl σ orbital of the two σ bonds undergoing cleavage may be delivered to the π bonding orbital of the alkene maintaining stereospecificity during the reaction. In this event the electrons in the corresponding antisymmetric aziridinyl σ orbital must be delivered with conservation of symmetry to an orbital in the cycloeliminated group, i.e. a y symmetric p or sp orbital on N_3 of the azide. This consideration dictates the direction in which the departing group moves away from the developing alkene in order to preserve maximum bonding during the elimination. Consideration of the present cycloelimination in an invariant coordinate system using conformation II-27 reveals that the departing azide (RN_3)can move away from the developing alkene in three distinct ways: (a) in a linear fashion along the z axis (II-28), (b) in a non-linear fashion in the xz plane II-29, or (c) in the yz plane II-30; each of which allows electrons in the antisymmetric aziridinyl σ orbital to be delivered to an orbital on N_3 of the developing azide possessing the proper symmetry. Only in the case of nonlinear motion in the yz plane are the electrons in the antisymmetrical aziridinyl σ orbital delivered to the nonbonding sp lone pair on N_3 in such a manner as to allow simultaneous development of the yz symmetric 4π system of the azide. This nonlinear mode of reaction

would then appear to be the most energetically favorable in the stereospecific aziridine → alkene transformation observed.

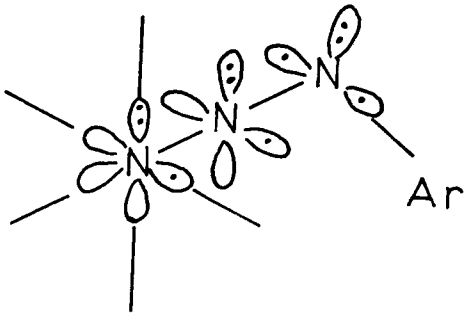


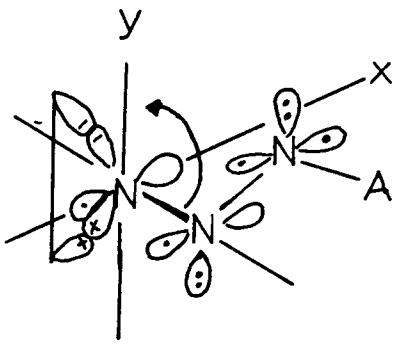
II-28



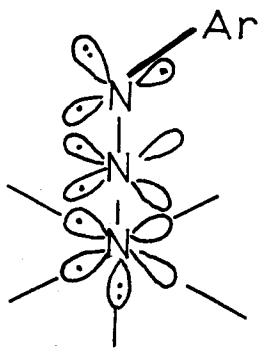


II-29





II-30



Alternatively, conservation of symmetry may be maintained by delivery of the electrons in the symmetric aziridinyl σ orbital to an orbital of proper symmetry on N_3 of the departing azide (this would be of necessity a

z symmetric p or sp orbital). In this event the electrons in the antisymmetric aziridinyl σ orbital would be delivered to the antibonding π orbital of the alkene resulting in a stereorandom aziridine → alkene transformation. Geometric analysis of these alternatives reveals the most energetically favorable mode of cycloelimination is the linear one (i.e. the departing azide moves along the z axis).

By this analysis[32] linear cycloelimination is favored in those cases where the electrons in the antisymmetric σ orbital of the σ bonds undergoing cleavage are delivered to the carbon skeleton of the ring opened species and nonlinear cycloelimination as indicated is favored in those cases where the electrons in this antisymmetric σ orbital are delivered to the cycloeliminated group. In the hope of determining if linearity, as discussed above, is a characteristic of this type of cycloelimination we undertook the investigation of the thermolysis and photolysis of N-arylazoazetidines II-21b and II-21c, N-arylazo-Δ^3-pyrrolines II-22a and II-22c, N-arylazo (and N-nitroso) 2,3-dihydrobenzisoquinolines (II-23b, II-23c and II-23e) and 2,7-dihydrodibenzazepines (II-24b and II-24d). The possible thermal cycloelimination of arylazide from N-arylazoazetidines to produce cyclopropane was of primary interest since if stereochemistry is maintained in the azetidine → cyclopropane transformation the process would be nonlinear by

the above treatment.‡ Our efforts in this direction were completely thwarted by the complete predominance of azo type cleavage (Scheme II, Table VI) in the derivatives studied.

A more intriguing approach to deduction of the linearity or nonlinearity of the present cycloelimination in larger systems was attempted by study of the thermolysis and photolysis of N-arylazo- Δ^3-pyrrolines. The production of butadiene via thermal cycloelimination of arylazide from these derivatives can take place in a conrotatory or disrotatory fashion. If the process in disrotatory the reaction would be predicted to involve linear departure of the azide since the electrons in the symmetric pyrroline σ orbital are delivered to the z symmetric sp lone pair on N_3 of the azide. In this instance the electrons in the antisymmetric pyrroline σ orbital are delivered to the highest occupied (yz antisymmetric) orbital of the butadiene. A conrotatory cycloelimination in this system should, by

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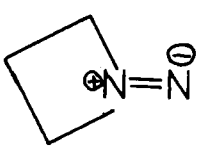
‡ The cycloelimination producing N_2 and cyclopropane from azetidines treated with difluoroamine has been reported[34]. This reaction presumably proceeds via diazene i and should be stereospecific if the nitrogen departs in a nonlinear fashion.



i

the above analysis, involve a nonlinear departure of azide*.

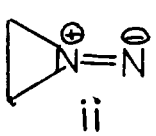
Our efforts in this direction were again completely thwarted by the predominance of azo type cleavage (Scheme II, Table VI) in these derivatives as well as in the N-arylazo (and N-nitroso) 2,3-dihydrobenzisoquinolines and 2,7-dihydrodibenzazepines.

The predominance of azo type cleavage in the N-arylazo-cyloamines possessing rings larger than the N-arylazoaziridines was at first surprising. Cycloelimination was symmetry allowed in each case studied and the extent to which N_2-N_3 π-overlap could occur in the N-arylazocycloamine possessing larger rings was larger than in the N-arylazoaziridines[36]. A consistent and qualitative rational emerges from a consideration of the electronic reorganization occuring during the cycloelimination process. In the simplest description of the electronic reorganization of the N-arylazoaziridines during cycloelimination, for example, the σ C-N Bonds and a sp^3 lone pair on N_3 are transformed into a π C-C bond, a π N_2-N_3 bond, and a sp lone pair on N_3. It

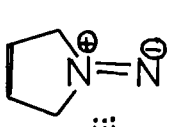
---

*The elimination of N_2 from aziridines treated with difluoroamine produces alkenes stereospecifically. The reaction is presumed to proceed via diazene ii[23] which by the geometric analysis given above must decompose in a non-linear fashion[32].

Similar deamination of Δ^3-pyrrolines give butadiene presumably via diazene iii. The reaction is highly stereospecific and disrotatory[19] suggesting a linear process is favored in this case[32].



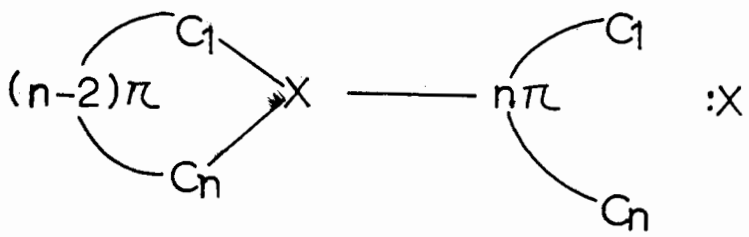
ii



iii

should proceed with most facility in those systems in which the C-N bonds as well as the lone pair on N_3 possess the greatest amount of p character. In such cases π bond formation between the two ring carbons as well as overlap in the 4 π system of the developing azide are more advanced in the reactant. Simultaneously the more energy is available to the system from rehybridization of one of the reactant orbitals to sp on N_3 of the azide.

The geometric analysis[32] applied above implies a direct relationship between the rotatory motion involved in cycloeliminations (e.g. in the Δ^3-pyrroline and 2,7-dihydroazepine systems) and the direction of departure of the cycloeliminated group. A most intriguing question raised by this treatment is whether cycloelimination of type will be characteristically linear or nonlinear. Both paths are symmetry allowed and may be characterized by determining the stereochemical course of reactions in a homologous series, e.g.



Experimental

Preparation of the aziridines:

Ethylenimine was used as supplied by Matheson, Coleman, and Bell. The cis and trans-2-isopropyl-3-methyl aziridines were prepared by the method of Hassner[25] from the cis and trans-4-methyl-2-pentenes supplied by J.T. Baker Chemical Co. The pure aziridines were obtained by this method in 50-60% yield. Each aziridine was shown to be uncontaminated with its geometrical isomer by glpc analysis on column B at 50°. The phenylurethane of the trans-2-isopropyl-3-methyl aziridine had m.p. 67-69°C. Calc. for $C_{13}H_{28}N_2O$: C, 71.53; H, 8.31. Found: C, 71.69; H, 8.27. The phenylurethane of the cis-2-isopropyl-3-methyl aziridine had m.p. 71-73°C. Found: C, 71.47; H, 8.46.

Preparation of N-Arylazoaziridines, II-13a-e.

The N-arylazoaziridines studied were prepared by coupling various substituted aryl diazonium salts with the appropriate aziridine in buffered aqueous solution according to Procedure F of ref.7. Each N-arylazoaziridine was extracted with ether and where possible crystallized from ether-petroleum ether solution. The yield in these coupling reactions ranged from 50-80%. Confirmation of the structure of the N-arylazoaziridines was obtained by conversion of each into the respective 1-aryl-1,2,3 Δ^2-

triazoline by reaction with sodium iodide in acetone[24]. The yields of these conversions were 75-85% after purification of the triazoline product by crystallization. See Table VII.

Thermal Decomposition of N-p-nitrophenylaza-2-isopropyl-3-methylaziridines II-11a and II-11b.

A benzene (15 ml) solution of 0.54 g. of II-12a was heated at reflux for 12 hr. Flash evaporation of the solvent into a cold trap (-70°) yielded 0.307 g. of residue which was chromatographed on 35 g. of neutral alumina. Using petroleum ether (bp 30-60°) as the eluent, 0.281 g. (78.2%) p-nitrophenylazide II-10a was isolated m.p. 71-72.5° (lit[37] mp 74°) mmp with an authentic sample[38] 71-73°. Thin layer chromatographic analysis of the crude reaction mixture revealed the absence of p-nitrobiphenyl, II-16c.

The portion of the reaction mixture which was evaporated into the cold trap was analysed by glpc on column B and revealed the presence of cis-4-methyl-2-pentene, II-12a, and the absence of (< 0.5%) of trans-methyl-2-pentene, II-12b. By comparison of the trap contents with standard solutions of the methyl pentene in benzene the yield of alkene was determined to be 67%.

Decomposition of II-11b in benzene yielded 82% p-nitrophenyl azide, II-10 and 71% trans-4-methyl-2-pentene, II-12b.

TABLE VII.

PROPERTIES OF N-ARYLAZOAZIRIDINES

N-Arylazoaziridine	mp	Aziridinyl Hydrogen (δ_{TMS})	$\lambda_{max}(\log_{10}\epsilon)$ hexane	1,2,3-Δ^2-triazoline isomer m.p.
II-13a	30-31° (Lit.[24] red liquid)	2.07	260(3.93)	100-101.5° (Lit.[24] 99-100.5°)
II-13b	57-58° (Lit.[24] 56-57°)	2.07	263(3.93) 240(4.08)	120-1° (Lit.[24] 121-122°)
II-13c	71-72° (Lit.[7] 70-70.5°)	2.28	287(3.93)	144-145.5° (Lit.[24] 145-146°)
II-13d	45-47° (Lit.[24] 44.5-45.5)	2.16	230(4.17)	99-101° (Lit.[24] 99-100.5°)
II-13e	16-17°	2.19	265(3.72) 238(4.05) 224(4.03)	95-96.5°
II-11a	Red liquid[a]	2.13	292(3.93)	-
II-11b	Red liquid[a]	2.13	291(3.93)	-

a) Repeated attempts to crystallize these compounds failed. Their structure is based on their nmr spectra and on determination of their molecular weight by the cryoscopic method using benzene as a solvent. For II-11a, Found: 235-238; II-11b, Found: 237.239. Calc. for $C_{12}H_{16}N_4O_2$: 248.

Thermal Decomposition of N-**p-nitro**phenylazoaziridine, II-13c, in Benzene

A benzene solution (10 ml) of 0.482 g. of II-13c was refluxed until infrared spectral analysis revealed the concentration of p-nitrophenyl azide (2090 and 2135 cm^{-1}) to be constant (6 hr). The solution was refluxed for an additional 6 hr after which time infrared revealed no change in azide concentration. The solvent was removed under vacuum to give a reddish residue (0.42 g) which crystallized (mp 69-74°) on standing. A portion (0.35 g) of the residue was chromatographed on 40 g of neutral alumina. Elution with pet ether (b.p. 30-60°) gave 0.30 g (87%) p-nitrophenyl azide m.p. 71-72°, (lit[38] m.p. 71-73°). Thin layer chromatographic analysis of the crude reaction mixture revealed the absence of p-nitrobiphenyl. The yield of p-nitrophenyl azide calculated in the reaction mixture by use of the 2090 and 2135 cm^{-1} absorptions from a Beer's law analysis was 91%.

Thermal Decomposition of N-Arylazoaziridines, II-13a, b, d and e in Benzene.

The decomposition of II-13a, b, d and e was carried out in the manner described above for II-13c using 0.5 g - 0.75 g samples in 10-15 ml of benzene. The decomposition vessel was equipped with a side arm venting to

a flask containing a benzene solution of phenyl isocyanate. The reaction was run under a N_2 gas purge. In this manner the ethylenimine formed was swept into the isocyanate solution. The N-aziridinyl-N-phenylurethane, II-17, formed was isolated by crystallization, m.p. 75-77°C. The yields for each reaction are reported in Table IV. Compound II-17 had mmp 75-77.5° with authentic sample (mp 77)78.5°) prepared from ethylenimine and phenyl isocyanate. Calc. for $C_9H_{10}NO_2$: Found: C, 66.83; H, 6.37.

The non-volatile reaction products were concentrated and chromatographed on neutral alumina. Elution with petroleum ether (b.p. 30-60°) gave aryl azides which were identified by comparison with authentic sample prepared by treatment of the corresponding aniline derivative with nitrous acid then sodium azide (Table VIII). Elution with petroleum ether: ether, 9:1 gave biphenyl derivatives which were identified by comparison of their U.V. spectra and mp with literature values. The yields of each of these products are recorded in Table IV. Each aryl azide was independently demonstrated to be stable under the reaction conditions. Glpc analysis of the crude reaction mixture on column A indicated the absence of (<2%) of biphenyl in each pyrolysate. Similarly the pyrolysates of III-13a and II-13b were shown to contain no 4, 4-dichlorobiphenyl

TABLE VIII.

IDENTIFICATION OF PRODUCTS OF THERMAL DECOMPOSITION OF II-13a, b, d AND e IN BENZENE

N-arylazoaziridine	aryl azide	biphenyl derivative, λ_{max}($\log_{10}\epsilon$) methanol
II-13a	II-14a, m.p. 17-18° (Lit.[39] liq.)	II-16a, m.p. 74-76°; 253(4.35), 212_4.41) (Lit.[40] m.p. 77°) [Lit.[31] 252(4.34)]
II-13b	II-14b, m.p. 20-21°	II-16b, m.p. 90-92°; 255(4.32), 213(4.38) (Lit.[40] m.p. 91°)
II-13d	II-14d, m.p. 67-68.5°	II-16d, m.p. 60-62°; 248(4.51), 209(4.39) (Lit.[41] m.p. 61-62°)
II-13e	II-14e, m.p. 27-28.5°	II-16e, m.p. 44-45°; 256(4.29), 211(4.32) (Lit.[42] m.p. 46°)

or 4, 4-dibromobiphenyl respectively. The N-arylaziridines corresponding to loss of nitrogen from II-13a, b, d, e were shown by glpc analysis (Column A) to be absent from the reaction mixtures and were independently shown to be stable in refluxing benzene.

Thermal Decomposition of N-Arylazoaziridines II-13 in Chloroform

The typical procedure for the isolation of the products of the thermal decomposition of the N-arylazoaziridines in chloroform is illustrated below.

A chloroform solution (10 ml) of 1.1 g of II-13 was refluxed for 2 hr. During this time the reaction vessel was purged with N_2 gas, the effluent being carried via a side arm to a flask containing a benzene solution of phenylisocyanate. Work up of the benzene solution after the thermal decomposition was complete, revealed no N-aziridinyl-N'-phenylurethane, II-17, had been formed in an case. The decomposition of II-13 was followed by infrared analysis in the 2090-2135 cm^{-1} region. After 2 hr, ir analysis revealed that in all cases the production of azide had stopped. Refluxing the solution for an additional 2 hr did not alter the amount of azide. The reaction was allowed to reflux for an additional 10 hrs. after which time the solvent was removed in vacuo. Nmr analysis of the nonvolatile residue

TABLE IX.

SPECTRAL CHARACTERISTICS OF N-2-CHLOROETHYL ANILINES

N-2-chloroethyl aniline	ir(CCl_4) cm^{-1}, (Free base)	nmr($CDCl_3$) δ,(Free base)	Mass Spec. m/e			
			Calc.		Found	
			(M-36)	$\frac{(M-34)^+}{(M+36)}$	$(M-36)^+$	$\frac{(M-34)^+}{(M+36)^+}$
II-19a HCl salt, mp 138-140.5°	3400(N-H), 1600,1495 (arom) 1255(C-N), 827(arom)	3.41(m,4H) 3.89(b,NH)[a] 6.35-7.33(m,4H)	189	0.641	189	0.654
II-19b HCl salt, mp. 143-145°	3400(N-H), 1595,1495 (arom) 1260(C-N),815(arom)	3.47(m,4H) 3.83(b,NH)[a] 6.32-7.22(m,4H)	233	1.250	233	1.304
II-19d HCl salt mp 149-151.5°	3400(N-H), 1605,1485 (NO_2,arom), 1258(C-N), 850,820(arom)	2.48(s,3H) 3.51(m,4H) 4.63(b,NH)[a] 6.47-7.73(m,3H)	214	0.327	214	0.332
II-19e HCl salt mp. 130-132°	3400(N-H), 1600,1485(arom) 1240(C-N), 805(arom)	3.56(m,5H)[b] 6.35-31(m,3H)	223	0.971	223	0.966

a=D_2O Exchange, b, 1H-D_2O exchangeable

revealed that all the N-arylazoaziridine has been consumed. Analysis of the residue by glpc on column A using a linear temperature program rate of 10°C min from 60° to 250° revealed the presence of arene, aryl azide and a third component which was isolated by column chromatography as described below.

A portion of the reaction mixture was chromatographed on ~60 g. of neutral alumina. Using petroleum ether (b.p. 30-60°) as the eluent the aryl azide and arene were eluted together. Glpc analyses on column A using comparison with standard solutions revealed the composition of the mixture. Elution with petroleum ether:ether (3:1) gave the N-2-chloroethylanilines (II-19), the structures of which were confirmed by their spectral properties (Table IX) and by comparison with an authentic sample prepared by the method of Heine[24].

Photodecomposition of N-p-chlorophenyl azoaziridine II-13a in Benzene

A benzene solution (100 ml) of II-13a (1.5 g) was irradiated with a 250 watt medium pressure Hanovia mercury lamp through a Pyrex filter for 1.5 hr. During this time the solution was purged with N_2 gas, the effluent being passed through a benzene solution of phenyl isocyanate. Work up of this solution after the photoreaction was complete, gave only a few mg of N-aziridinyl-N'-phenyl-urethane (II-17). The solvent was removed from the photoreaction in

vacuo. Infrared analysis of the residue revealed no azide absorption. Glpc analysis of the mixture on column A showed no presence of chlorobenzene (17%), p-chlorobiphenyl (47%), and N-p-chlorophenylaziridine (28%); (bp 65-67° 0.5 mm). The structure of the latter compound was ascertained from its spectra: ir (thin film), 3010(C-H, 1595, 1490 (aromatic), 1325, 1095 (C-N), and 843 cm^{-1} (1,4-disubstituted benzene ring); nmr ($CDCl_3$) δ1.86 (s, 4H), 6.66-7.10 (m, 4H, aromatic). Mass spec. (M+)=153, $(M+2)^+/(M^+)$=0.30. This compound was identical in all respects to the product formed upon photodecomposition of 1,2,3-Δ^2-triazoline (II-20a) in benzene, a reaction known to lead to N-aryl-aziridinyl products in high yield[26].

Kinetic Procedure for the Determination of the Rate of Azide Production from the N-Arylazoaziridines, II-13.

Sealed Tube Method: Solutions of N-arylazo-aziridine (II-13) 0.05-0.1M in benzene (or chloroform) were prepared, at room temperature and transferred to small open tubes. These tubes were immediately cooled to -70°C and sealed. Infrared analysis of the freshly prepared solution revealed no azide absorption. All but three of the tubes (which were retained for zero calculations) were allowed to warm to room temperature after which time they were placed in a constant temperature bath. Ten to twelve sets of three tubes were withdrawn at regular intervals and analysed by infrared using balanced solution

cells. The analysis was performed between 2090 and 2135 cm^{-1}, a region where solvent and other products did not absorb. A typical run involved a change in absorbance of 0.65. The rate of aryl azide production was calculated by comparison of the 2090-2135 cm^{-1} absorption intensity with that of solutions of known concentration of the same aryl azide in the same solvent (e.g. Fig. 4). The reactions followed good first-order kinetics on duplicate runs log a/ (a-x) vs t to 45% reaction then showed definite negative deviations. It was assumed that the azide and ethylene formed were reacting. This assumption was apparently justified when no such deviation was observed when the reactions were run in open vessels as described below.

Open Vessel Method: Solutions of the N-arylazo-aziridines 0.50-0.1M benzene or chloroform were made at room temperature under a N_2 gas blanket and immediately immersed in constant temperature baths. After the temperature of the reaction reached the bath temperature zero time readings were taken and thereafter 10-12 sets of duplicate samples were withdrawn and analyzed by infrared as described above. The rate of azide production from the N-arylazoaziridines was cleanly first-order (e.g. Fig. 5).

Preparation of N-arylazoazetidines, II-21b,c

N-(p-bromophenylazo)-azetidine, II-21b

A solution of p-bromoaniline in 12N HCl (10 ml) and water (10 ml) was treated with sodium nitrite

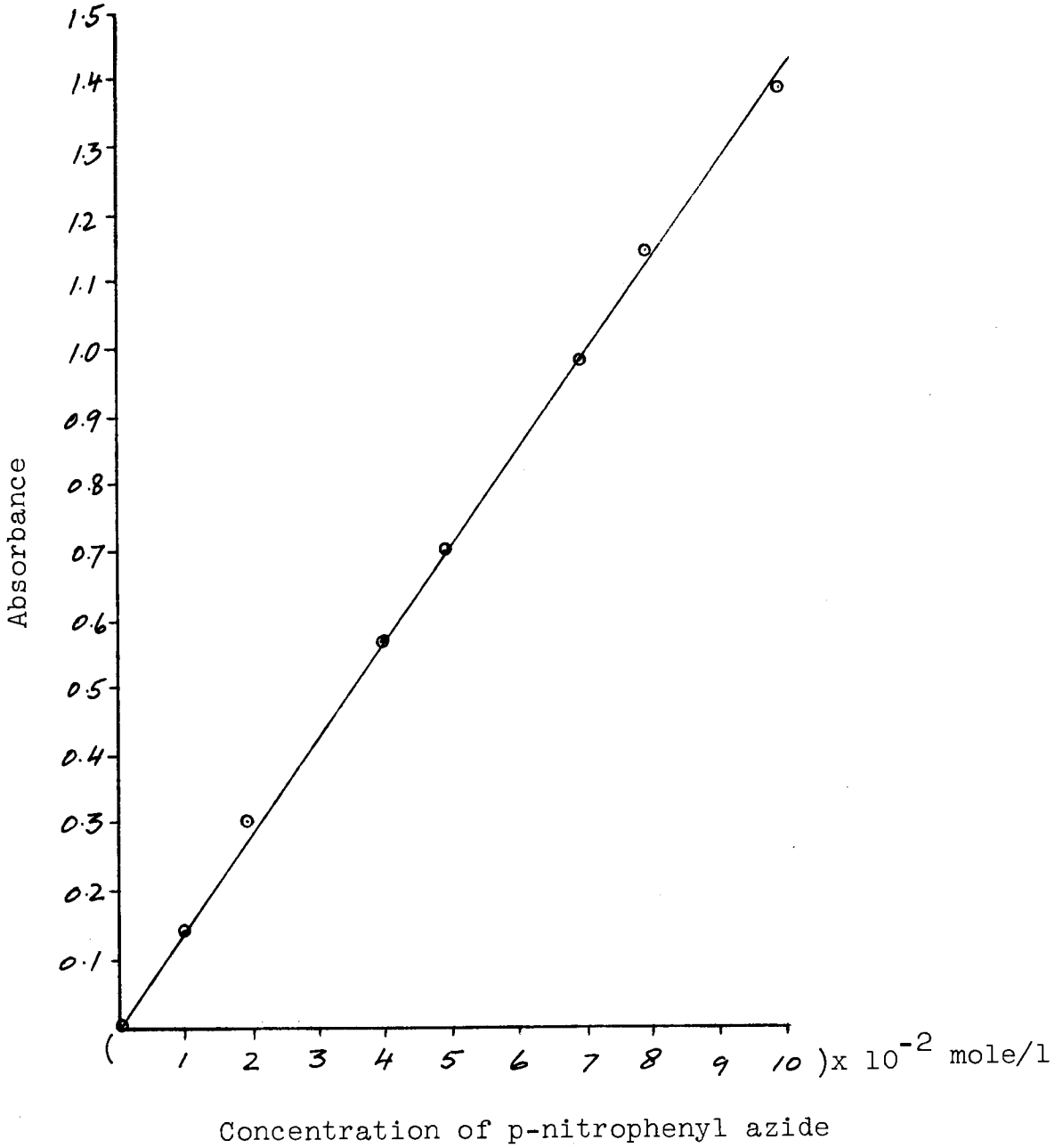


Fig. 4: A plot of absorbance (infrared) vs the concentration of p-nitrophenyl azide in benzene

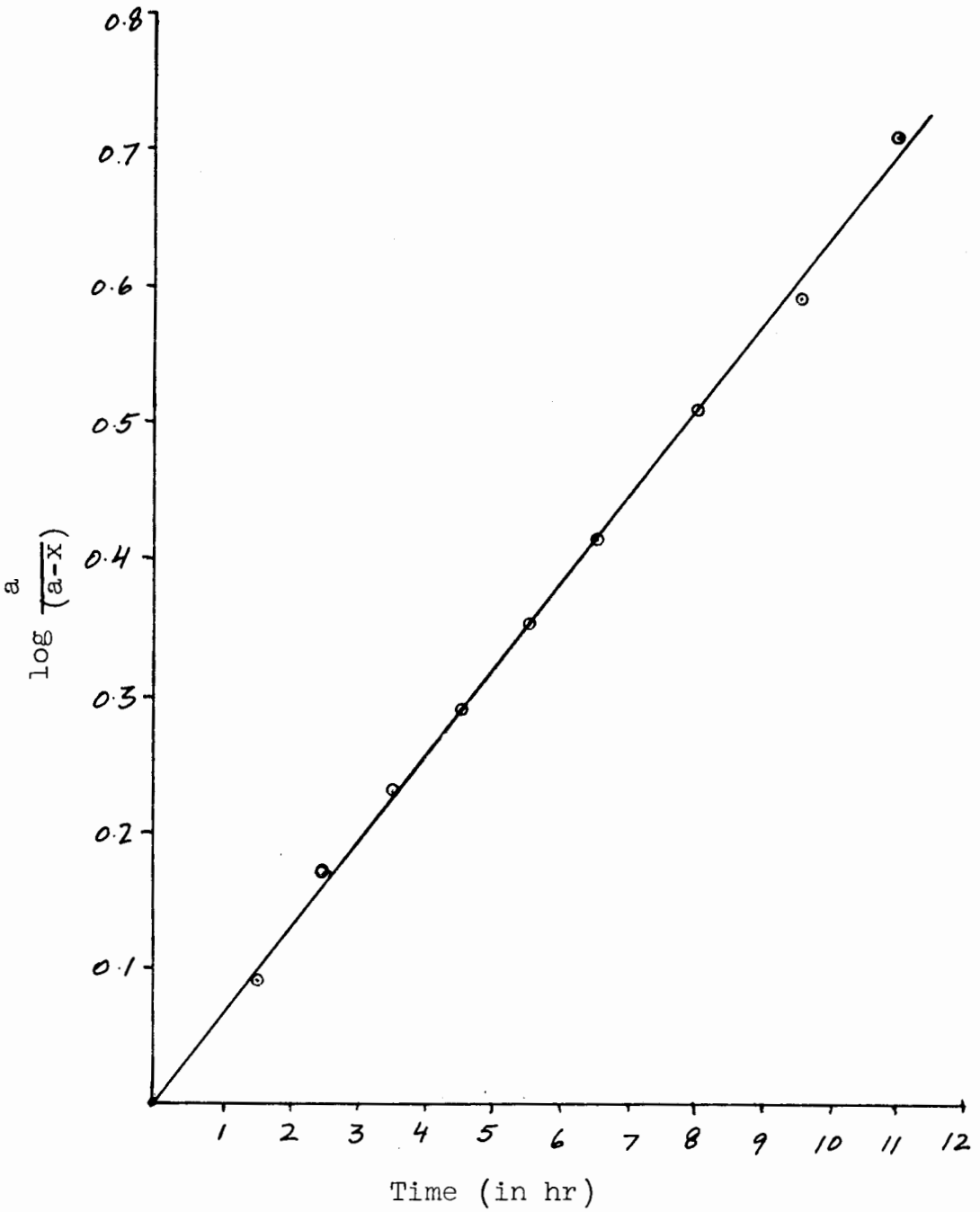


Fig. 5: A plot of the rate of formation of p-nitrophenyl azide on thermal decomposition of N-p-nitrophenylazoaziridine (II-13c) in benzene at 70°.

(1.4 g) at 0-5°. After 10 minutes a saturated sodium acetate solution was added until the pH of the reaction mixture was maintained at 5.9-6.0. The solution was then treated with decolorizing charcoal and filtered. Addition of azetidine[43], II-21a, (1.5 M excess) to this solution gave a thick ppt which was filtered, washed with water, and dried to give 3.3 g (69%) N-p-bromophenylazoazetidine (II-21b), mp 71-74°. Recrystallization from methanol gave: mp 73-74°; ir (KBr) 2920, 2850 (C-H), 1470 (aromatic), 1402, 1380 (azo linkage), and 30 cm^{-1} (1,4-disubstituted benzene ring); nmr ($CDCl_3$) δ 2.39 (quintet, 2H, J = 7.5 Hz); 4.19 (t, 4H, J = 7.5 Hz), 7.15-7.51 (m, 4H, aromatic), U.V. (CH_3OH) m μ (ε) 320 (log 4.23), 292 (log 4.21).
Calc: for $C_9H_{10}BrN_3$: 239 (M^+); $(M+2)^+ / (M^+)$ = 0.98
Found: Mass spec. 239 (M^+); $(M+2)^+ / (M^+)$ = 0.99.

The preparation of N-p-nitrophenylazoazetidine (II-21c) was effected in 83% yield by the above procedure from p-nitroaniline and azetidine; mp 148-149°; ir (KBr) 2950, 2860 (C-H, 1585, 1510 (nitro and aromatic), 1410, 1394 (azo linkage) and 843 cm^{-1} (1,4) disubstituted benzene ring); nmr ($CDCl_3$, δ 2.41 (quintet, 2H, J = 7.5 Hz), 4.41 (t. 4H, J = 7.5 Hz), and 6.67-8.21 (m, 4H, aromatic); UV (CH_3OH), m μ (ε) 340 (log 4.27); and 275 (log 4.24).
Calc: for $C_9H_{10}N_4O_2$: 206 (M^+); $(M+1)^+ / M^+$ = 0.114
Found: Mass spec. 206 (M^+), $(M+1)^+ / M^+$ = 0.118.

Preparation of N-arylazo-3-pyrroline, II-22b-c

The N-(p-chlorophenylazo)-3-pyrroline (II-22b) was prepared in 81% yield from p-chlorobenzenediazonium chloride and Δ^3-pyrroline, II-22a, (Aldrich Chemical Co.) Recrystallization from methanol-pet ether gave: mp 97-98°, ir (KBr) 2940, 2860 (C-H), 1487 (aromatic), 1430, 1403 (azo linkage), and 840 cm^{-1} (1,4-disubstituted benzene ring); nmr ($CDCl_3$) δ4.47 (s, 4H), 5.88 (s, 2H), and 7.25 (s, 4H, aromatic).

Calc: for $C_{10}H_{10}ClN_3$: 207 (M^+), $(M+2)^+ / M^+ = 0.37$.

Found: Mass spec. 207 (M^+), $(M+2)^+ / M^+ = 0.35$

The N-(p-nitrophenylazo) 3-pyrroline (II-22c) was prepared by a similar procedure in 77% yield: mp 201-202°; ir (KBr) 2900, 2850 (C-H), 1590, 1510 (nitro and aromatic) 1405, 1398 (azo linkage), and 850 (1,4-disubstituted benzene ring); nmr (CF_3COOH) 4.10 (s, 4H), 5.71 (s, 2H), and 7.21-8.11 (m, 4H, aromatic)

Calc: for $C_{10}H_{10}N_4O_2$: 218 (M^+); $(M+2)^+ / M^+ = 0.011$

Found: Mass spec. 218 (M^+); $(M+2)^+ / M^+ = 0.009$.

Preparation of N-(p-chlorophenyl)-3-pyrroline, II-22d

A benzene solution (90 ml) of 4.1 g of cis-1,4-dichloro-2-butene[100], p-chloroaniline (3.8 g) and triethylamine (10 g) was stirred at 40-45° for 25 hr. The ppt of triethylamine hydrochloride was removed by filtration.

The supernatant was washed first with 5% HCl and then with cold water. The organic layer was dried, the drying agent was removed by filtration, then the solvent was removed to give 2.8 g (53%) II-22d, mp 109-112°. Recrystallization from methanol gave: mp 113-114.5°; ir (KBr) 2830 (C-H), 1603, 1505 (aromatic), 1260 (C-n), and 810 cm^{-1} (1,4) disubstituted benzene ring); nmr ($CDCl_3$) δ3.95 (s, 4H), 5.81 (s, 2H), and 7.10-7.42 (m, 4H, aromatic).

Calc: for $C_{10}H_{10}ClN$: 179 (M^+); $(M+2)^+ / (M^+)$ = 0.37.

Found: Mass spec. 179 (M^+); $(M+2)^+ / M^+$ = 0.36.

Preparation of N-arylazo-2,3-dihydro-1H-benz-(de) isoquinolines, II-23 b,c

The N-(phenyl)-2,3-dihydro-1H-benz-(de)isoquinoline (II-23 b) was prepared in 77% from benzenediazonium chloride and 2,3-dihydro-1H-benz-(de)isoquinoline[44] (II-23a) in the manner described for the preparation of N-arylazoazetidines. Recrystallization from methanol gave: mp 103-104.5°; ir (KBr) 3020, 2850 (C-H), 1603, 1510, 1495 (aromatic), 1430, 1402 (azo linkage), 808.775 (naphthyl ring); and 695 cm^{-1} (bromo substituted benzene ring); nmr ($CDCl_3$) δ 5.10 (s, 4H), and 7.05-7.66 (m, 11H, aromatic); UV (CH_3OH), m μ(ε) 299 (log 4.33).

Calc: for $C_{18}H_{15}N_3$: 273 (M^+); $(M+1)^+ / (M^+)$ = 0.209; $(M+2)^+ M^+$ = 0.022

Found: Mass spec. 273 (M^+); $(M+1)^+ / (M^+)$ = 0.211; $(M+2)^+ M^+$ = 0.025.

The N-(p-nitrophenylazo)-2,3-dihydro-1H-benz-(de) isoquinoline (II-23c) was prepared in 80% yield in the manner described above for II-23b. Recrystallization from methanol gave: mp 183-184°; ir (KBr) 2900 (C-H); 1580, 1510 (nitro and aromatic), 1422, 1410, 1395 (azo linkage); 850 (1,4-disubstituted benzene ring); 810, and 787 cm^{-1} (naphthyl ring); nmr ($CDCl_3$) δ 5.54 (s, 4H), and 6.84-7.94 (m, 10 H, aromatic).

Calc: for $C_{18}H_{15}N_4O_2$: 319 (M^+); $(M+2)^+/(M^+)$ = 0.023.

Found: Mass spec. 319 (M^+); $(M+2)^+/M^+$ = 0.024.

Preparation of N-aryl-2,3-dihydro-1H-benz-(de)isoquinoline, II-23d,e

N-(phenyl)-2,3-dihydro)1H-benz-(de)isoquinoline, II-23d

To a warm (40-45°) benzene solution (25 ml) of 1,8-bis(bromomethyl)-naphthalene[44] (2.1 g) was added to benzene (15 ml) containing aniline (1.8 g) over a period of 20 min. After the addition was completed, the solution was allowed to reflux for 12 hr. After this time aniline hydrobromide was removed by filtration, the supernatant was washed with two (10 ml) portions of 5% HCl then with water. The organic layer was separated, dried and concentrated in vacuo. The residue remaining after removal of the solvent, 1.2 g (74%) solidified upon standing. Recrystallization from ether-pet ether gave orange plates; mp 52-53° (Lit[45] mp 57-58°); ir (KBr) 3005 (C-H), 1605, 1500, 1455

(aromatic), 810, 70 (naphthyl ring), and 680 cm^{-1} (mono-substituted benzene ring); nmr ($CDCl_3$), δ 4.48 (s, 4H), and 6.71-7.59 (m, 15H, aromatic).

Preparation of N-(p-chlorophenylazo)-2,7-dihydro-3H,5,7-dibenzazepine, II-24b

The N-(p-chlorophenylazo)-2,7-dihydro-3,4,5,7-dibenzazepine, II-24b, was prepared in 50% yield from p-chlorobenzenediazonium chloride and the hydrochloride of 1H-2,7-dihydro-3,4,5,7-dihydrobenzazepine[46], II-24a, in the manner described for the preparation of N-arylazoazetidines. Recrystallization from methanol-pet ether gave: mp 114-115.5°; ir (KBr) 3010, 2920 (C-H), 1495 (aromatic), 1420, 1392 (azo linkage), and 835 cm^{-1} (1,4)disubstituted benzene ring); nmr ($CDCl_3$) δ 4.56 (s, 4H), and 7.05-7.43 (m, 12H, aromatic); UV (CH_3OH), $m\mu$ (ε) 316 (log 4.40), and 288 (log 4.41).

Calc: for $C_{20}H_{16}N_3Cl$: 333 (M^+); $(M+2)^+ / (M^+)$ = 0.340

Found: Mass spec. 333 (M^+); $(M+2)^+ / M^+$ = 0.338

Preparation of N-(p-chlorophenyl)-2,7-dihydro-3,4,5,7-dibenzazepine II-24c

A benzene solution (45 ml) of 2,2 -bis(bromomethyl) biphenyl[47] (2.0 g) and p-chloroaniline (2.3 g) was refluxed overnight. The solution was filtered and the supernatant washed with water, dried, and the solvent was evaporated in vacuo. Recrystallization of the residue from methanol-pet ether gave 1.4 g (78%) of II-24c; mp 147-148.5°

(Lit[48] mp 147-9°); ir (KBr) 2940, 2830 (C-H), 1590, 1565, 1500 (aromatic), 1357, 1305 (C-N), and 830 cm^{-1} (1,4-disubstituted benzene ring); nmr ($CDCl_3$) δ 4.08, (s, 4H), and 6.73-7.43 (m, 12H, aromatic).

Preparation of N-nitroso-2,7-dihydro-3,4,5,7-dibenzazepine, II-24d

To a suspension of II-24a hydrochloride (4.5 g) in water (5 ml) and glacial acetic acid (50 ml) was added solium nitrite (3.5 g) in water (10 ml). Spontaneous warming occurred and the suspended hydrochloride gradually dissolved. The reaction was allowed to stand at room temperature for 1.5 hr then diluted with water (200 ml) to ppt the N-nitrosoaniline, 3.2 g (73%). Recrystallization of II-24d from hot ethanol gave: mp 109-110.5°; ir (KBr) 3050 (C-H), 1490, 1450 (aromatic), 1428, 1350 (N-nitroso), and 755 cm^{-1} (1,2-disubstituted benzene ring); nmr ($CDCl_3$) 4.51 (s, 2H), 5.10 (s, 2H), and 7.20-7.55 (m, 8H); UV (CH_3OH) $m_\mu(\varepsilon)$ 347 (log 2.0).

Calc: for $C_{14}H_{12}N_2O$: 224 (M^+); $(M+1)^+/(M^+)$ = 0.161, $(M+2)^+/(M^+)$ = 0.014.

Found: Mass spec. 224 (M^+); $(M+1)^+/(M^+)$ = 0.161, $(M+2)^+/(M^+)$ = 0.015

Thermal Decomposition of the N-arylazo derivative of the cyclic amines, II-21b-II-24b.

Benzene solutions 10% in N-arylazoamine were heated in sealed tubes at 170-200° for 8-12 hr. After this time the tubes were cooled, opened, and the contents analyzed by infrared and glpc on columns A and C using temperature program rate of 10° min. from 60° to 250° and 60° to 190°, respectively. The products of each reaction were determined by mixed injection comparison with authentic samples described above. In the case of identification of N-p-bromophenyl-azetidine II-21d comparison was made with the sample of II-21d prepared from irradiation of II-21b as described below. The product yields were determined by comparison of peak areas generated upon injection of standard solutions of pure sample of each product with those obtained from injection of the reaction mixture. The product yields from decomposition of the N-arylazoamines given in Table VI are averaged for duplicate runs which were reproducible within ± 2%.

Photolysis of N-(p-bromophenylazo)azetidine, 21b.

A sample of N-(p-bromophenylazo)azetidine (1.0 g) was dissolved in anhydrous benzene (100 ml) and was irradiated under nitrogen atmosphere with a 250 watt Hanovia lamp for 10 hr. The excess solvent, removed under vacuum, was collected at -30°C. The nmr of the red residue indicated the complete consumption of the azoazetidine. Analysis of the mixture on column A showed the presence of bromo-

benzene, p-bromobiphenyl, a small amount of p-bromoaniline, and an unidentified product. A fraction (750 mg) of the mixture was chromatographed on 45 g of neutral alumina using 30-60 pet-ether as the eluent. The 30-60 pet-ether fraction gave bromobenzene (120 mg, 20%), further elution with 10% benzene-pet ether gave a pale yellow compound, p-bromobiphenyl (380 mg, 41%), mp 87-9°C. Further elution with 20% benzene-pet ether gave a yellow liquid, (220 mg, 25%), which solidified on cooling, mp 39-42°C. Recrystallization of this solid from pet-ether gave: mp 42-43.5°; ir (KBr) 3020, 2950 (C-H), 1600, 1470 (aromatic), 1290 (C-N), and 835 (1,4-disubstituted benzene ring); nmr ($CDCl_3$) δ 2.99 (quintet, 2H, J = 7.2 Hz), 3.97 (t, 4H, J = 7.2 Hz), and 6.75-7.45 (m, 4H, aromatic).

Calc: for $C_9H_{10}BrN$: 211 (M^+), $(M+2)^+ / M^+ = 0.98$

Found: Mass spec. 211 (M^+), $(M+2)^+ / M^+) = 0.075$

On the basis of the observed spectra the solid was assigned the structure II-21d. Attempted preparation from 1,3-dibromopropane and p-bromoaniline was unsuccessful. The solvent evaporated from the above photolysis reaction was treated with phenyl isocyanate. Work up in the usual manner gave: 198 mg (30%) of N-azetidinyl-N'-phenylurea, mp 189-191°, m mp 189-191°C with an authentic sample prepared from azetidine and phenyl isocyanate.

Photodecomposition of N-arylazoderivatives of the cyclic amines, II-22b-II-24b

Benzene solutions 1-2% in N-arylazoamine were irradiated in Pyrex under nitrogen with a 250 watt Hanovia medium pressure mercury lamp for 12-18 hr. After this time the solvent was removed in vacuo and the reaction mixture was analyzed by glpc on columns A and C as described above for the thermal decomposition. The yield of II-22a was obtained by treating the solvent removed from the photolysate with phenyl isocyanate as described above for azetidine. The yields are recorded in Table VI.

Attempted thermal decomposition of N-nitrosocycloamines, II-23e and II-24d

A solution of II-24d (110 mg) in o-xylene (10 ml) was refluxed for 47 hr. Upon cooling and evaporation of the solvent, 85 mg II-24d was recovered.

This experiment was repeated using II-23e (100 mg) in o-xylene (110 mg) at reflux for 47 hr. Evaporation of the solvent gave 90 mg II-23e. Analysis of the crude reaction mixtures by glpc on column A in both cases failed to reveal any accnaphthene or 9,10-dihydrophenanthrene.

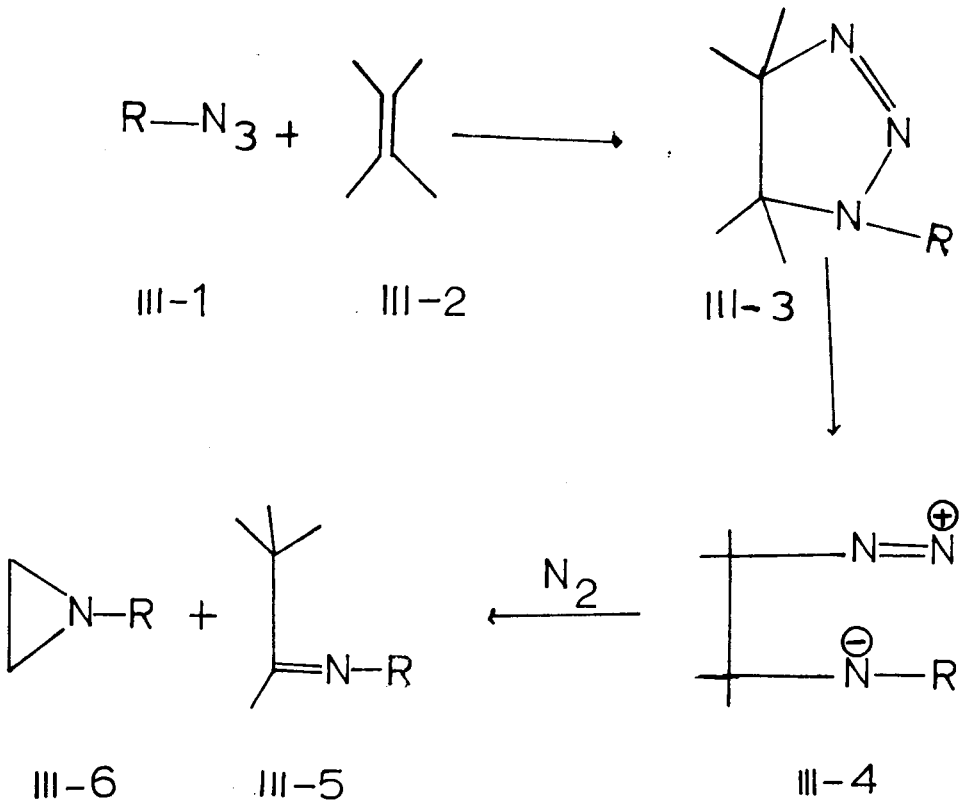
CHAPTER III

CYCLOADDITION OF AZIRIDINES TO 2 π AND 4 π SYSTEMS

Introduction

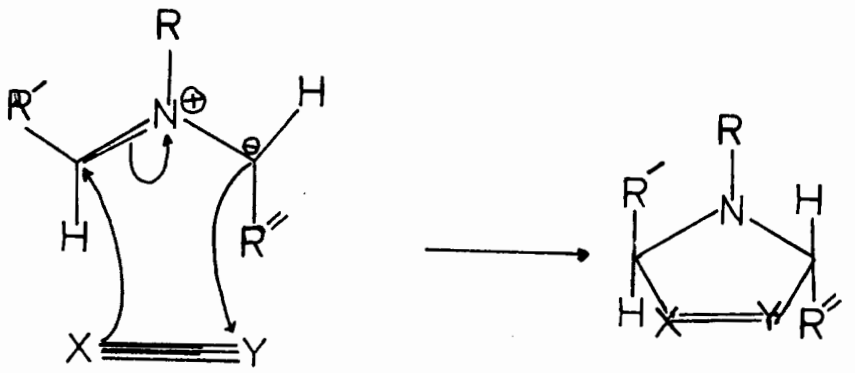
In recent years the chemistry of aziridines has received considerable attention. Although there have been developed several novel synthetic methods for the N-unsubstituted, N-halo-, and N-alkylaziridines,[49] the 1,3-dipolarcycloaddition of aryl azides to alkenes is still the best procedure for the preparation of N-arylaziridines. In general, reaction of aryl azides with alkenes results in the formation of 1,2,3-Δ^2-triazolines which can be decomposed with loss of a molecular nitrogen to yield aziridine and imine.[50] The rate of 1,3-dipolarcycloaddition of aryl azide is enhanced by electron-withdrawing groups attached to the aryl ring[51] or by electron-donating substituents on the olefin participant.[26]

The thermal decomposition of 1,2,3-Δ^2-triazolines affords mixtures of aziridine and imine products.[50] The relative amounts of these two product types is greatly affected by aryl substituents as well as the alkene precursor substituents. Electron-donating groups attached to the aryl ring favor high yields of aziridines, whereas highly electron-withdrawing substituents favor the formation of imine.[36] The photodecomposition of 1,2,3-Δ^2-triazolines affords nearly quantitative yields of aziridines.[26,36]



The primary reactions of aziridines involve the reaction of the ring nitrogen as a basic function and cleavage of the strained three-membered ring. The aziridinyl nitrogen is in general a weaker base than are secondary or tertiary aliphatic amines since the lone pair has more s-character. Recations due to the strained three-membered ring involve ring opening either by C,N bond or by C,C bond cleavage to give acyclic or ring expanded producta. A discussion of C,N bond cleavage is presented in Chapter II. The present discussion is limited to examples involving C,C bond cleavage and subsequent

addition of the ring opened species to carbon-carbon and heteromultiple bonds. The cleavage of the C,C bond of

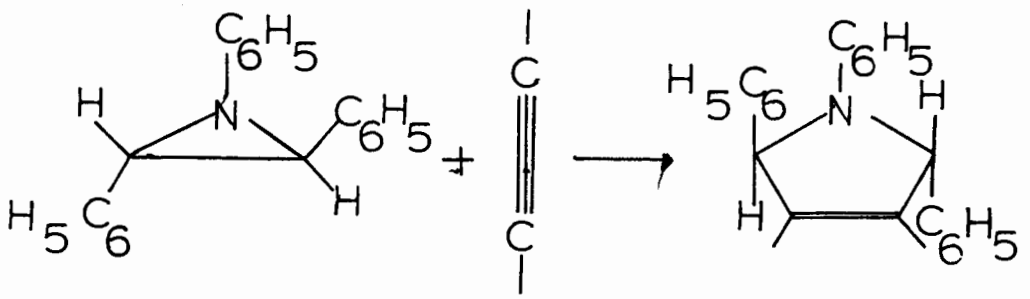


III-8 III-9

aziridine is in general promoted by ring carbon substituents which can support a negative charge in a conjugative fashion (e.g., carbonyl, aryl).

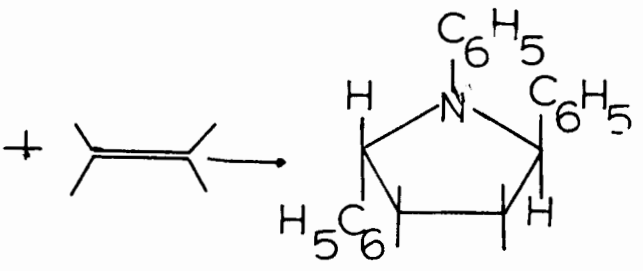
The reactions of substituted aziridines involving cleavage of C,C bond and subsequent addition to carbon-carbon, and heteromultiple bonds are useful synthetic routes to pyrrole,[52-55] pyrrolidines,[52,55,57,59,60,67,68,71] pyrrolines,[52,56,59,60,68,69,71] thiazolines,[61,62] imidazolines,[63,64] and oxazolidines.[58,65,66]

Heine and Peavy[52] were the first to show that heating 1,2,3-triphenylaziridines (III-10) in the presence of alkynes and alkenes results in a cycloaddition reaction yielding pyrrolines (III-11) and pyrrolidines (III-12), respectively. Padwa and Hamilton[54,55] have reported that



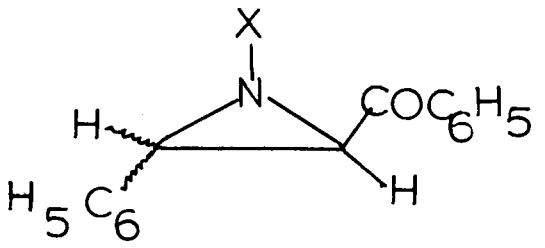
III-10

III-11

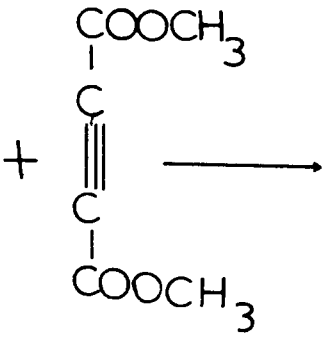


III-12

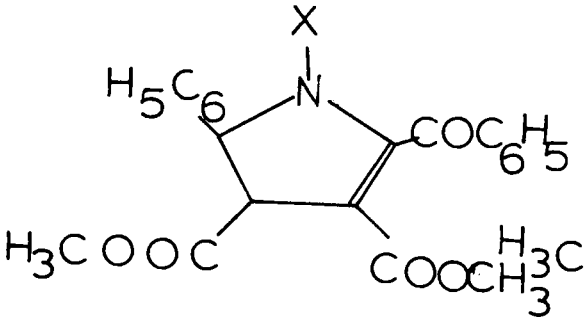
the reactions of aziridines III-13 with dimethyl acetylenedicarboxylate (III-14) gave a mixture of Δ^2- pyrroline, III-15, and a substituted pyrrole III-16, presumably through a Δ^3-pyrroline intermediate.



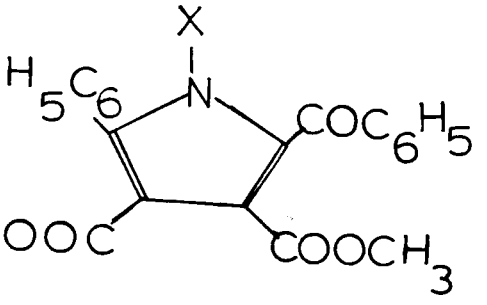
III-13a, X = H
b, X = c-C_6H_{11}



III-14

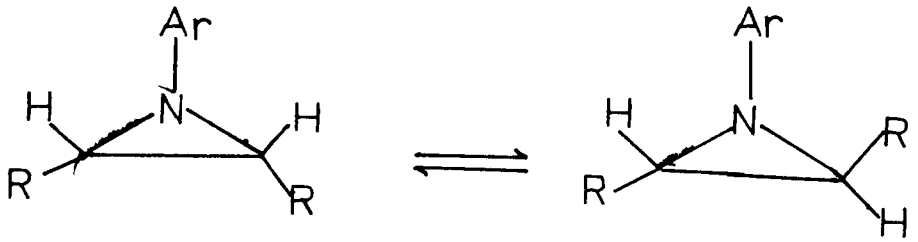


III-15



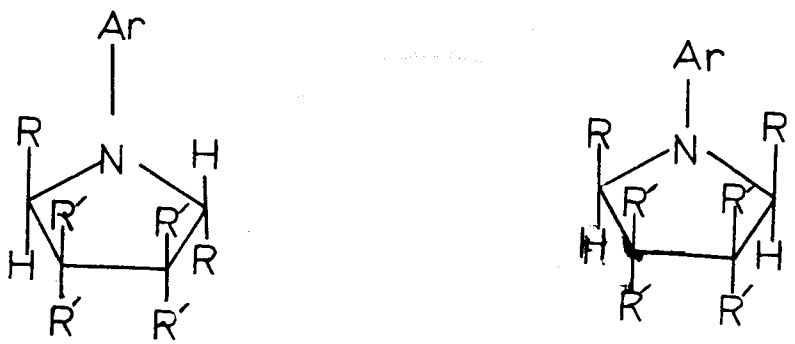
III-16

Huisgen and co-workers[56,57] have contributed to the understanding of the nature of the intermediate involved in the cycloaddition reaction of aziridines to alkenes and alkynes. They observed that although aziridines III-17a and III-17b were stable at room temperature, they equilibrated at 100°C. Furthermore, reaction of a 15:85



III-17a

III-17b

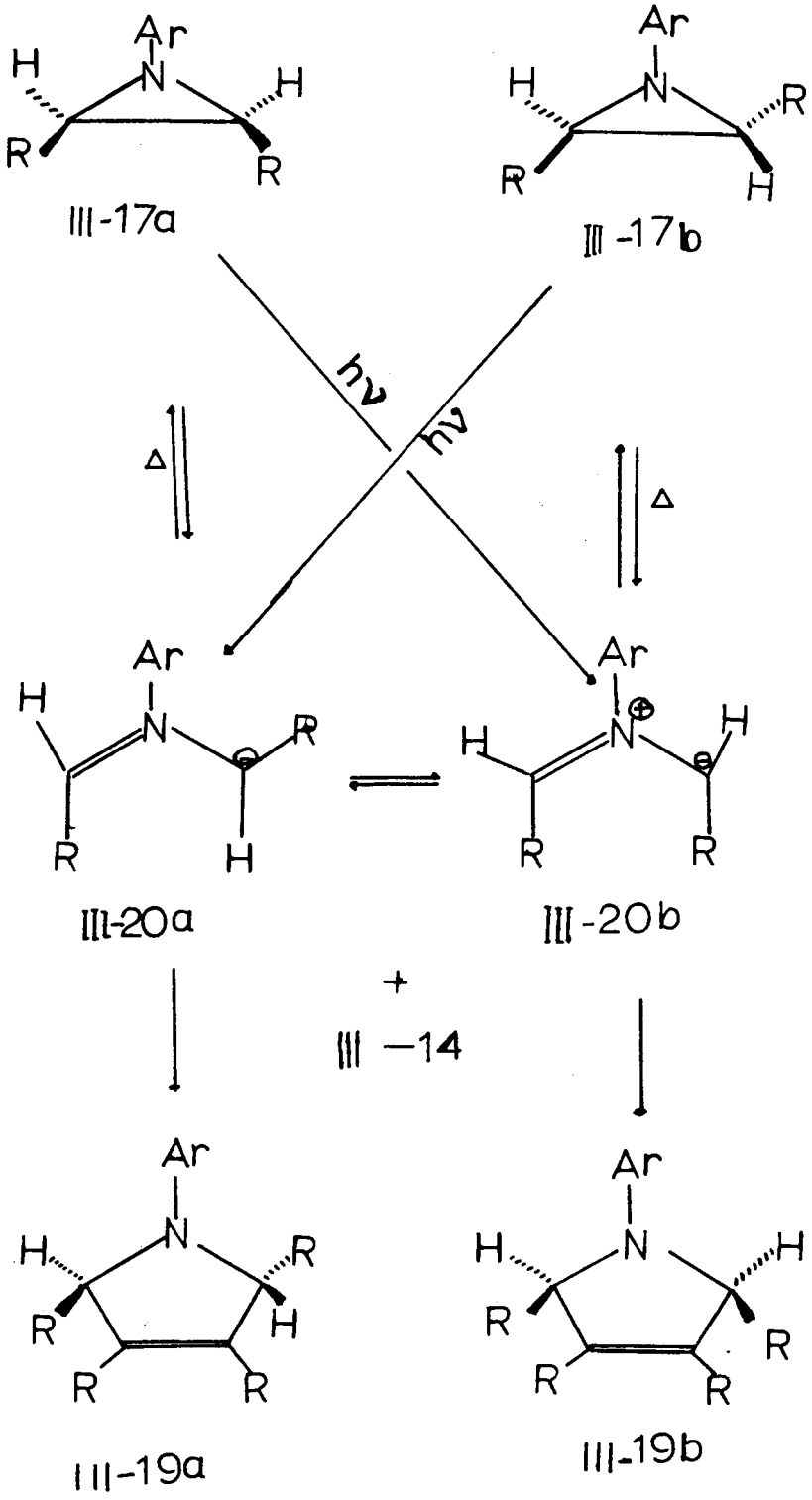


III-18b

III-18a

Ar = C_6H_4-OCH_3, R = $COOCH_3$, R´ = $COOC_2H_5$.

mixture of III-17a:III-17b with tetraethyl ethylenetetracarboxylate gave III-18a and III-18b in 65 and 35% yield, respectively.[56] On the other hand, when pure III-17a is heated with an excess of III-14, product III-19a is obtained in quantitative yield,[57] whereas aziridine III-17b gave III-19b in 71% yield with no contamination by adduct III-19a. These experimental data led them to postulate the following reaction sequence.



Ar = C_6H_4-OCH_3 , R = $COOCH_3$

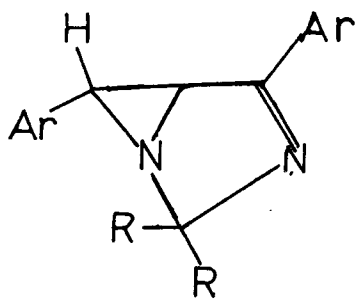
The cycloaddition to dipolarophiles was considered to compete with the equilibrium process. The more active the dipolarophile the higher the stereoselectivity of the overall process. The high reactivity of dialkyl azodicarboxylates, tetracyanoethylene and dimethyl acetylenedicarboxylate completely supresses equilibration between III-17a and III-17b.

Orbital symmetry[32] considerations predict that the thermal isomerization of the cyclopropyl anion to allyl anion will proceed in a conrotatory manner, whereas photochemical cleavage should follow a disrotatory course. No experimental evidence is available in support of this prediction for the parent cyclopropyl system. However, the quantitative transformation of III-17a and III-17b to III-19a and III-19b, respectively, confirms the above prediction in the isoelectronic aziridine case. The thermal conrotatory ring opening of III-17a and III-17b was considered by Huisgen and co-workers to generate the 1,3-dipoles (azomethine ylides) III-20a and III-20b, respectively, which in turn reacted with III-14 in a concerted[70] fashion to yield III-19a and III-19b, respectively. Similarly, the photochemical reaction of III-17b in 2% solution of III-14 in dioxane yielded 69% of III-19a.[57] However, the photochemical cycloaddition of III-17a with III-14 produced a mixture of III-19a and III-19b, and yield of III-19b increased with increasing concentration of III-14 suggesting a competition between the photo and the thermal

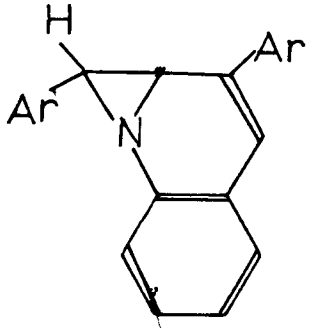
opening.[57]

Although the thermal reactions to yield III-19a and III-19b from III-17a and III-17b, respectively have been termed stereospecific reactions, it should be pointed out that in such reactions the stereospecificity refers to the stereochemistry with respect to the starting aziridines and not to any groups on the alkene since this aspect of the reaction was not studied.

Bicyclic aziridines pose a challenge to the understanding of the nature of the intermediate involved, since bicyclic aziridines can be envisioned which possess geometry in which conrotatory C,C bond cleavage cannot take place. It would obviously be of interest to determine the mode of opening and the ease of reaction of bicyclic aziridines. A few bicyclic aziridines, such as 1,3-diazabicyclo(3,1.0)hex-3-ene, III-21, and 1,1a-dihydro-1,2-diarylazirino(1,2-a)quinoxaline, III-22, have been thermally decomposed and added to active alkynes and alkenes.[53,58]

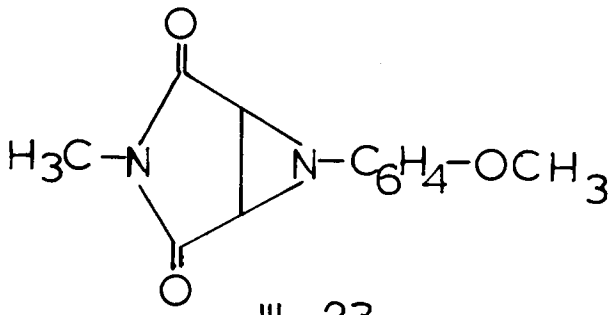


III-21



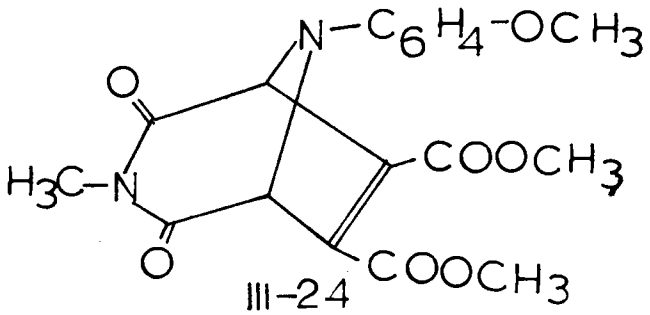
III-22

The reactions of these aziridines are essentially equivalent to the reactions of the monocyclic aziridines described above. The thermal decomposition of bicyclic aziridine III-23 failed,[71] presumably since the geometry of aziridine III-23 permits only a disrotatory opening, and thermally such an opening is forbidden by orbital symmetry.[32]



III-23

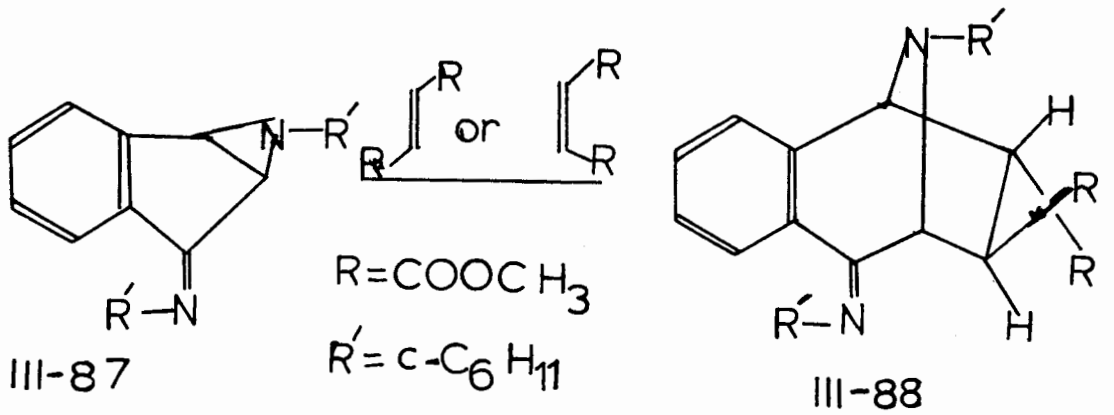
This observation is not suprising since photochemical opening (presumably in a disrotatory manner) and subsequent addition of III-23 to alkyne III-14 gave III-24



III-24

However, the thermal decomposition of the bicyclic aziridine,[87] III-87, in the presence of either

dimethyl maleate or dimethyl fumarate afforded III-88. The formation of III-88 from reaction of III-87 and dimethyl maleate may be due to either stepwise addition, or prior



isomerization of dimethyl maleate to dimethyl fumarate, or, subsequent epimerization of the initially formed stereospecific cis adduct.

A search of the literature reveals that there existed, until recently,[60] ambiguities about the stereospecificity of the thermal cycloaddition of aziridines to alkene with respect to the geometry in the alkene reactant. Heine et al.[52,53] and Cromwell[59] observed that aziridines added to alkenes stereospecifically when trans 1,2-disubstituted alkenes were used but reported a change in stereochemistry of the olefinic participant when cis 1,2-disubstituted olefins were used. They concluded that the overall reaction was stepwise and not stereospecific.

Outline of Present Study.

The present study was undertaken in an effort to

more fully understand the 1,3-cycloaddition of aziridines to olefins. In particular we wished to determine the influence of geometry of ring opening on the participation of the aziridinyl lone pair in the ring opening process. Participation of the lone pair in the thermally allowed conrotatory opening of monocyclic aziridines seemed likely since the transformation (A) would be isoelectronic with a cyclopropyl

(A)

anion to allyl anion transformation (B).

(B)

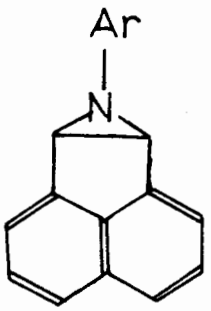
(C)

Orbital symmetry control of the cyclopropyl to allyl transformation in theory allows the thermal reaction to proceed in a conrotatory fashion for the anion, and in a disrotatory fashion for the cation (C).[32] Intriguing questions

are thus raised in the case of the apparently analogous aziridine ring opening (A). Can thermal disrotatory opening of an aziridine ring be made to occur? If disrotatory opening is achieved, will the aziridinyl nitrogen lone pair participate to generate a ring opened species isoelectronic with the allyl anion or will the disrotatory opening force the lone pair into a nitrogen substituent and generate an allyl cation analog as the ring opened intermediate?

To investigate these possibilities it was necessary to determine not only the rate of opening of appropriately N-substituted monocyclic and bicyclic aziridines but to trap the ring opened species from each in a definitive manner. To determine the participation of the aziridinyl lone pair in the ring opening reaction it was necessary to construct and kinetically study both monocyclic and bicyclic aziridines with N-substituents capable of varying the electron density on the aziridinyl nitrogen in a predictable manner. The 1,2,3-triphenyl aziridine system was selected as the monocyclic models for this study since it was structurally very similar to the bicyclic system investigated. The choice of a bicyclic aziridine system to study this reaction was more difficult since several criteria had to be met. First of all, the C,C bond of the bicyclic aziridine must be situated so that only disrotatory cleavage is geometrically possible.

Secondly, the carbon substituents must be suitable for support of either positive or negative charges which could be generated in the ring opening process. Finally, the N-substituent must be capable of varying the electron density on the aziridinyl nitrogen in a predictable fashion. All these criteria are met by the new aziridinyl system III-25,



III-25

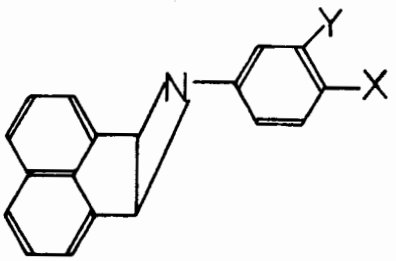
since disrotatory, and from the kinetic results apparently cation like (C) opening of aziridines of type III-25 were achieved. It was possible to design trapping experiments to ascertain the electronic nature of the ring opened intermediates. The design of these experiments rests on the principles of orbital symmetry control in the subsequent reactions of the ring opened aziridines. Thus, if the ring opened species is isoelectronic with an allyl anion, it is allowed to add in a thermally concerted (and predictably stereospecific) reaction to olefins and in a 1,2-fashion to 1,3-dienes. If the ring opened species resembles an allyl cation, thermally concerted addition is allowed to proceed in a 1,4-fashion with 1,3-dienes, but 1,2-addition to 1,3-dienes and olefins is predicted to be stepwise (and thus

probably not stereospecific). As is apparent from the above discussion alkenes substituted with carbonyl and aryl groups conjugated with the alkene linkages should be among the most efficient traps easily available. Accordingly, we chose dimethyl acetylenedicarboxylate, dimethyl maleate, dimethyl fumarate, maleic anhydride and similarly substituted dienes as traps.

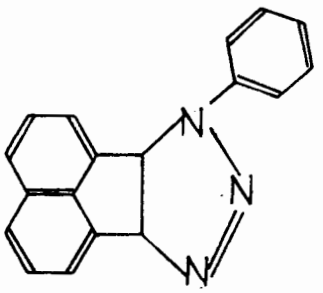
Results

The aziridines III-25a-f employed in this study were synthesized by reacting the appropriately substituted azide with acenaphthylene. The reaction of olefins with azides to give 1,2,3-Δ^2-triazolines is well established. These adducts in turn can be decomposed thermally or photochemically to give aziridine and imine products. Thus, a dichloromethane solution containing an equimolar amount of acenaphthylene and phenyl azide was allowed to stand in dark at room temperature for a period of two and a half months, a solid, mp 168-171°C, was isolated in 76% yield. The nmr spectra of the solid showed a singlet at δ4.21 due to two hydrogens, and multiplet in the region of δ6.51-7.49 due to eleven aromatic hydrogens. The expected triazoline III-26 may be discarded on the basis of the nmr since in III-26 the two benzylic protons are in different environments and would have different chemical shifts. The structure III-26 was further ruled out by elemental and mass spectral analysis. The mass spectrum contained a peak at m/e 243, but did not show a base peak at m/e 28, a characteristic of triazoline fragmentation upon electron impact.[36] It was concluded that compound III-26 had decomposed to give either III-25a or III-27, since there are many reported examples for azide addition to alkenes occurring to give triazolines which readily decompose to give aziridines and

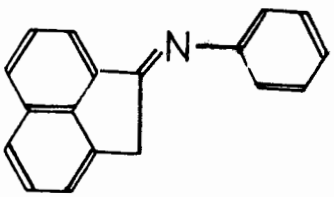
imines as the first isolated products.[50] We investigated the infrared spectrum of the solid for absorption in the region of 1700-1600 cm^{-1} which is associated with -C=N stretching absorption.[72] The solid did not show any absorption in that region; furthermore it could not be hydrolyzed to a ketone (III-28). The structure III-27 for the solid was therefore eliminated.



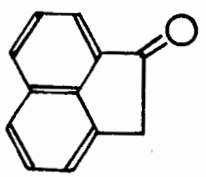
III-25a, X=Y=H,
b, $X=CH_3$, Y=H
c, $X=OCH_3$, Y=H
d, X=Br, Y=H
e, $X=NO_2$, Y=H
f, X=Y=Cl



III-26



III-27

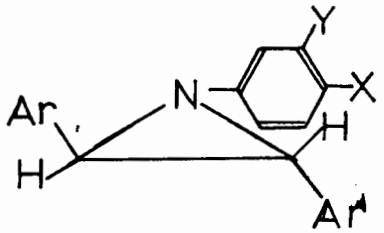


III-28

Large quantities of III-25a-f were prepared by reacting 1.5-2 molar quantities of azide with acenaphthylene at 50-60°C for varying lengths of time, i.e., from 4-days to 15-days. The yield of aziridine is dependent on azide

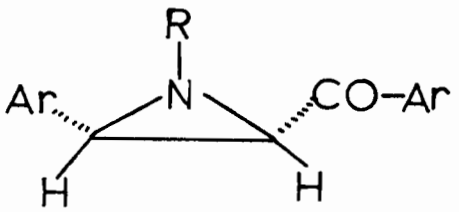
structure, thus the more reactive the azide, higher the yield of aziridine, and shorter the reaction time. In the absence of excess azide, the dimerization and polymerization of acenaphthylene becomes an undesirable side reaction. If an excess of acenaphthylene is used, the addition of aziridine to olefin is observed, whereas a temperature above 100°C caused explosion and dimerization of aziridine. Important physical constants of aziridines III-25a-f are collected in Tables XVIII and XIX.

The aziridines III-29a-d; III-30a,b; and III-31a,b were obtained by the reported procedures.[73-75] Their physical properties are listed in Table XXI.

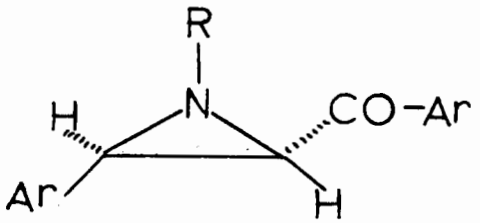


III-29a, X=Y=H
b, X=CH$_3$, Y=H
c, X=Cl, Y=H
d, X=Y=Cl

Ar= C$_6$H$_5$



III-30a, R=CH$_2$-Ar
III-31a, R=c-C$_6$H$_{11}$



III-30b, R=CH$_2$-Ar
III-31b, R=c-C$_6$H$_{11}$

In contrast to previous attempts to thermally decompose the bicyclic aziridine III-23, the aziridine

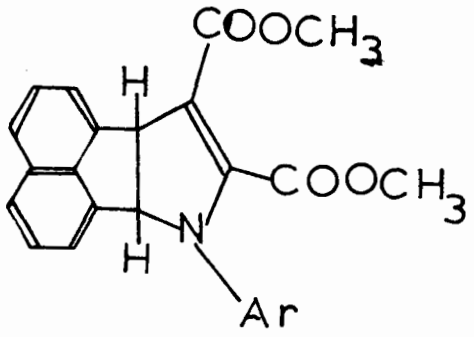
III-25a smoothly decomposed in refluxing benzene in the presence of alkenes. Thus, heating benzene solution equimolar in aziridine and olefin in a sealed tube at 140°C for 8-16 hr gave, after removal of solvent, solid products which were 1:1 aziridine:alkene addition products.

Aziridine III-25a reacted readily with dimethyl acetylenedicarboxylate, maleic anhydride, dimethyl maleate, dimethyl fumarate, methyl crotonate, and acenaphthylene but sluggishly with cyclohexene, cis- and trans-stilbene, and norbornylene. The bicyclic aziridines III-25 also add to dienes, such as 1,3-cyclohexadiene, trans-trans-2,4-hexadiene, and the dimethyl ester of 1,3-butadiene-1,4-dicarboxylic acid.

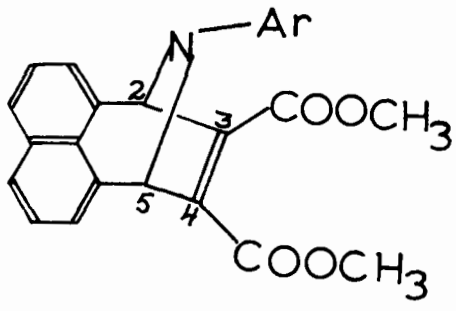
The reaction of aziridines III-29a; III-30a,b; and III-31a,b with olefins also occurred to give products of 1:1 addition.

Reaction of III-25a with III-14.

Dimethyl acetylenedicarboxylate, III-14, and aziridine III-25a condense readily at 140°C to give a 1:1 adduct in 93% yield. The infrared spectrum of the adduct shows an absorption at 1720 cm^{-1} attributable to a conjugated ester. An absorption at 1645 cm^{-1} is attributed to tetrasubstituted double bond conjugated with a carbonyl group. The two structures, III-32 and III-33, are consistent with the elemental analysis and infrared spectra, and are expected on mechanistic grounds. The nmr spectrum of the product exhibits a six proton resonance at δ3.73 (two methyl



III-32



III-33

esters), and a two proton signal at δ5.78, and an eleven proton multiplet in the region of δ6.45-7.71. If the correct structure were III-32, then it would be surprising that the two methoxyl and the two benzylic proton resonances occur at the same frequencies. Only one structural assignment, dimethyl 1-phenyl-2,5[1,8-naphtho]-Δ^3-pyrroline-3,4-dicarboxylate, III-33, is compatible with this evidence. The assignment of structure III-33 to the 1:1 adduct indicates that the addition of alkyne is occurring across the C,C bond and not across the C,N bond of the aziridine moiety.

Reaction of aziridine III-25a with olefins.

Aziridine III-25a undergoes an addition reaction with olefins to give substituted pyrrolidine derivatives. Temperatures above 130° are desirable for reasonable rates, and therefore, a sealed tube vessel is advantageous for

reaction with low boiling olefins. Electron-donating substituents on the olefinic bonds decrease the reaction rate, whereas electron-withdrawing groups accelerate the reaction. In general, longer reaction time and high concentration of olefin were necessary for reaction of electron rich olefins in order to prevent the formation of undesirable side reactions, i.e., dimerization of the aziridine.

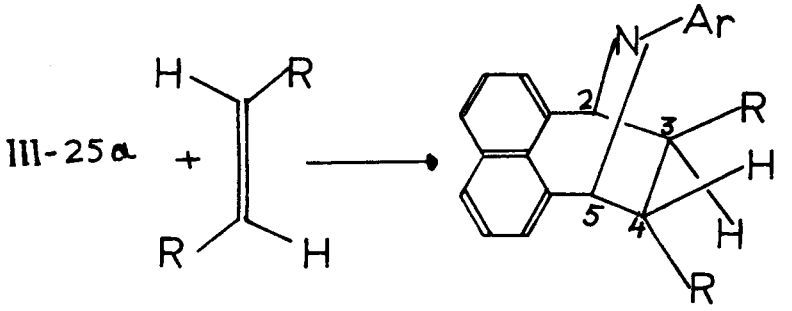
Most of the adducts were characterized by spectral means. The nmr data for the cyclo adducts if summarized in Table X. These data are quite consistent with the data for similar adducts studied by other workers.[52, 60-65]

It will be seen from the discussion below that aziridine III-25a adds cleanly to 1,2-disubstituted olefins to give products which retain the stereospecificity of the reacting olefins. Dimethyl fumarate, III-34, and aziridine III-25a react at 140° to give a single 1:1 adduct dimethyl-1-phenyl-2,5[1,8-naphtho] pyrrolidine-3-exo-4-endo-dicarboxylate, III-35, in 89% yield. Evidence that the adduct is III-35 is found in the infrared and nmr spectral data. The infrared spectrum of III-35 shows absorption at 1730 and 1718 cm^{-1} due to two ester groups in two different environments. The nmr spectrum of III-35 contains signals due to two different ester groups at δ3.46 and δ3.75. The resonance due to other protons, except aromatic protons gave a simple spectrum. The protons at C_3 and C_4 exhibited a doublet at δ3.66 ($J_{3,4}$ = 5.7 Hz), and at δ4.28 (d of d,

TABLE X.

CHEMICAL SHIFTS (δ-VALUES OF RING PROTONS OF 1-PHENYL-2,5[1,8-NAPHTHA]-PYRROLIDINES

Adduct	C_2	C_5	C_3	C_4	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$
III-35	5.55	5.49	3.66	4.28	-	5.7	7.0
III-39	5.41	5.41	4.05	4.05	-	-	-
III-40	5.56	5.56	3.47	3.47	-	-	-
III-43	5.76	5.76	3.84	3.84	-	-	-
III-44	5.42	5.42	4.19	4.19	7.0	-	2.5
III-52	4.70	5.46	2.84	3.37	-	6.5	6.5
III-53	5.07	5.49	3.23	2.57	6.5	6.5	-
III-54	5.09	5.09	5.09	5.09	-	-	-
III-55	5.79	5.79	5.79	5.79	-	-	-
III-57	5.69	5.69	5.07	5.07	7.5	-	3.0

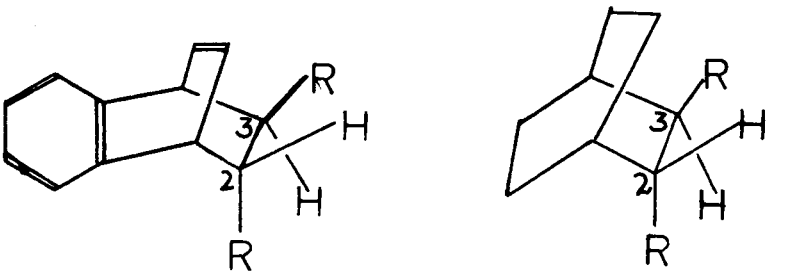


III-34 III-35

R = $COOCH_3$

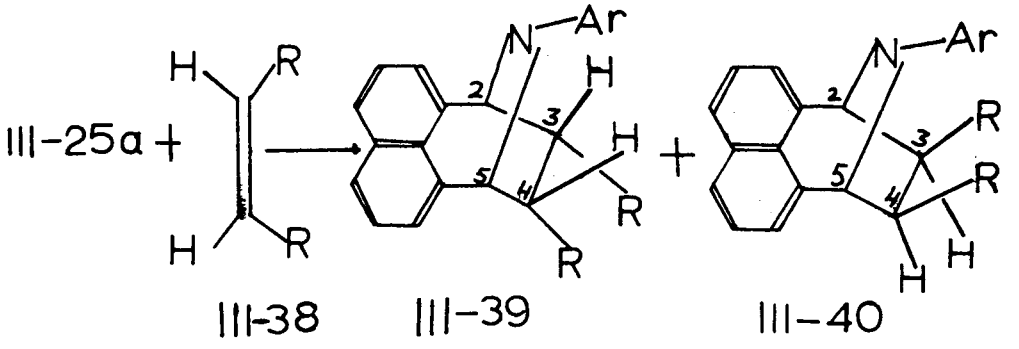
$J_{3,4}$ = 5.7 Hz; $J_{4,5}$ = 7.0 Hz), respectively; whereas protons at C_2 and C_5 were almost magnetically equivalent and appeared as a doublet. Half of the doublet due to the C_5 proton overlapped with the singlet due to the C_2 proton (δ5.55). The absence of any significant coupling of the C_2 proton with the C_3 proton indicates a trans relationship between these two. The coupling between the C_3 and C4 protons (J = 5.7 Hz) is in agreement with the reported values for a trans relationship between these two protons as may be seen from the following examples, III-36 and III-37.[76] The observed coupling of 7.0 Hz between the C4 and C_5 protons is in agreement with reported cis-vicinal couplings in pyrrolidines.[77]

Reaction of dimethyl maleate, III-38, and aziridine III-25a in benzene at 140° gave, after evaporation of solvent, a red oil. Analysis of the reaction mixture by nmr revealed the absence of trans adduct III-35. Two isomeric



III-36 R=$COOCH_3$ III-37

adducts III-39 and III-40 were obtained in 43 and 41% yield, respectively. Both adducts show characteristic ester



III-38 III-39 III-40

R=$COOCH_3$

absorption in the infrared at 1730 and 1740 cm^{-1}, respectively. The nmr spectra of the isomers are quite different. The nmr spectrum of III-39 shows a sharp singlet due to six ester protons at δ3.29; whereas the protons at

C_3,C_4 showed a set of quartet centred at δ4.05. Similarly, the protons at C_2,C_5 exhibited a set of quartet centred at δ5.41 (Fig. 6).

The nmr spectrum of isomer III-40 shows a sharp singlet due to two carbomethoxy groups at δ3.73; the spectrum also shows two sharp singlets due to the C_3,C_4 and C_2,C_5 protons at δ3.47 and δ5.56, respectively. The absence of any coupling between protons at C_2,C_3 and those at C_4,C_5 indicates a <u>trans</u> relationship between the C_2 and C_3 protons and between the C_5 and C_4 protons. This observation is substantiated by the nmr spectra of the compound III-41[71] which gives a somewhat broadened singlet due to the C_2 and C_5 protons, i.e., there is no coupling of these with C_3 and C_4 protons. Only structure III-38 is compatable with these spectral data.

After 8 hr at 140° maleic anhydride, III-42, and III-25a gave a mixture of two 1:1 adducts III-43 and III-44 in 57 and 32% yield, respectively. The compound III-43 was isolated as a crystalline product, mp 256-257.5°. Treatment of III-43 with ethereal diazomethane gave III-40. The adduct

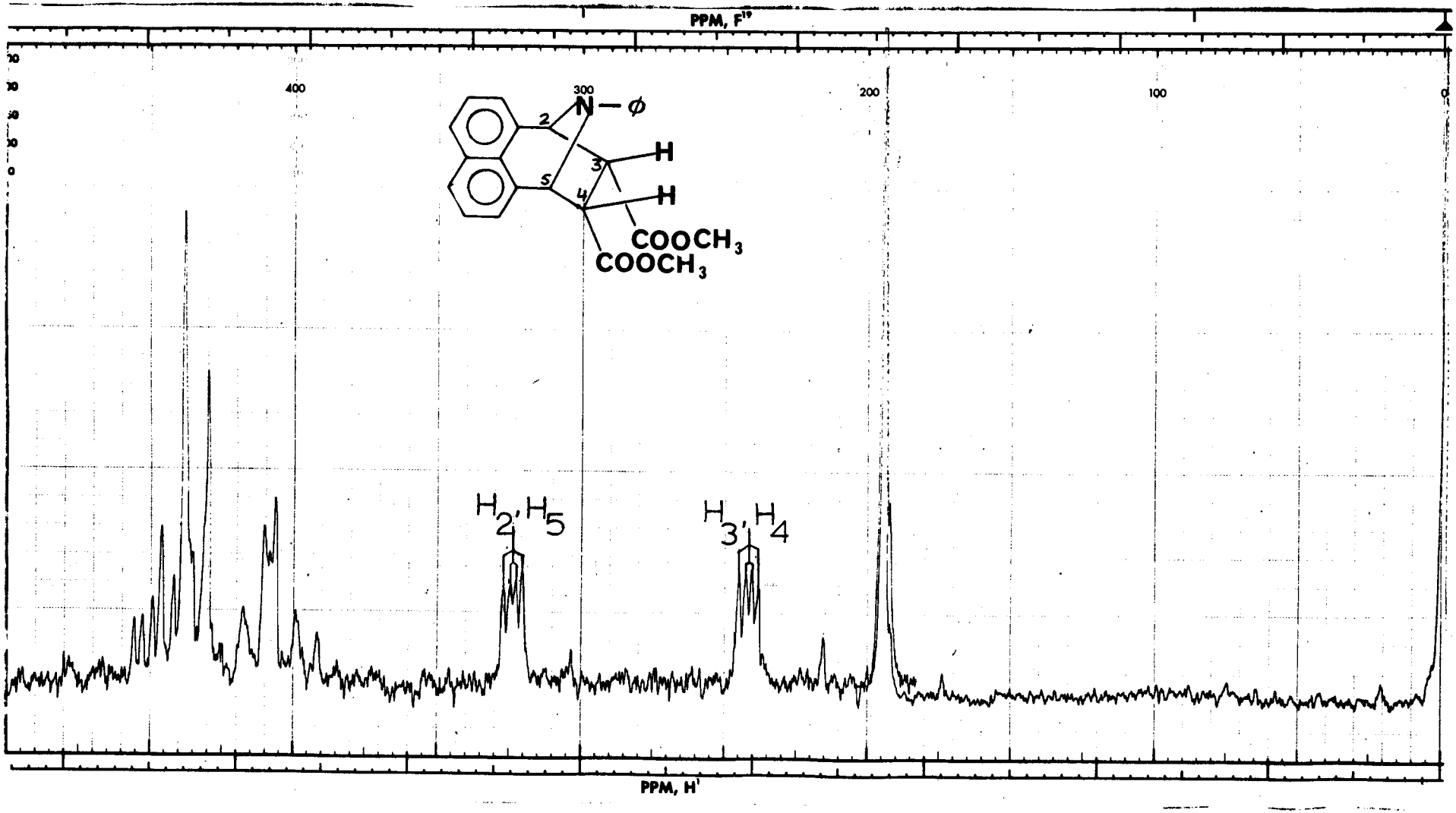
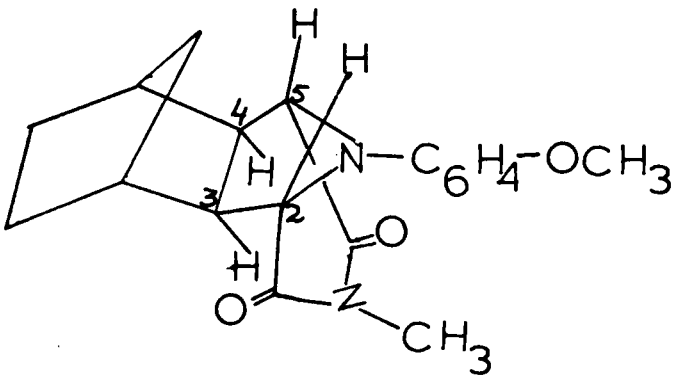
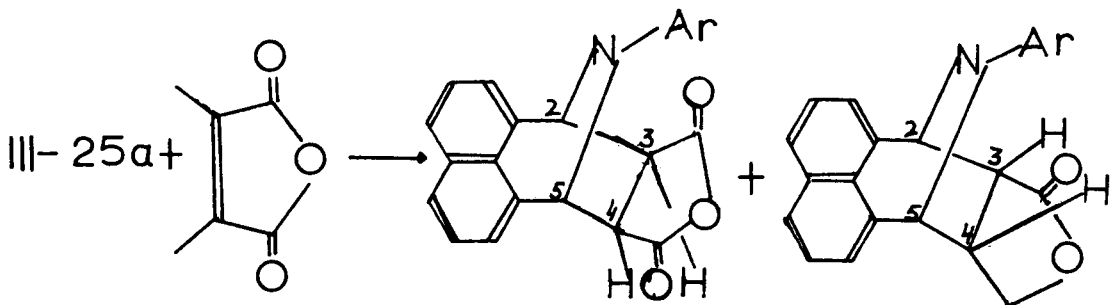


Fig.6: Nmr spectrum of III-39 obtained with A-60 spectrometer.



III-41

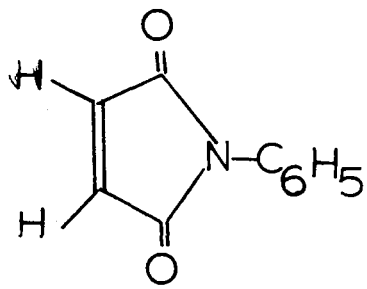
III-44 could not be isolated in pure form but its structure was established by conversion to its dimethyl ester



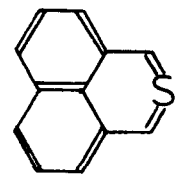
III-42 III-43 III-44

derivative III-39. The infrared spectra of III-43 and III-44 exhibited anhydride absorption. The proton spectrum of III-43 (in DMSO-d6) exhibited an A_2X_2 pattern for the pyrrolidine ring protons with no coupling with the bridgehead protons (C_2,C_5). The spectrum indicated a <u>trans</u>

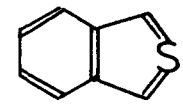
relationship between C_2 and C_3 protons, and between C_5 and C_4 protons. Furthermore since the π-electron system of III-42 is electronically very similar to that of N-phenyl maleimide (III-45), it is to be expected that the nmr spectra of the III-42 adducts with III-25a will show features similar to these obtained from the III-45 adducts of III-46 and III-47. Consequently, the determination of the stereochemistry



III-45



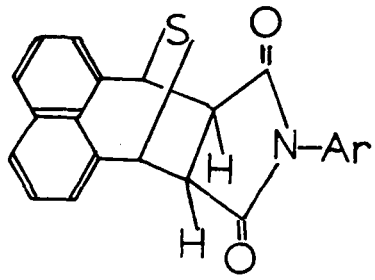
III-46



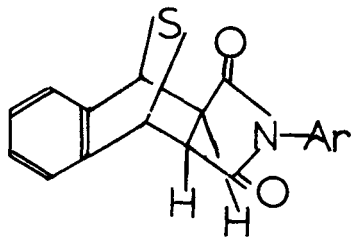
III-47

of these adduct pairs will also indicate the stereochemistry in other systems. The stereochemistry of III-45 adducts with III-46 and III-47 has previously been reported.[78-80]

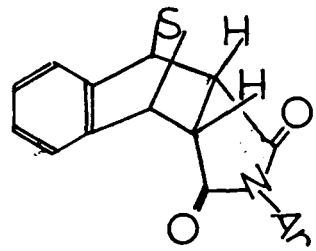
The assignment of stereochemistry to the III-25a and III-42 adducts involves a choice between <u>exo</u>-configuration III-43 and the <u>endo</u>-configuration III-44. Since the benzylic proton resonance position of the adducts III-48, III-49 and III-50 differ only by a small value, it is apparent that those resonances should occur at approximately the same field strength as those of the corresponding protons of III-43 and III-44; regardless of the stereochemistry of the latter. On the other hand, these protons C_3 and C_4 of III-48 and III-49



III-48



III-49



III-50

Ar = C_6H_5

resonate at an appreciably higher field (δ3.78; δ3.30, respectively) than the equivalent hydrogens of III-50 (δ4.10).

An examination of molecular models of the endo adducts III-44 and III-50 indicates that the C_3,C_4 protons lie near the periphery of the fused aromatic ring, and they should be deshielded relative to the corresponding C_3, C_4 protons of the exo isomers III-43, III-48 and III-49 which lie over a portion of the fused aromatic ring. Comparison of the chemical shifts of the C_2,C_5 protons in III-43 and III-44 with III-48, III-49 and III-50 reveals the former at a lower field (Table X). This is probably due to deshielding from phenyl group on nitrogen atom in III-43 and III-44. The observation that endo protons at C_3 and C_4 of III-43 appear at a higher field than those of exo protons at C_3 and C_4 of III-44 can be efficiently used in establishing more firmly the orientation of the substituents at C_3 and C_4

positions in adducts arising from the addition of III-25a to III-34 and III-38 discussed above.

Inspection of Table XI reveals that in compounds III-39 and III-40 the ester methyl resonances appear at δ3.29 and δ3.73, respectively. These observations are in agreement with the above deductions since in isomer III-39 the ester groups are in endo-position and experiencing the induced shielding effect of the naphthalene ring. On the other hand, the ester groups on adduct III-40 are in exo-configuration and are being deshielded. Both of these effects should be expected in diester adduct III-35. In fact, III-35 exhibits two ester resonances at δ3.46 and δ3.75, which may be assigned to endo- and exo-ester groups, respectively. A similar phenomenon is observed in isomers III-52 and III-53 discussed below.

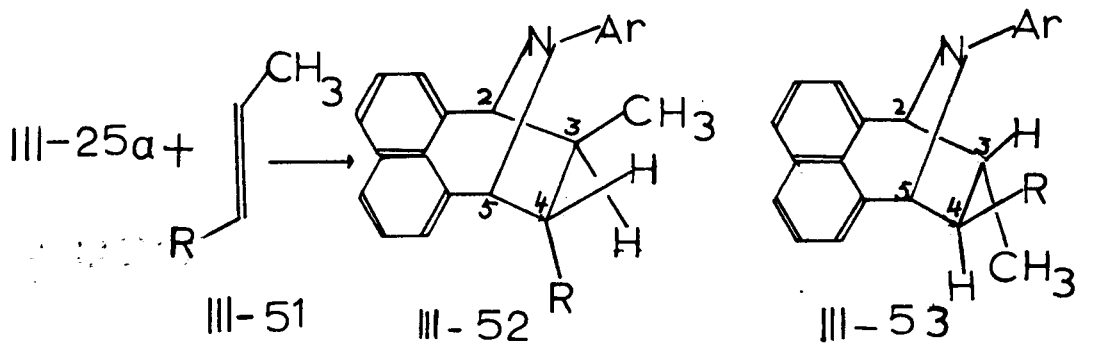
A careful analysis of Table XI reveals that protons at C_2 and C_5 show a shift depending on the orientation of substituents at C_3 and C_4 positions. It is observed that when ester functions are exo, the C_2,C_5 protons show a downfield shift (i.e., higher δ-value); whereas an upfield shift is noticed when ester groups are endo. This seems to indicate that in the exo-configuration the C_2,C_5 protons lie in the deshielding zone of the carbonyl groups which they are in the shielding cone when the ester functions attain an endo geometry. The methyl substituent, on the other hand, shows a reverse and more pronounced shift.

TABLE XI.

CHEMICAL SHIFTS (δ-VALUES) FOR SUBSTITUENTS AT 3, AND 4 POSITION OF 1-PHENYL-2,5[1,8,NAPHTHO]-PYRROLIDINES

Adduct	C_3-Subst.	C_4-Subst.
III-35	3.75	3.46
III-39	3.29	3.29
III-40	3.73	3.73
III-52	1.43	3.37
III-53	0.83	3.70

The reaction of trans-methyl crotonate (III-51) and III-25a gave a mixture of two compounds, III-52 and III-53, which were isolated in 50 and 41% yield, respectively.



$R = COOCH_3$

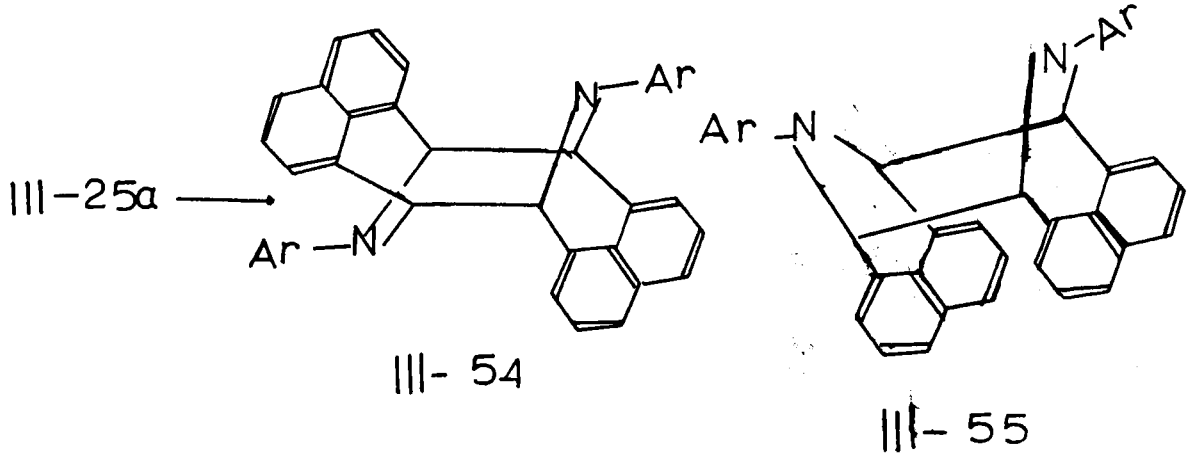
Compounds III-52 and III-53 were shown to be isomeric by mass spectrometry (molecular ion m/e 333, and base peak at m/e 243 common to both). The infrared spectra of both compounds show an ester function absorption at 1730 cm^{-1}. The nmr spectra of III-52 and III-53 are definitive. Compounds III-52 shows a AA'XX' pattern spectrum with no coupling between the C_2 and C_3 protons. A singlet at δ4.70 is assigned to the proton at C_2. The singlet structure of this resonance indicates a trans orientation between the C_2 and C_3 protons. The assignment of this orientation is substantiated by the observation that CH_3-group at C_3 is less shielded in III-52 than in III-53. A doublet at δ5.46 (J = 6.5 Hz) was assigned to the proton at C_5 which is coupled with C_4 proton. The position and coupling of this

signal are consistent with the chemical shift for those observed for protons in similar environments, e.g., see III-35, III-39 and III-40 (Table XI) a triplet centered at δ3.37 (J = 6.5 Hz, center peak overlap with the ester methoxyl protons) arises from the C_4 proton and its coupling with the C_3 and C_5 protons. The C_3 proton is expected to exhibit an eight line pattern due to its coupling with the geminal methyl group which in turn can be further split by the proton at C_4. In fact, a quintet is observed at δ2.84 suggesting an identical coupling between C_3 proton and CH_3; and between C_3 and C_4 protons. These data are most readily interpretable in terms of the assigned structure III-52.

The nmr spectra of III-53 contains a singlet at δ5.49 which is assigned to the C_5 proton. A trans geometry of C_5 and C_4 proton is indicated by the lack of observable coupling in these signals. A doublet at δ5.07 (J = 6.5 Hz) can be attributed to C_2 which is coupled with the C_3 proton. The observed coupling indicates that C_2 and C_3 protons have a cis geometry. The low field position of the signal assigned to the proton at C_2 in III-53 compared to the position of the C_2 resonance in III-52 is due to the deshielding effect of $-CH_3$ group at C_3. The C_4 proton appears as a doublet at δ2.57 (J = 6.5 Hz), whereas the C_3 proton gives a symmetrical sextet at δ3.23 (J = 6.5 Hz). These spectral data unambiguously support structure III-53

The thermal dimerization of III-25a was found to

occur when III-25a was heated in the absence of olefins. This reaction was also found to compete with the addition reaction of III-25a to olefins when olefins lacking conjugated carbonyl substituents were used. Thus, when a benzene solution of III-25a was heated at 140° for 24 hr, no unchanged aziridine was detected by nmr or TLC analysis. Two crystalline products were isolated by fractional crystallization. The mass spectrum of each showed a parent ion peak at m/e 486 and a base peak at m/e 243 suggesting a dimeric structure for both these compounds. Structure assignments have been made by comparison of the nmr spectra; with those of the acenaphthylene photodimers.[81]



III- 54

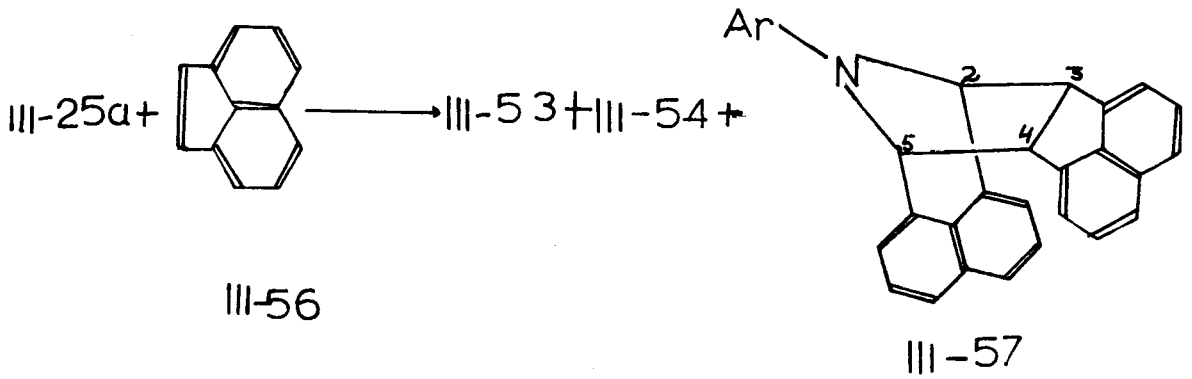
III- 55

Compound III-54 is very slightly soluble in organic solvents, whereas adduct III-55 is soluble in chloroform, benzene, and ether. Infrared spectra for both adducts were very similar and were not helpful in assigning structure. On the other hand, the nmr spectra of III-54 and III-55 were

quite different. The nmr spectra of III-54 (dilute solution in $CDCl_3$) shows a sharp singlet at δ5.09 assigned to four bridgehead protons; multiplets in the region of δ6.30-7.01 for ten protons (two N-phenyl groups); and another set of multiplets in the range of δ7.33-7.83 for twelve protons (two naphthyl group protons), while in CF_3COOH it exhibits a sharp singlet at δ5.54 for four protons, multiplets for ten protons in the region of δ6.12-6.63, and another set of multiplets in the range of δ7.10-7.61 for twelve protons. The assigned structure is in full agreement on the basis of chemical shifts as discussed below.

The proton spectrum of III-55 (in $CDCl_3$) shows a sharp singlet at δ5.78 for four bridgehead protons and multiplets in the region of δ6.63-7.03 for twenty-two protons. The observed nmr spectrum is consistent with the structure III-55.

Aziridine III-25a reacts with acenaphthylene, III-56, at 140° to produce III-54 (8%), and a 1:1 adduct in 77% yield. The presence of compound III-55 was indicated by nmr, but it was not isolated. The infrared spectrum shows the naphthyl and monosubstituted phenyl group at 795-775 and 700 cm^{-1}, respectively. The nmr spectrum of adduct III-57 exhibits a A_2X_2 type resonance very similar to those observed for III-39 and III-44. The resonance due to C_2,C_5 was observed as a four line pattern centered at δ5.09. This spectrum also shows four lines due to C_2 and C_5 protons



III-56

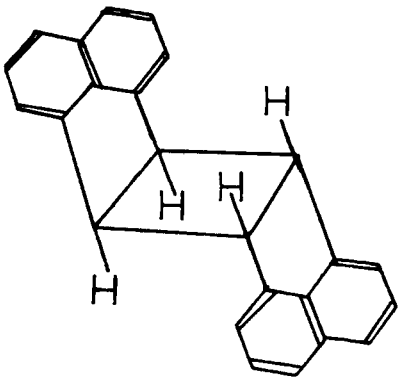
III-57

centered at δ5.69. The seventeen aromatic protons appeared in the region δ6.95-7.28. The observed chemical shifts are in accord with the assigned structure III-57.

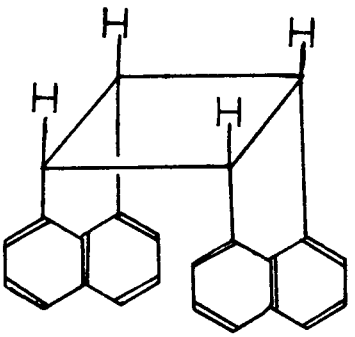
The assignment of stereochemistry to the dimers of III-25a and its acenaphthylene adduct were substantiated by comparison of their nmr spectra with those of the acenaphthylene photodimers. Acenaphthylene photodimerizes to afford two dimers, α-, and β-heptacyclene III-58, and III-59, respectively.[81] The stereochemistry of α-, and β-heptacyclene has been fully documented by x-ray analysis.[82]

Similarities between acenaphthylene and aziridine III-25a dimerization are apparent. Both III-25a and III-56 afford two dimers, and in each case one dimer is highly soluble in ordinary organic solvents and this dimer has a lower melting point than its less soluble partner.

In addition it is well documented that aromatic protons which emanate from aromatic rings which lie closely



III-58



III-59

over each other experience an appreciable shielding effect.[83] This phenomenon is very evident in the spectra of III-58 and III-59. The aromatic protons of III-58 appear in the region of δ7.46-7.83, whereas those for III-59 are in the range of δ6.58-7.28. It is also interesting to note that the four benzylic protons of III-58 resonate at δ4.07, while those for III-59 appears at δ4.78. These observations are again in full agreement with the expected chemical shifts since in III-58 the deshielding effect of naphthalene rings are in opposition; consequently, these protons should resonate in the normal benzylic proton region. In III-59 these protons are experiencing the combined deshielding effect from both naphthalene rings which lie on the same side, and should show a downfield shift.

In the nmr spectra of III-54 and III-55 a similar situation was observed. The nmr spectrum of III-54 shows multiplet due to the two naphthyl ring protons, in the

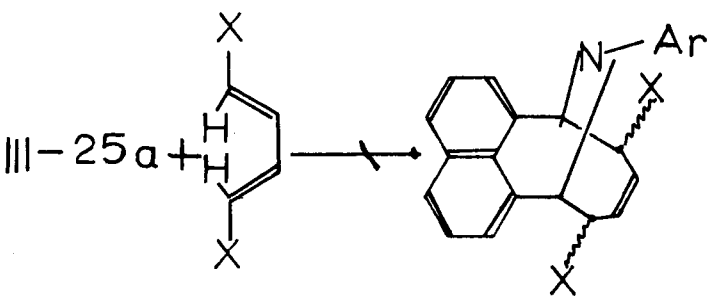
region of δ7.33-7.83, in addition, the spectrum also shows another set of multiplet in the range of δ6.30-7.01 the N-phenyl ring protons, as well as the expected singlet for four benzhydral protons at δ5.07. The resonance of the naphthyl protons at such low field (δ7.83) is compatable only with the anti-configuration for the insoluble dimer, III-54. The proton spectrum of the soluble dimer, III-55, showed complex multiplets for all aromatic protons in the region of δ6.63-7.03, and a singlet for four benzylic protons at δ5.79. The spectral data are in quite agreement with the syn-configuration III-55. A further important feature is observed in the chemical shift of the N-phenyl group protons. In the anti dimer III-54, the N-phenyl group protons appear at δ6.30-7.01, while the corresponding protons in the syn dimer III-54 were in the region of δ6.63-7.03. Further evidence in support of the assigned structures for the dimers are obtained from uv spectral data. The proximity of aromatic rings in the syn-dimers has an appreciable effect on their uv spectra. Thus, III-58 has major absorption bonds (in CH_3CN) at 313, 299 and 226 mμ, whereas III-59 shows major absorption bonds at 285 and 224 mμ; as well as several weaker bonds at longer wavelength. Likewise, the dimer III-54 has absorption at 303, 291, 250 and 225 mμ, while dimer III-55 exhibits absorptions at 303, 282, 250 and 224 mμ.

The proton spectrum of III-57 shows complex multiplets for aromatic protons in the region of δ6.95-7.28, and also A_2X_2 type spectra for the benzhydral protons (C_3

and C_4 at δ5.07 and C_2,C_5 protons at δ5.69). It was again observed that the aromatic protons of III-57 and III-59 appeared in the same region indicating that the two naphthalene rings lie over each other in both compounds. The protons at C_3 and C_4 appear at slightly lower field than those in III-59. This may be due to the deshielding effect of the N-phenyl group. These data unambiguously support the assigned structure III-57.

Reaction of III-25a with dienes.

The reaction of III-25a with 1,3-dienes was of particular interest, since these unsaturates could in theory undergo 1,4-addition across the C,C bond of aziridine III-25a to yield adducts of type III-60.

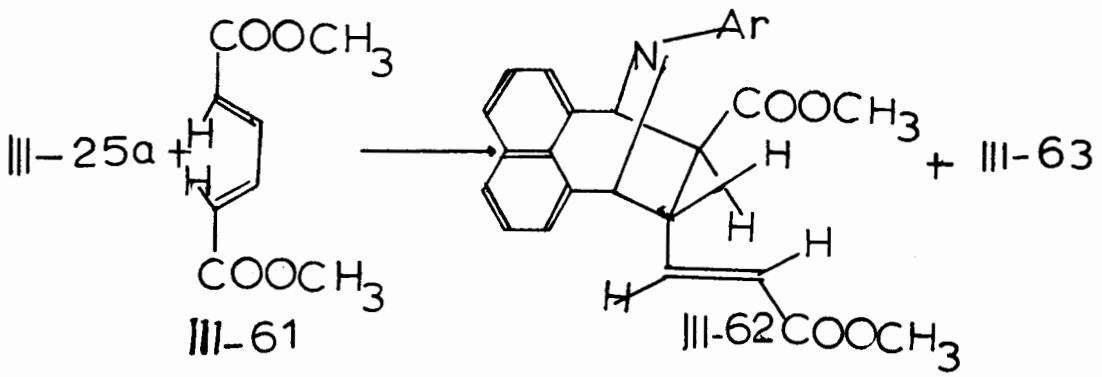


III-60

Although, it was expected on mechanistic grounds (see Discussion) that both 1,2-, and 1,4-, addition products would be formed. The products isolated from the reaction of three different dienes with III-25a did not provide any

evidence of 1,4-addition. In all cases, the product derived from addition of III-25a to diene were of the 1,2-type and had the stereochemistry as in diene. The relevant nmr spectral data are recorded in Table XII.

Upon heating a benzene solution of dimethyl trans, trans-1,3-butadiene-1,4-dicarboxylic acid, III-61, and III-25a at 140° for 12 hr, two products, a low melting 1:1 adduct III-62, and a high melting bis-adduct III-63, were formed in 63 and 31% yield, respectively.



The presence of an α,β- unsaturated ester function in III-62 was substantiated by infrared absorption at 1710 (conjugated ester), 1658 (double bond conjugated with a carbonyl group), and 970 cm^{-1} (weak band, trans-disubstituted olefin),[84] in addition an absorption at 1733 cm^{-1} (non-conjugated ester) was also observed. The nmr spectrum of III-62 shows two vinyl hydrogens mutually coupled (J_{AB} = 15.5 Hz) also indicating a trans stereochemistry.[72] The appearance of a singlet for C_2 proton at δ5.52 indicates a

TABLE XII.

CHEMICAL SHIFTS (δ-VALUES) OF DIENE ADDUCTS OF AZIRIDINES III-25a, d and f

Adduct	C_2	C_5	C_3	$C_4(X)$	C_A	C_B	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$	$J_{A,B}$	J_{AX}
III-62	5.52	5.20	2.93	3.98	6.17	5.86	-	6.2	6.0	15.5	8.0
III-66	5.20	5.20	2.92-3.51	2.92-3.51	5.52	5.52	6.5	-[a]	6.5	10.5	-
III-68	5.05	5.05	2.90-3.45	2.90-3.45	5.42	5.42	6.5	-[a]	6.5	10	-
III-73	4.57	4.96	1.98	2.89	4.96	5.50	-	6.5	6.0	15.0	9.0

a, broad peak, could not be measured

trans-configuration between the C_2 and C_3 protons; whereas the doublet due to the C_5 proton (J = 6.0 Hz) at δ5.20 supports a cis stereochemistry for C_5 and C_4 protons. A doublet assigned to the C_3 proton (J = 6.2 Hz) at δ2.93 is in agreement with this interpretation. The protons at C_4,C_7 and C_6 display an ABX pattern with signals at δ3.98, 5.86 and 6.17, respectively (Fig. 7). No coupling was observed between the C_4 and C_7 protons. On irradiation at δ6.17, the multiplet at δ3.98 collapsed to a triplet, whereas that at δ5.86 gave a singlet. Thus, clearly demonstrating that the C_6 proton is coupled with the C_4 and C_7 protons. Two ester methyl signals at δ3.53 and δ3.70 could be assigned to the exo-ester group on C_3, and to the α,β-unsaturated ester function at C_4 in an endo position, respectively. The observed chemical shift for α,β -unsaturated ester is in agreement with the recorded for dimethyl fumarates III-34, and dimethyl maleate, III-38, (δ3.83 and δ3.78, respectively). Further evidence for the α,β-unsaturated ester function being in the endo-position in III-62 is provided by the scrutiny of the chemical shifts of the C_2, C_3, C_4 and C_5 protons. A comparison between III-35 and III-62 can be made from the Table XIII. It is observed that the C_2 proton in both III-35 and III-62 resonates at an identical field strength, whereas the protons at C_3, C_4 and C_5 in III-62 show a positive shift in comparison to their counterparts in III-35. Examination of a molecular model

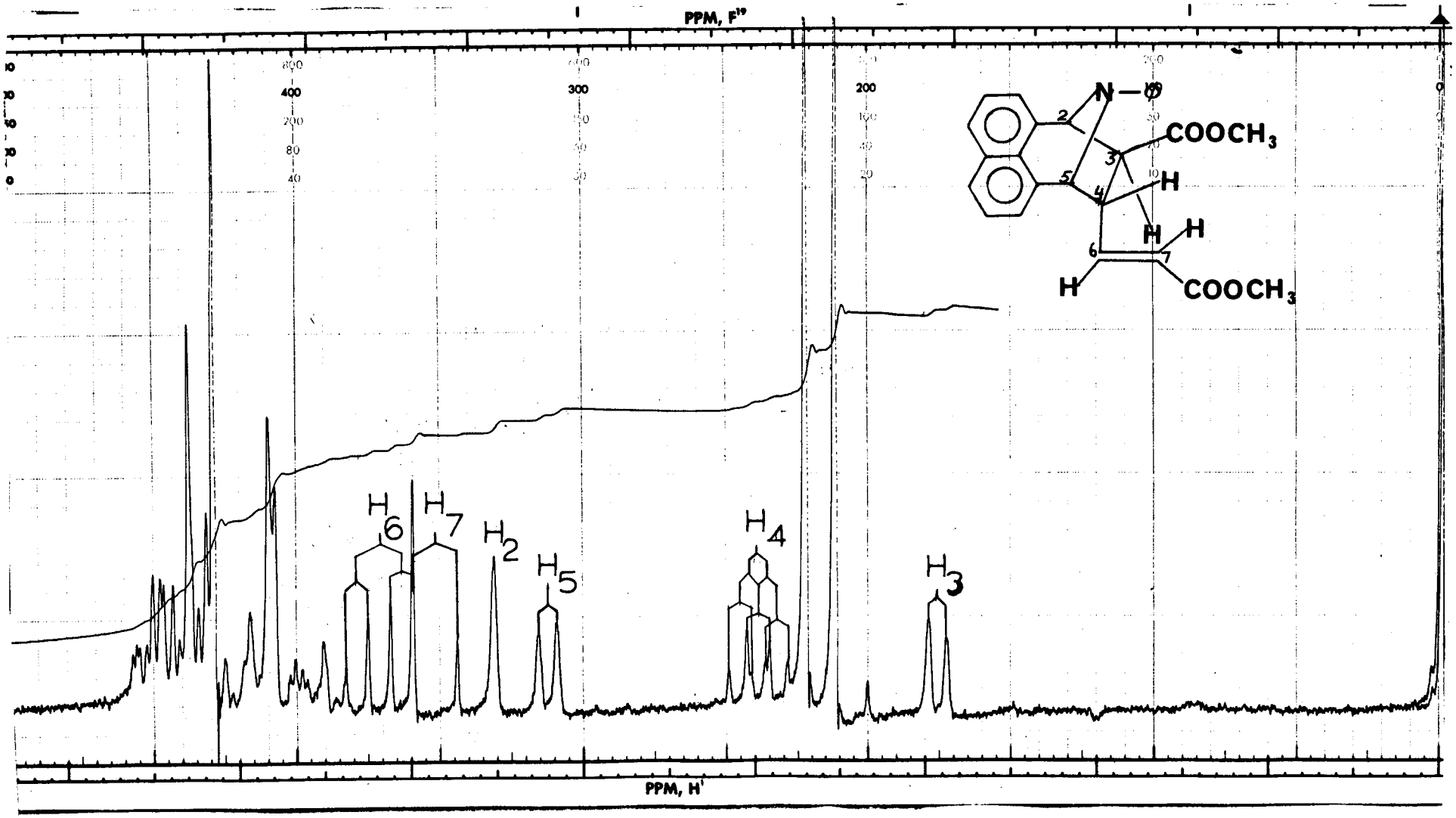


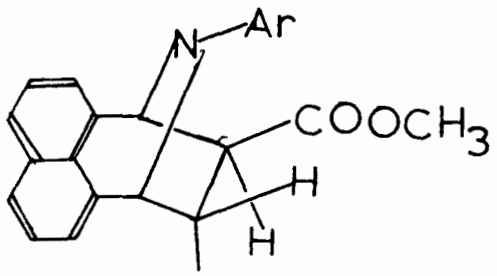
Fig.7: Nmr spectrum of III-62 obtained with A-60 spectrometer.

TABLE XIII. COMPARISON OF CHEMICAL SHIFTS OF ADDUCTS III-35 AND III-62

Adduct	C_2	C_5	C_3	C_4
III-35	5.55	5.49	3.66	4.28
III-62	5.52	5.20	2.93	3.98

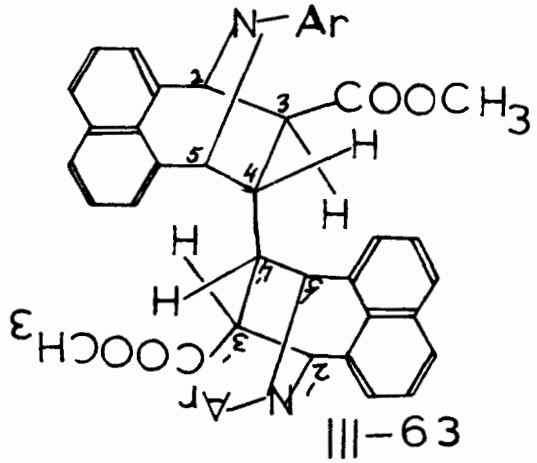
of compound III-62 reveals that protons attached to C_3, C_4 and C_5 lie over the II-electron cloud of the double bond part of the time, due to free rotation about the C4 and C6 bond, hence these protons experience a shielding effect compared to the corresponding protons in III-35. If the olefinic group had been in the exo-position, an appreciable positive change would have been anticipated in the chemical shift of C_2 proton. On the basis of this spectral analysis, the assigned structure of 1:1 adduct is as shown in formula III-62.

The infrared spectrum of III-63 exhibits ester carbonyl absorption only at 1737 cm^{-1}. The nmr spectrum exhibits a three proton singlet at δ3.53, a doublet (δ5.50), and a singlet (δ5.28) which may be assigned to methyl ester, C_5 and C_2 protons, respectively. The C_3 proton exhibits a doublet at δ3.25 (J = 6.5 Hz); whereas C_4 proton resonance appears as a broad peak in the region δ3.80-4.21. The eleven aromatic protons appear in the range of δ6.48-7.67. The nmr spectral data is compatible with the partial structure III-64:



III-64

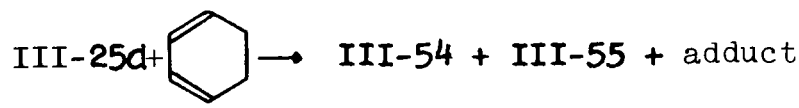
Interestingly, the mass spectrum shows a parent ion peak at m/e 656, suggesting that the group X is identical to the rest of the molecule. This is substantiated by the observation of a peak at m/e 328. This type of fragmentation would be expected if the molecule was a symmetrical bis adduct.[85] The simplicity of nmr spectrum and observation of only one resonance for ester methyl hydrogens clearly indicates that both halves are symmetrical with respect to a common plane. The nmr spectra unambiguously support the assigned structure III-63 for the bis adduct.



III-63

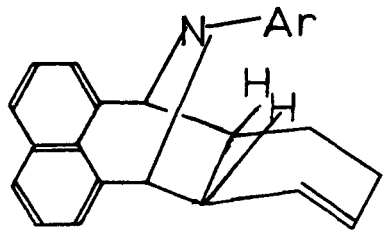
The comparatively high field position of the ester methoxyl resonance may be due to shielding effect of naphthalene rings. When an equimolar amount of III-25a and adduct III-62 are heated, a 75% yield of adduct III-63 was obtained. In other words, product III-62 undergoes a further cycloaddition reaction with aziridine III-25a to give III-63.

Reaction of 1,3-cyclohexadiene, III-65, and aziridine III-25a afforded a 1:1 adduct (32%) as well as dimers III-54 and III-55. The proton spectrum of the adduct consists of resonances at δ1.11-1.81 (four methylene protons), δ2.92-35 (two methine protons), δ5.20 (d, two protons),

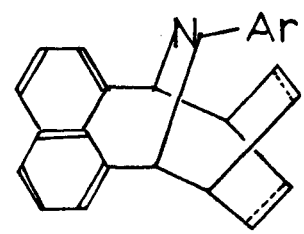


III-65

δ5.51 (quart. J = 10 cps), and δ6.41-7.59 (m, eleven aromatic protons). The nmr spectral data do not provide sufficient information to make a definite choice between the 1,4-, or 1,2-cycloadducts shown, III-66 and III-67.



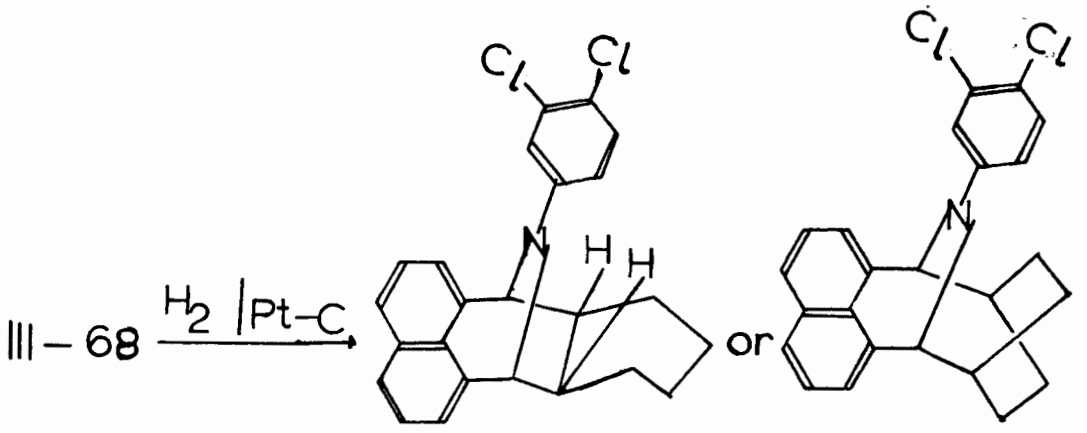
III-66



III-67

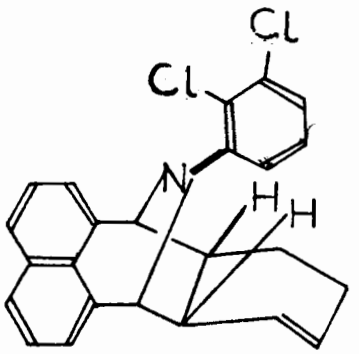
However, since the vinyl hydrogens do appear as an AB quart., the 1,2-cycloadduct is more reasonable. All attempts to gain information, on the nature of addition, by oxidative cleavage (OsO_4-$NaIO_4$; $KMnO_4$-$NaIO_4$) gave black residues which exhibited unresolved nmr spectra.

In an attempt to increase the yield of the 1,3-cyclohexadiene adduct, aziridine III-25f was reacted with a 5-molar excess of the III-65 to give a 1:1 adduct III-68 in 72% yield along with some insoluble dimer III-69. The nmr spectrum of III-68 was very similar to those obtained from reaction of III-25a with III-65, indicating that in both cases the same type of 1:1 adduct had been formed. The proton spectrum of III-68 shows a AB quart. (J = 10 Hz) centered at δ5.44 (two protons) which was assigned to vinylic protons since it disappeared on catalytic reduction of III-68. A doublet at δ5.05 (two protons) remained unaffected, and could be unequivocally assigned to the bridgehead (C_2,C_5) protons. The hydrogenated product has either of the following structures, III-70, III-71. When a cyclohexene solution of III-25f is heated at 140°, a crystalline product is obtained in 7-8% yield which has a nmr spectrum identical to that of compound obtained on catalytic reduction of III-68. In addition, their mixed melting point was undepressed. This clearly established the structure of hydrogenated product as III-70 and not III-71. On this basis, the structure of III-25a and III-25f adduct with III-65 is assigned as III-66



III-70 III-71

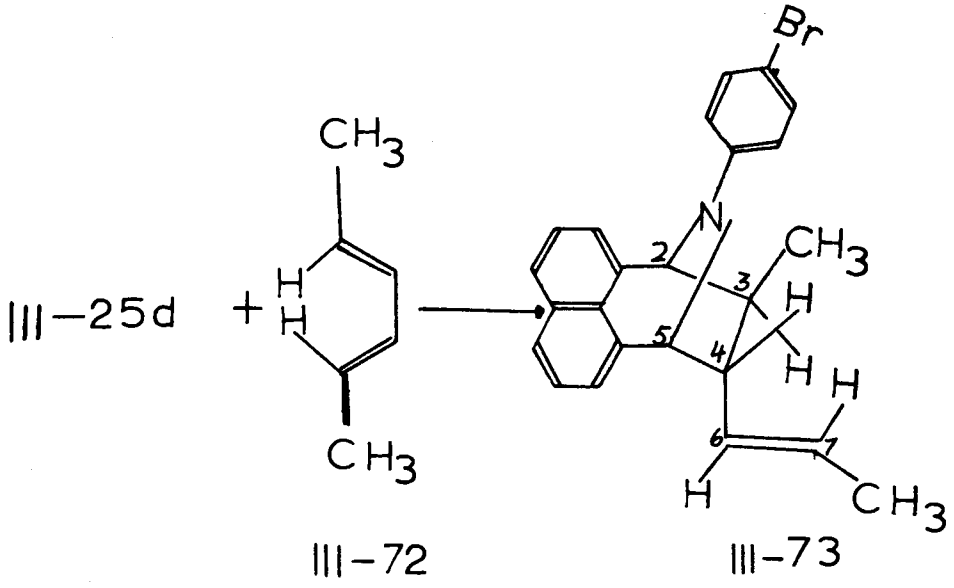
and III-68, respectively. The endo-configuration of the



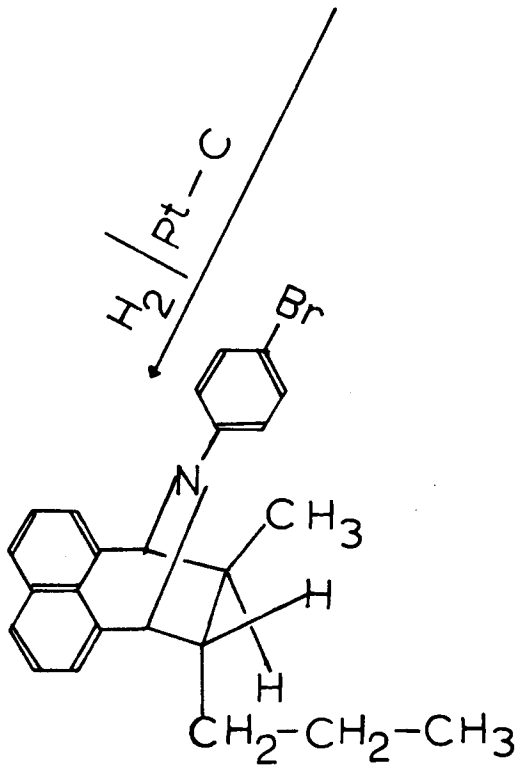
III-68

cyclohexene ring in III-66 and III-68 is assigned on the basis of the coupling constant between C_2 and C_3 (J = 6.5 Hz) which is in agreement with observed cis coupling values for C_2 and C_3 protons.

Reaction of trans,trans-2,4-hexadiene, III-72, and III-25d gave a 1:1 adduct III-73, in 58% yield, along with dimer III-74. The presence of a trans-disubstituted



III-72 III-73



III-75

alkene was indicated by a weak absorption of 965 cm^{-1}.[84] The proton spectrum of III-73 revealed vinylic protons mutually coupled (J_{AB} = 15.0 Hz). Two distinct methyl signals at δ1.31 (d, J = 6.5 Hz), and δ1.47 (d of d, J = 6.5 Hz, and J = 1.0 Hz) are observed. The resonance at δ1.31 is assigned to methyl group at C_3 in an exo-configuration since it remains unaffected on catalytic hydrogenation of III-73 to III-75. On the other hand, the signals at δ1.47 shift to a higher field and appear as a triplet at δ0.78 (J = 6.5 Hz). They can thus be assigned to a methyl substituent on a double bond. This shift to a higher field indicates an endo-configuration for propyl group in III-75. A similar observation has been made in the case of compound III-53 where a methyl group is in endo position. The C_2 and C_5 protons in III-73 exhibited a singlet at δ4.57 and a doublet (J = 6.0 Hz) at δ4.96, respectively, in agreement with the observed coupling constant and chemical shift for III-53. The other important feature of the nmr spectrum of III-73 includes an ABX pattern for protons at C_4, C_6 and C_7 (Fig. 8). The structural data are in agreement with the proposed structure III-73.

A similar 1:1 adduct is obtained on a reaction between III-25a and III-72 as is indicated by the similarity of its nmr spectrum with that of III-73.

Catalytic and lithium aluminium hydride reduction of III-25a.

Both the catalytic and LAH reduction of III-25a

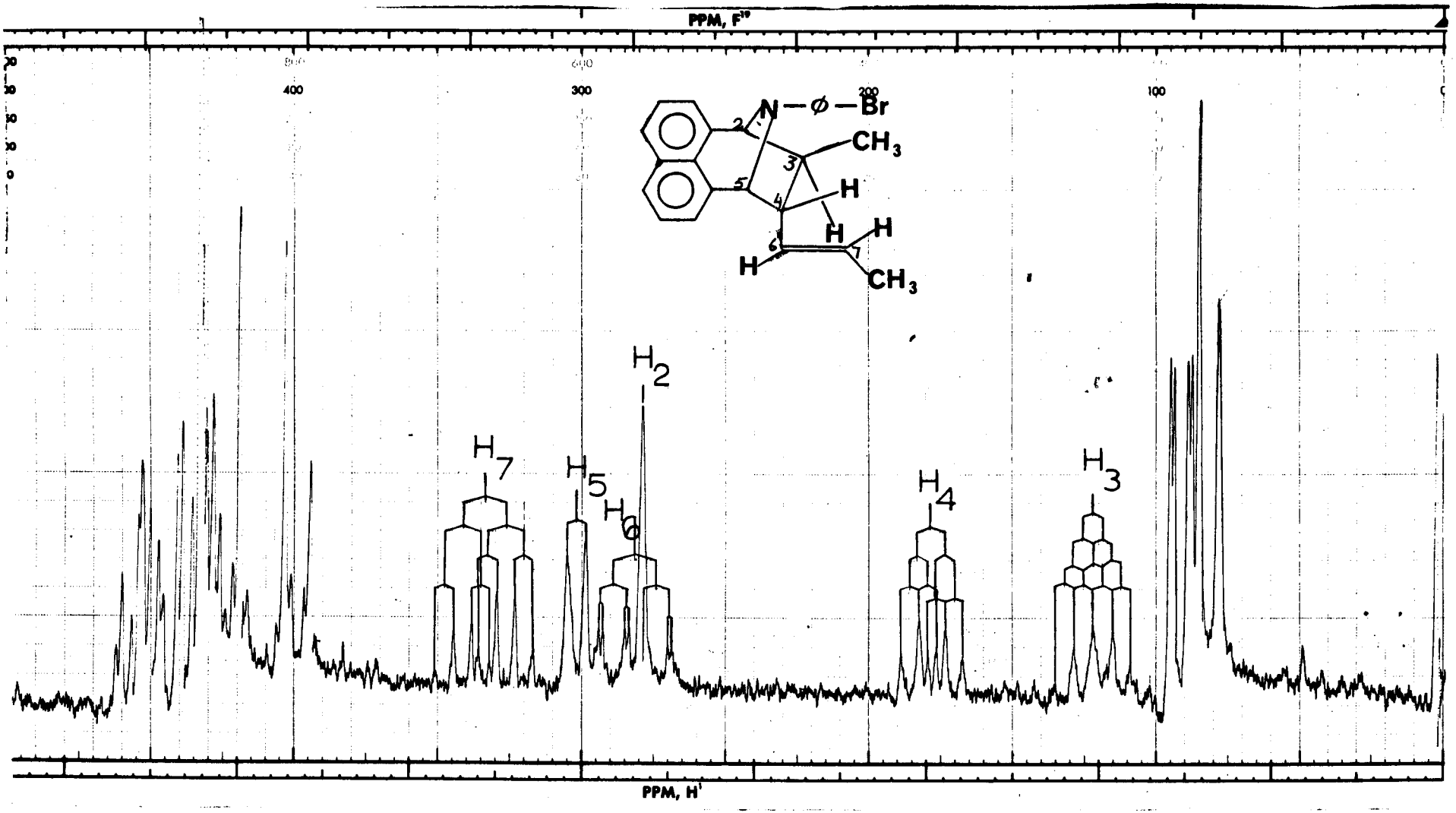
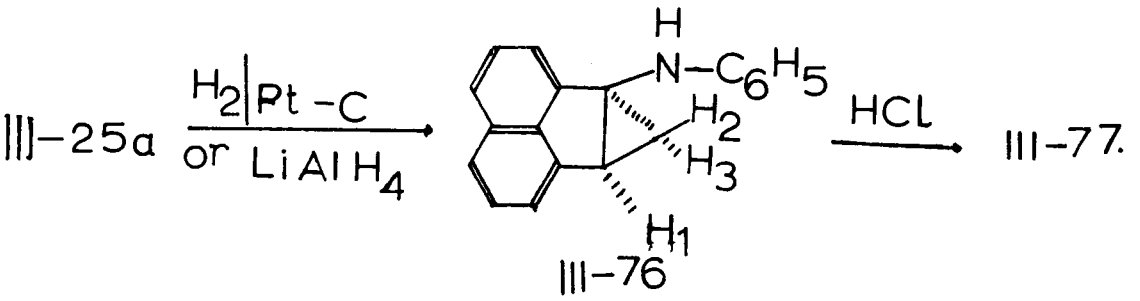


Fig.8: Nmr spectrum of III-73 obtained with A-60 spectrometer.

afforded compound III-76. The presence of -NH group was easily detected by the presence of a sharp band at 3450 cm^{-1} in infrared spectrum.[28] The nmr spectrum shows an AB quartet for protons H_2, H_3, J_{AB} = 16.5 Hz. Amine III-76 readily forms a hydrochloride salt, III-77.

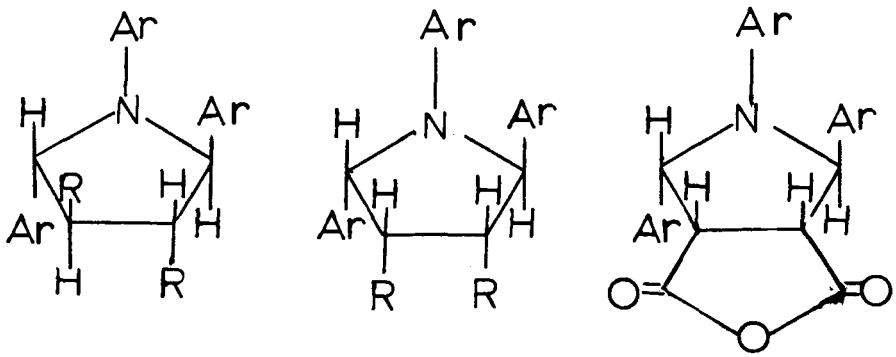


Reaction of III-29a, III-30a,b and III-31a,b with active olefins.

The reactions of these aziridines with olefins, such as dimethyl fumarate (III-34), dimethyl maleate (III-38) and maleic anhydride (III-42) afforded substituted pyrroldines in good yield. The stereochemistry of olefin moiety in the final product is retained. In general, toluene solutions containing equimolar quantities of the aziridine and olefins were heated at reflux for 6-16 hr. After removal of the solvent the crude mixture was analyzed by nmr. Stereochemical assignments of the cyclo adducts are made on the basis of nmr spectra; and observed coupling constants are in agreement with the reported values.[52,60-65]

Heating toluene solutions of III-29a with III-34,

III-38, and III-42 gave the adducts III-78, III-79 and III-80, respectively. Maleic anhydride (III-42) adduct III-80 has been reported previously.[52]



III-78 III-79 III-80

$Ar = C_6H_5$, $R = COOCH_3$

The observed chemical shifts and coupling constants of the ring protons of adducts III-78 to III-80 are listed in Table XIV.

The anhydride adduct III-80 has features identical to those reported previously,[7] Table XIV. The nmr spectrum of III-80 also exhibits a coupling between the C_3 and C_4 protons which has not been reported by previous workers.[7] The observed coupling of 8.7 Hz for C_3,C_4 protons is in agreement with the reported values for cis-vicinal couplings in pyrrolidines.[15]

Heine et al.[52] claimed that the cycloadduct III-81 of diethyl maleate and III-29a has a structure in which the two ester functions are trans to each other.

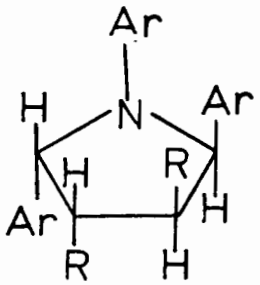
TABLE XIV.

CHEMICAL SHIFTS (δ-VALUES) AND COUPLING CONSTANTS (HZ) FOR

1,2,5 - TRIPHENYLPYRROLIDINES

Adduct	C_2	C_5	C_3	C_4	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$
III-78	5.59	5.50	4.09	4.17	2.5	-	2.5
a	5.78	5.78	3.57	3.57	1.2	-	1.2
b	5.70	5.60	4.69	4.73	2.5	-	2.5
III-79	5.89	5.63	3.39	3.89	7.3	7.5	7.0
c	5.90	5.60	3.69	3.69	8.0	-	8.0
III-80	5.86	5.62	3.63	4.19	1.3	8.7	10.0
d	5.92	5.67	3.67	4.22	1.2	-	10.0

Ref.52 reported values for 1,2,3 triphenylaziridine adduct with, a) diethyl fumarate b) trans-dibonzoylethene c) diethylmaleate, and d) maleic anhydride



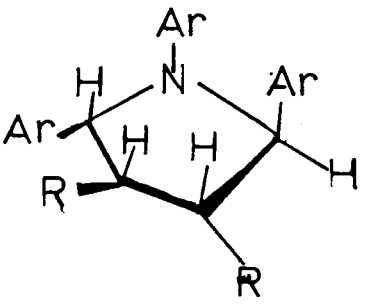
$Ar = C_6H_5$

$R = COOC_2H_5$

III-81

Their reason for assigning a trans-configuration was that no coupling between the C_3 and C_4 protons was observed. However, the nmr spectrum of adduct III-79 (obtained from III-29a and III-38 reaction) shows that the C_3 and C_4 protons are mutually coupled ($J_{3,4}$ = 7.5 Hz), in addition to an almost identical coupling constant for C_2, C_3 (J = 7.3 Hz), and C_4, C_5 (J = 7.0 Hz) protons. The compound III-79 is also isolated in quantitative yield by treating the adduct III-80 with an excess of ethereal diazomethane solution indicating that both the diester and anhydride adducts have a cis geometry about C_3 and C_4.

The unusually large coupling between the C_2,C_3 protons can be due to steric repulsion between the substituents at C_3, C_4 and C_5 distorting the pyrrolidine skeleton of III-79. This would cause the C_2H-C_3H angle to increase to well over 120°. This twisting would further relieve eclipsing of protons and substituents at C_4 and C_5.[60] The coupling constant $J_{4,5}$ of III-79 should thus show a decrease from the



$Ar = C_6H_5$, $R = COOCH_3$

normal value, whereas the values for $J_{2,3}$ and $J_{3,4}$ should increase. In fact, this trend is observed, Table XIV. On this basis the assigned stereochemistry of the III-38 and III-29a adduct as III-79 is reasonable. The failure by Heine et al.[52] to detect any coupling between C_3 and C_4 protons in the diethyl maleate-aziridine III-29a adduct may be, in part, due to the masking of triplets by the methylene ester proton signals.

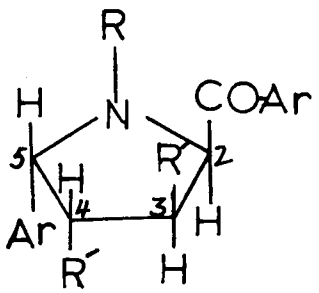
The aziridine III-29a and III-34 react to yield one adduct, III-78, in 94% yield. The nmr analysis shows small coupling constants ($J_{2,3}$ = 2.5 cps) which are in agreement with the values for trans vicinal couplings.[52,60]

Two pair of cis-trans-aziridines III-30a,b and III-31a,b have been reacted with III-34, III-38, and III-42 to yield substituted pyrrolidines. These reactions are stereospecific with respect to olefin, but show complete stereoselectivity with respect to aziridine. In other words, both cis- and trans-, aziridines with an olefin gave a

product in which the aziridine substituents are trans to each other. The stereochemistry in the pyrrolidine have, again, been established by nmr analysis, and their chemical shifts and coupling constants are listed in Table XV.

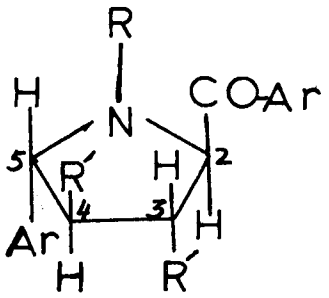
The reaction of aziridines III-30a,b and III-31a,b with III-34 afforded two cycloadducts in each case. Adducts III-82a and III-83a were derived from the reactions of III-30a,b while the compounds III-82b and III-83b were formed from III-31a,b. The coupling constants obtained for $J_{2,3}$ and $J_{4,5}$ in adducts III-83a,b clearly indicate a trans relationship between the interacting protons. In other words, in adducts III-83a,b all ring protons are trans to each other, and the coupling constants are small since the steric interactions are minimized and trans-vicinal couplings in these compounds are restored to their normal values.[86] On the other hand, a large coupling between the C_2,C_3 and C_4,C_5 protons in III-82a,b are indicative of a cis geometry for these protons. In addition, the C_3,C_4 protons exhibit an unusually large mutual coupling (10-11 Hz). This large trans-vicinal coupling can be explained in terms of distortion of the pyrrolidine ring due to steric interactions between the substituents at C_2,C_3 and C_4,C_5 in such a manner as to increase the angle C_3H-C_4H over normal values. A very similar observation has been made for compound III-86.[60]

The aziridines III-30a,b undergo cycloaddition reactions with III-38 to yield one adduct, III-84a, in which



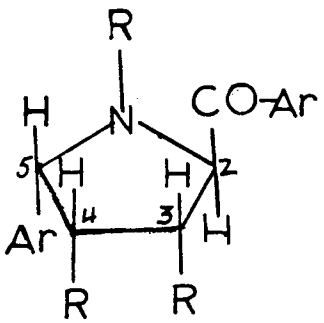
III–82a, R = CH_2–Ar,

b R = c–C_6H_{11}



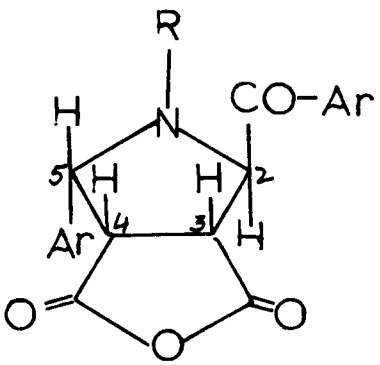
III–83a, R = CH_2–Ar

b, R = c–C_6H_{11}



III–84a, R = CH_2–Ar

b, R = C_6H_{11}



III–85a, R = CH_2–Ar

b, R = c–C_6H_{11}

Ar = C_6H_5

R = $COOCH_3$

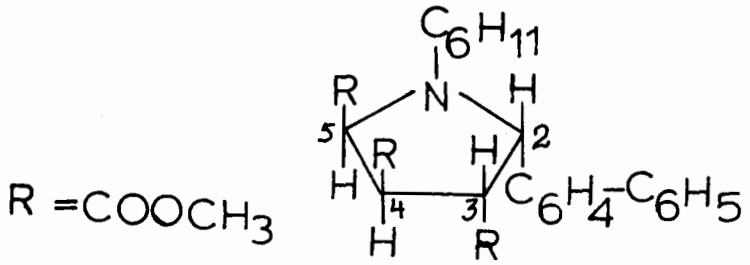
TABLE XV

CHEMICAL SHIFTS (δ-VALUES) AND COUPLING CONSTANTS OF

1-ALKYL-2-BENZOYL-5-PHENYL PYRROLIDINES

Adduct	C_2	C_5	C_3	C_4	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$
III-82a	5.25	5.12	4.25	4.67	7.0	10.0	10.0
III-82b	5.46	5.21	4.29	4.64	7.2	11.1	10.0
III-83a	5.12	4.83	3.33-3.63[b]	3.53-3.63[b]	2.0	-[a]	4.5
III-83b	5.62	5.12	3.45-3.60[c]	3.45-3.60[c]	1.2	-[a]	4.5
III-84a	5.63	4.93	3.37-4.02[b]	3.37-402[b]	6.0	-[a]	5.5
III-84b	5.58	5.08	3.40	3.82	4.5	8.3	8.0
III-85a[d]	5.26	5.14	2.50	3.30	-	9.5	8.2
III-85b	5.64	5.42	3.37	3.87	-	9.5	8.5

a) Coupling constants were not determined, b) chemical shifts of H_3,H_4 are identical and are masked by - CH_2 - signals c) chemical shifts of H_3,H_4 are identical and overlap with ester signals d) nmr spectrum was recorded in benzene solution.



$J_{2,3} = 6.9$ Hz

$J_{3,4} = 11.5$ Hz

$J_{4,5} = 9.5$ Hz

III-86

the two ester groups are cis to each other. A large trans vicinal coupling ($J_{2,3}$ = 6.0 Hz), again, can be explained by distortion of the pyrrolidine ring due to steric interactions between substituents at C_3, C_4 and C_5. An identical observation is made in the case of adduct III-84b which is derived from the reaction of aziridine III-31a,b with III-38.

Both aziridines III-30a,b and III-42 gave the adduct III-85a in good yield. Similarly, the aziridines III-31a,b afforded adduct III-85b with III-42. Their stereochemistry was established by nmr.

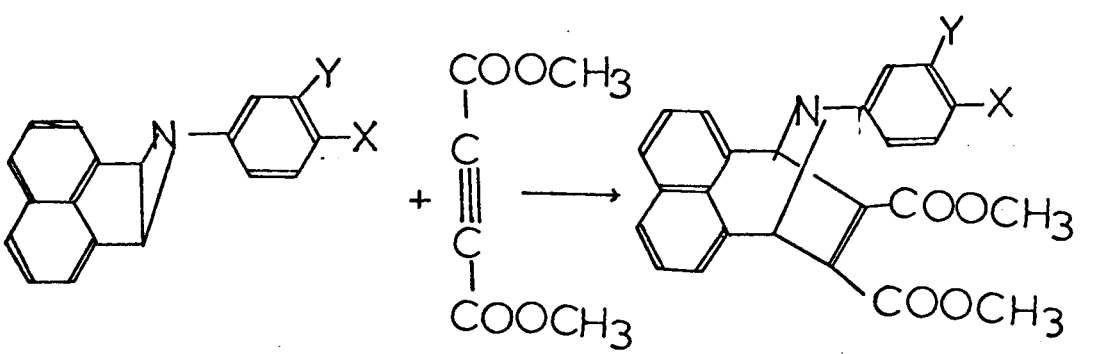
Kinetic Studies

In the preceeding section it was demonstrated that the aziridine-alkene reactions observed in this study involved cycloaddition of the aziridines to the alkenes in a manner involving cleavage of the carbon-carbon bond of the aziridines. The reaction was observed to proceed in all cases in a highly stereospecific fashion with respect to the alkene substituents and no 1,4-addition was noted

in cycloadditions with the 1,3-dienes. In order to determine the nature of the reactive intermediates in these reactions and determine the kinetic sequence of events, studies of the cycloaddition of aziridines III-25a-f to dimethyl acetylenedicarboxylate (DMAD, III-14) have been carried out in detail. A similar study of the reaction of III-25f with an olefin has been made. For comparative purposes the kinetics of the addition of aziridines III-29a-d to DMAD have also been investigated.

Kinetics of addition of III-25a-f to DMAD (III-14).

The addition of aziridines III-25a-f to DMAD in benzene at 119.5° gives a single adduct III-33a-f from each reaction in quantitative yields. The reaction displays first



III-25a-f III-33a-f

order kinetics with respect to the disappearance of the azirine. It is possible to obtain reproducible first-order rate constants, by following either the disappearance of the aziridine, ester or the appearance of the product. Since the product precipitates from the solution, most reactions may only be followed to 60% completion. The first-order rate constants for the reactions of III-25a-f with DMAD are given in Table XVI.

The first-order calculation in Table XVI for those reactions involving the use of excess of DMAD are made using the disappearance of the aziridine reactant since the ester proton signals of the products are masked by the DMAD resonance. The rate constants for the reaction involving comparable concentrations of aziridine and DMAD were made by following both the disappearance of the aziridine and DMAD as well as the appearance of the product.

It is seen from the data of Table XVI that large changes in DMAD concentration have very little effect on rate of reaction. This indicates that the rate determining step does not involve DMAD, and hence rules out the possibility of a "one-step" reaction process.

A two-step reaction sequence, considered likely is the slow equilibration of the aziridine with an intermediate activated species that in turn reacts rapidly with the olefin. This sequence may be treated kinetically by the application of steady-state approximation to the

TABLE XVI. FIRST-ORDER RATE CONSTANTS FOR THE REACTION OF THE AZIRIDINES III-25A-F WITH DIMETHYL ACETYLENEDICARBOXYLATE (DMAD)

Aziridine	$[\text{Aziridine}]_o$ mole/l.	$[\text{DMAD}]_o$ mole/l.	$k_1 \times 10^5 \times \text{sec}^{-1}$
III-25a	0.187	0.137	4.85
	0.183	1.002	5.02
	0.113	0.087	5.43
III-25b	0.184	0.129	4.09
	0.163	1.014	4.50
	0.110	0.068	4.07
III-25c	0.185	0.141	3.45
	0.187	0.285	3.67
	0.201	1.008	3.81
III-25d	0.182	0.151	7.54
	0.147	0.603	6.93
	0.118	1.741	7.18
III-25e	0.035	0.055	16.64
	0.038	0.116	17.28
	0.029	0.504	16.97
III-25f	0.181	0.147	10.95
	0.204	0.704	10.43
	0.192	1.253	10.74
	0.143	0.456	10.14

activated species. This formulation leads to the rate expression

$$\text{Aziridine} \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} [\text{Aziridine}]^*$$

$$[\text{Aziridine}]^* + \text{III-14} \xrightarrow{k_2} \text{Product}$$

of equation 7

$$\frac{dP}{dt} = \frac{k_1 \cdot k_2[Az][E]}{k_{-1} + k_2[E]} \qquad (7)$$

where P = Product, Az = aziridine, and E = dimethyl acetylenedicarboxylate, III-14.

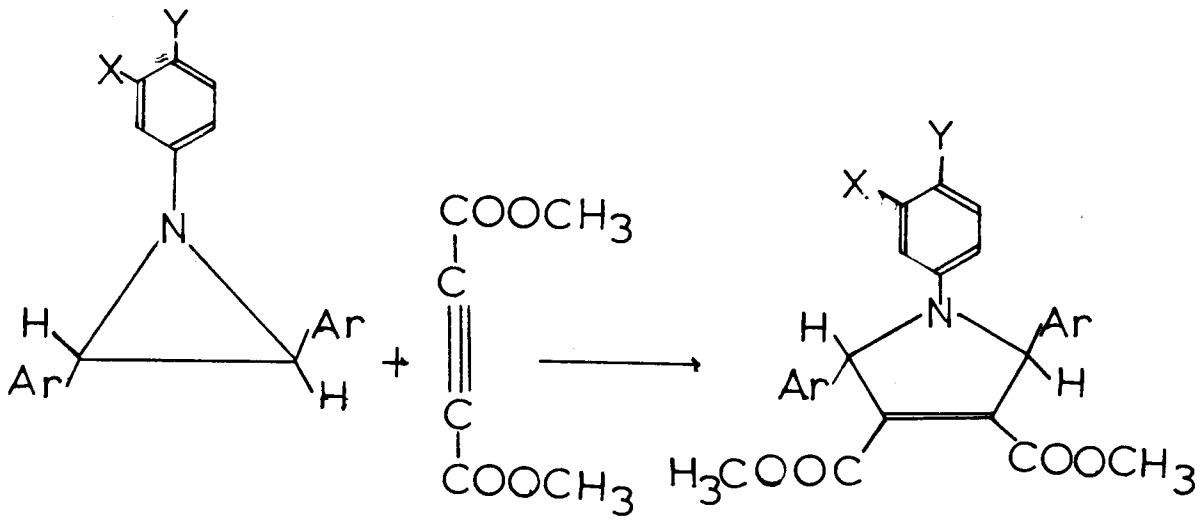
From the equation 7 it is apparent that if product $k_2[E]$ is sufficiently large, k_{-1} may be neglected in the denominator, and equation 7 reduces to equation 8.

$$\text{rate} = k_1[Az] \qquad (8)$$

Consequently, an increase in the concentration of a sufficiently reactive olefin should have little or no effect on k_1. In other words, the conversion of aziridine to $(\text{aziridine})^*$ should become rate controlling. This is in fact the case in the reaction of aziridine and DMAD.

A comparative study for the reaction of aziridines III-29a-d with DMAD has been carried out. It is observed that they also display a simple first-order reaction rate with DMAD. Since the rate of reaction of aziridines III-29a-d

with DMAD is much faster than their counterparts III-25a-f, the kinetics were investigated at 110° in benzene solution. The first-order rate constants are collected in Table XVII.



III-29a-d

III-113a-d

TABLE XVII . FIRST-ORDER RATE CONSTANTS FOR THE REACTION OF AZIRIDINES III-29A-D AND DIMETHYL ACETYLENEDICARBOXYLATE AT 110.1°±.1°C

Aziridine	[Aziridine]$_o$	[DMAD]$_o$	$k_1 \times 10^4 \times sec^{-1}$
III-29a	0.211	0.543	2.35
	0.213	0.742	2.59
	0.204	1.043	2.28
III-29b	0.206	0.547	3.17
	0.208	0.753	3.29
	0.198	0.973	3.38
	0.101	0.074	3.01
III-29c	0.205	0.529	1.73
	0.216	0.738	1.64
	0.204	0.941	1.87
III-29d*	0.213	0.498	0.91
	0.221	0.741	1.05
	0.141	0.542	0.98

*The first-order constant of III-29d with III-14 at 119.5°C was found to be 4.16×10^{-4} sec^{-1}.

Discussion

It has been shown kinetically that the thermal reaction of III-29a-d as well as III-25a-f with alkynes is not a single step reaction. The reaction therefore involves at least two steps. The structural changes occurring during the reaction are easily accommodated by a two step mechanism. The first step in both aziridine series is considered to be thermal cleavage of the aziridinyl C,C bond. The second step is then the cycloaddition of this ring opened dpecies to the 2π system of an alkyne.

As pointed out in the introduction, a key facet of this investigation was the determination of the participation of the aziridinyl nitrogen lone pair in the ring opening of the monocyclic and the bicyclic aziridines. The relationship of the stereochemistry of the aziridinyl substituents observed by Huisgen[57] for the cycloaddition of monocyclic aziridines III-17a and III-17b to DMAD was that predicted for conrotatory cleavage of the C,C bond of the aziridine to give a ring opened species which subsequently added to DMAD. If the nitrogen lone pair participates in the opening process, the transformation becomes isoelectronic with the cyclopropyl anion to allyl anion transformation. The conrotatory cleavage of the C,C bond of III-17a and III-17b is then expected to involve, at one carbon, development of a C,N double bond utilizing the electrons of the

nitrogen lone pair and, at the other carbon, a carbanion. Such C,N overlap will be facilitated by increased ability of the aziridinyl nitrogen to support a positive charge In order to test the electronic description we have determined the rate of thermal reaction of the four N-aryl-2,3-diphenyl-aziridines, III-29a-d. The presence of an electron donating substituent in the N-aryl ring indeed increases the rate of reaction, whereas electron-withdrawing groups retard the rate of reaction. Furthermore the rate of reaction bears a linear relationship to the value of the N-aryl substituents (Fig. 9).

Since the reactions were carried out under conditions where the rate of reaction was independent of the DMAD concentration the observed relationship between the N-aryl substituent and the rate of reaction are attributable to participation of the aziridinyl lone pair in a prior slower reaction. We consider this prior reaction to be the thermal ring cleavage. The ring opened species may be designated by many resonance forms, the most important of which are III-89a-d.

The contribution due to the biradical from III-89d must be neglible since heating III-29a-d in xylene or hydrocarbon solution in an esr cavity to the reaction temperature (110-130°) gave no detectable signal. Although the now polar open form III-89c may be formed upon opening of aziridines III-29a-d, it does not appear to participate in

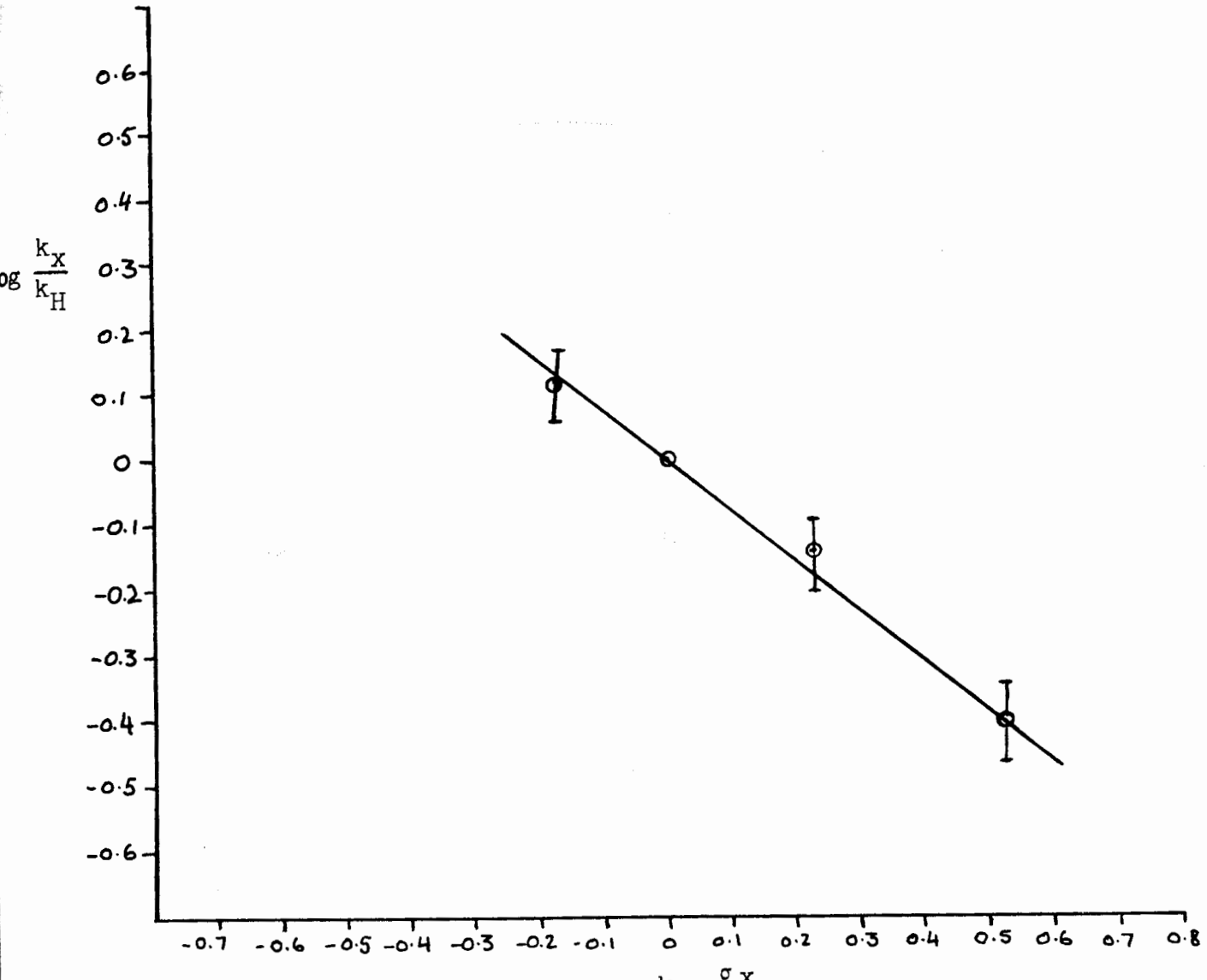
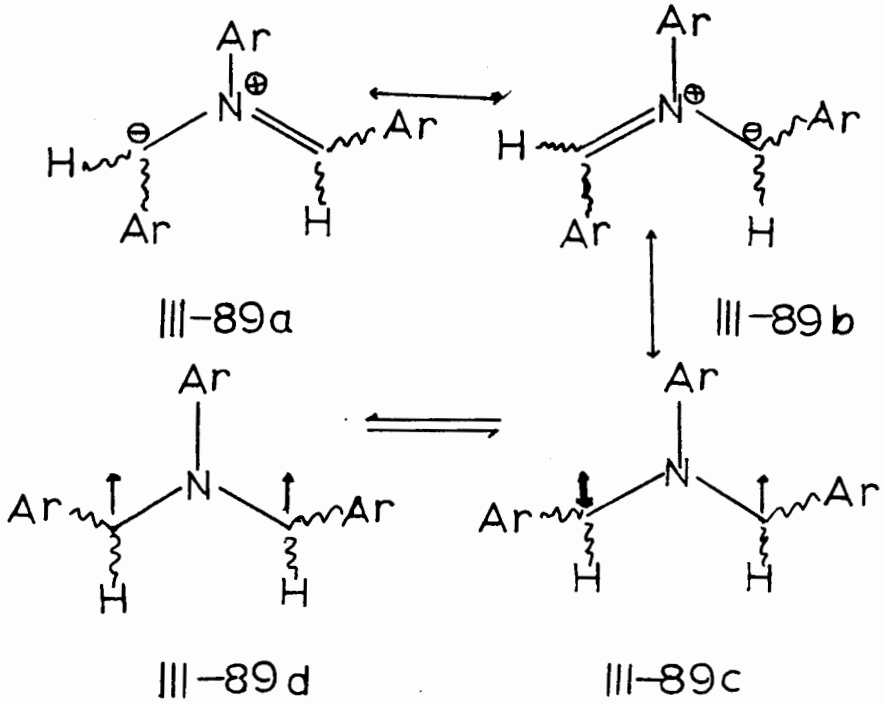


Figure 9: Correlation of log $\frac{k_X}{k_H}$ and σ_X for the decomposition of monocyclic aziridines (III-29a-d).

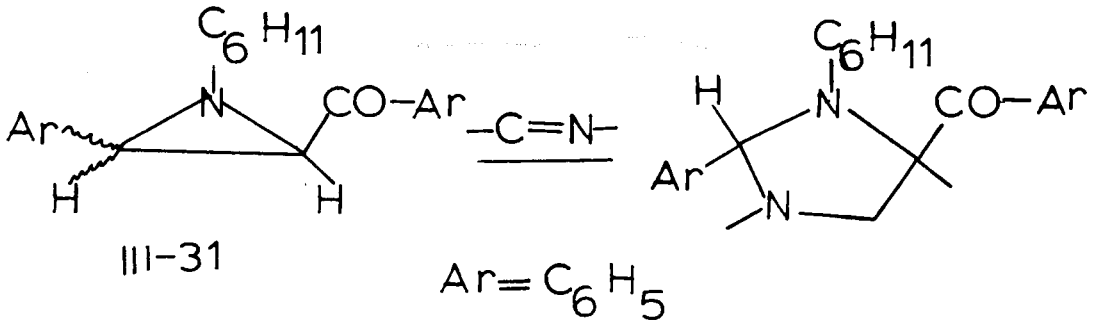


III-89a III-89b

III-89d III-89c

any of the reactions observed (as discussed below). The dipolar forms III-89a and III-89b are the ring opened forms of the aziridines III-29a-d considered to participate in the subsequent cycloaddition reactions with alkenes and alkynes. Although no kinetics were carried out on the reaction of III-30a,b and III-31b with alkenes or alkynes reactions most probably proceed via ring opened intermediates similar to III-89a and III-89b with a bias toward carbanion character at the carbon adjacent to the carbonyl group. This type of bias readily explains the orientation of addition of closely

related aziridines such as III-31 to polarized double bonds



III-31

Ar= C_6H_5

such as imines and ketones.[63,66]

The stereochemistry of the cycloaddition reaction of the ring opened aziridines to alkenes has two aspects. First, there is stereospecificity with respect to the alkene if, for example, a 1,2-disubstituted alkene is used. In all cases investigated the overall cycloaddition reaction was stereospecific with respect to the alkene component. This result is expected if the ring opened aziridine participates in the cycloaddition as a 3p-4π electron component and the alkene participates as a 2π electron component. Secondly, there is the steric relationship between the aziridinyl substituents as they are attached to the aziridine and as they finally appear in the pyrrolidine product. Huisgen[57] adequately demonstrated that under conditions where a very reactive alkyne (III-14) was added to III-17a and III-17b this aspect of the reaction was stereospecificity in concert with conrotatory opening of the aziridine ring and subsequent stereospecific cis-addition

of the ring opened species without isomerization.

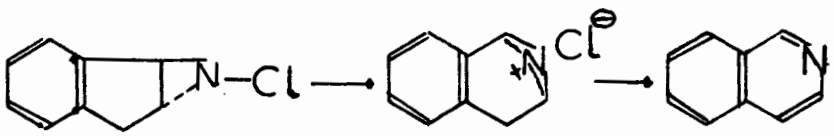
The reaction of either cis- or trans-1-benzyl-2-benzoyl-3-phenyl aziridine, III-30a,b, with DMAD, III-34, and III-38 afforded compounds in which the phenyl and the benzoyl groups were trans to each other. Similar results were obtained from the reaction of either cis- or trans-1-cyclohexyl-2-benzoyl-3-phenyl aziridine, III-31a,b, with the alkyne and alkenes mentioned above. It seems probable that in these reactions the cycloaddition is stereospecific, but in the case of cis-adduct a post isomerization to the more stable trans-adduct occurs. This has been suggested in the cycloaddition of related aziridines.[63] A similar interpretation can be advanced for the reaction of 1,2,3-triphenylaziridine with III-34, III-38 and III-42, which affords pyrrolidine derivatives in which the two phenyl groups are trans to each other.

As mentioned in the introduction the N-aryl 2,3-diphenylaziridine system (III-29a-d) was chosen for kinetic study because of its close structural similarity to the bicyclic aziridine system studied. Comparison of the rate of reaction of these two systems reveals that reaction of III-29a with III-14 is about 10 times faster than the reaction of III-25a under conditions where the cleavage of the aziridine ring is rate determining. We consider the origin of the difference to lie in the geometrical constraints of the bicyclic system which force the C,C bond of the latter aziridine to cleave by disrotation. Investigation of the

effect of N-arylsubstitution on the rate of ring opening revealed quite surprisingly that (in contrast to the observations made in the monocyclic series) electron-withdrawing groups attached to the N-aryl ring increased the rate of ring opening. Indeed the thermal rate of C,C bond cleavage gave a linear relationship with the σ substituent constants (Fig. 10).

This reversal of substituent effect demonstrates that by forcing the allowed 4π electron conrotatory opening of an aziridine to take a thermal disrotatory course one may reverse the electronic flow from the aziridinyl nitrogen during the cleavage so that as the ring cleaves electron flow proceeds from nitrogen into the N-aryl ring thus the transition state for cleavage has less than 4π electrons in its three developing p-orbitals (assuming sp^2 hybridization of the aziridinyl nitrogen and carbons in the ring opened species).

Consideration of resonance form III-25X of III-25 reveals that during the opening of III-25a minimum of three electrons will occupy the three developing p-orbitals. This consideration makes the present disrotatory opening fundamentally different than that observed in the solvolysis of III-90 which involves a two electron system.[88] A basic



III–90

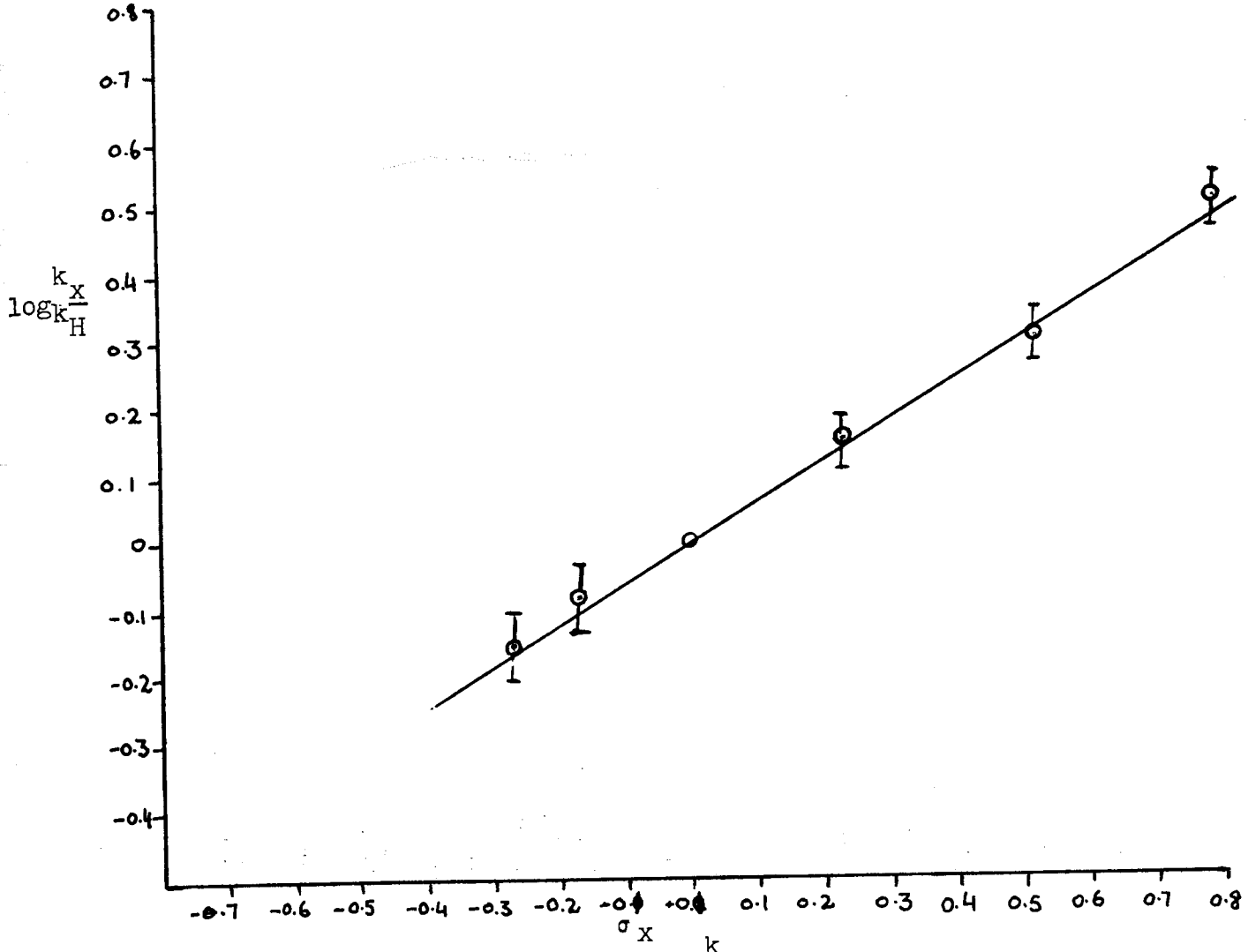


Figure 10: Correlation of $\log \frac{k_X}{k_H}$ and σ_X for the decomposition of bicyclic aziridines (III-25a-f).

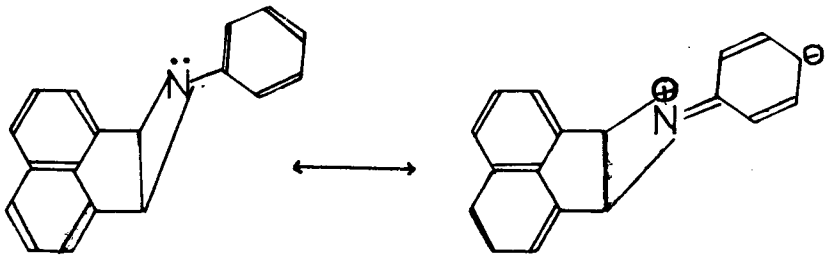
question which arises at this point is whether the ring opening may be considered more closely analogous to the cyclopropyl cation to allyl cation (2 electron system) transformation or the cyclopropyl radical to allyl radical (3 electron system) transformation[Longuet-Higgins][89] has suggested that the thermal isomerization of the cyclopropyl radical by a disrotation should be more difficult than its isomerization by a conrotation. Furthermore, since both modes of isomerizations are thermally forbidden by orbital symmetry, the energy necessary to effect the disrotatory isomerization of the cyclopropyl radical is expected to be higher than that of the cation while conrotatory radical isomerization is more difficult than that of the anion.

Considering the substituent effect observed in the cleavage of C,C bond of III-25 in the present study disrotatory cleavage of a cyclopropyl radical appears to require less energy than disrotatory cleavage of the anion. Since disrotatory rearrangement of the cyclopropyl cation is expected to be more facile than that of the radical. One might further query the nature of the initial ring opened species generated upon disrotatory opening of III-25; i.e., will it behave as an allyl radical or as an allyl cation? This question assumes that the substituent effect observed in its disrotatory opening of III-25 will, in fact, generate an intermediate possessing electron deficiency in the aziridinyl portion of III-25. This is by no means assured

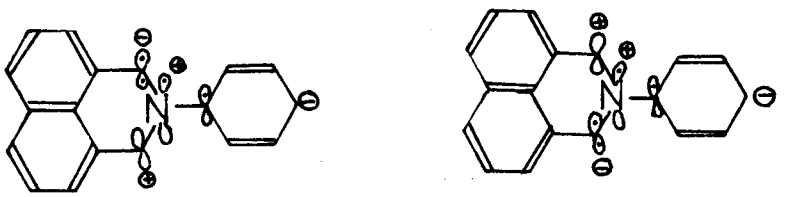
since the substituent effect observed requires only the transition state during the opening reaction to be electron deficient in this portion.

Delocalization of the aziridinyl N-electrons into an N-substituent as C,C bond cleavage occurs formally yields III-91a,b,c. Evidence as to whether or not III-91a,b,c represents a reactive intermediate in the reactions of these bicyclic aziridines or is merely a representation of a transition state generated during the C,C bond cleavage was sought in two ways. First, we considered III-91a,b,c as a 3p-2π electron system (i.e., analogous to an allyl cation) from standpoint of its reactivity with other π systems.

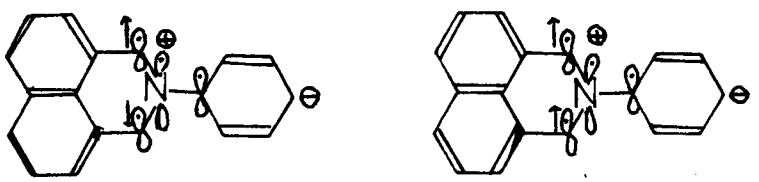
Since 1,4-cycloadditions of 1,3-dienes to 3p-2π electron systems are allowed to be concerted and have been demonstrated to occur with facility in a number of instances[90] we attempted the cycloaddition of several 1,3-dienes to the bicyclic aziridines III-25a-f. All additions occurred in a 1,2 and not a 1,4-fashion. Indeed, the cycloaddition reactions of aziridines III-25a with 1,3-dienes as well as appropriately 1,2-disubstituted alkenes were stereospecific with respect to the alkyne substituents, a behaviour expected of 3p-4π electron systems and analogous to the cycloadditions of the monocyclic aziridines discussed above. The intermediate considered to be undergoing these cycloadditions is represented by resonance hybrids III-91e and III-91f. That is, even if the bicyclic aziridines undergo cleavage as two or three electron systems, they add to alkene and 1,3-dienes as



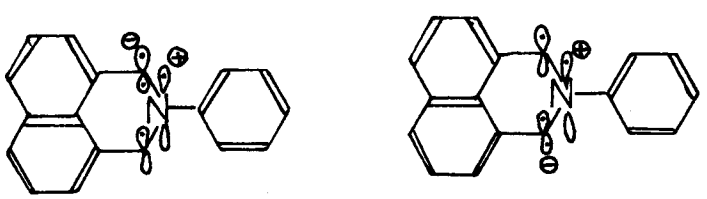
III–25 III–25X



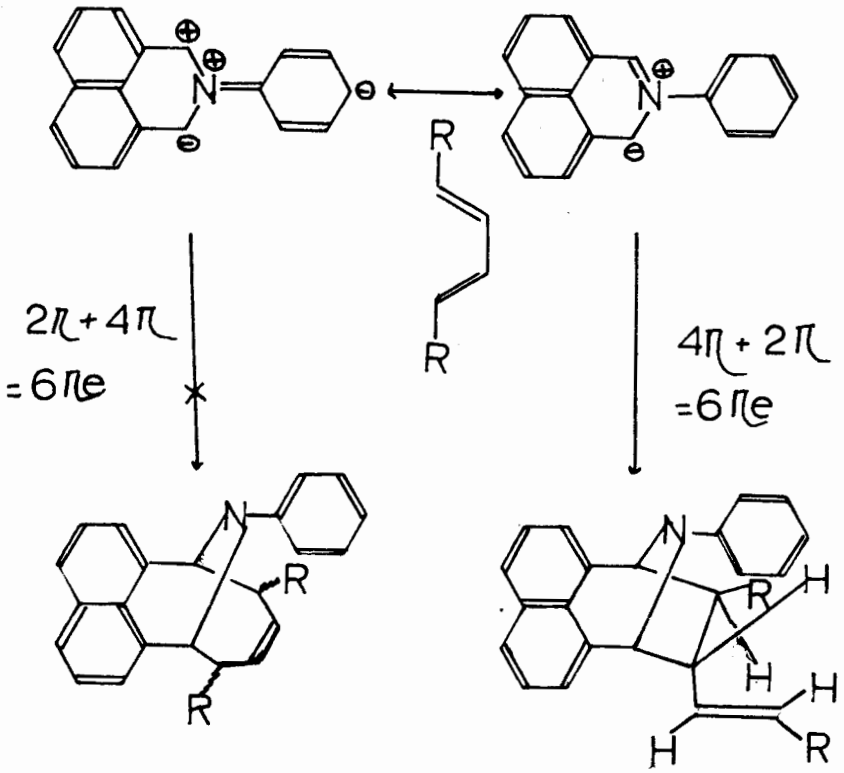
III–91a III–91b



III–91c III–91d

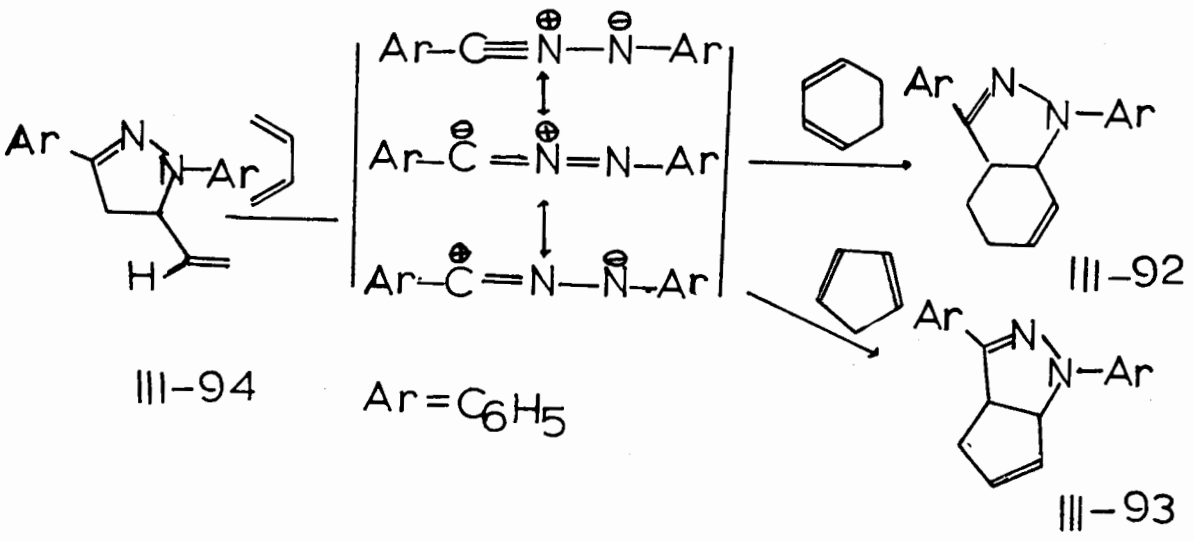


III–91e III–91f



3p-4π electron systems. Although few studies have been made to determine the mode of cycloaddition of 3p-4π systems to 1,3-dienes, an observation similar to that above has been reported in the addition of diphenyl nitrile imine to 1,3-cyclohexadiene,[91] 1,3-cyclopentadiene,[91] and 1,3-butadiene.[92] All of these dienes added to this system exclusively in a 1,2-fashion to give III-92, III-93, and III-94, respectively.

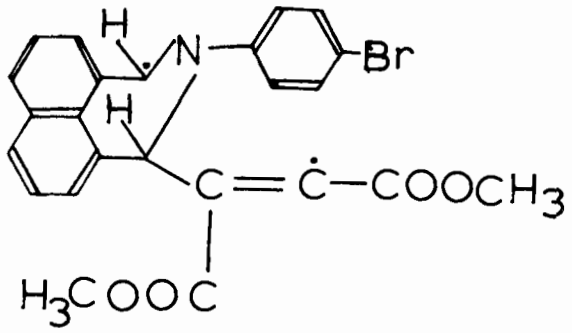
We next considered the initial ring opened species of III-25 as an allyl radical. In an effort to observe hydrogen abstraction from solvent by III-25 we decomposed III-25a in cyclohexene, cumene and xylenes. No products of



III-94 Ar = C_6H_5 III-92 III-93

hydrogen abstraction were observed. Indeed, only dimerization of the aziridine occurred in these solvents. Furthermore the presence and absence of oxygen had no noticeable effect on the reaction of III-25a in its thermal reactions of cycloaddition or dimerization. Evidence for the presence of a radical species was, however, obtained by heating (100-140°) III-25d in either hydrocarbon or aromatic (xylene, naphthalene) solvents in an esr cavity. With no precautions as to the exclusion of oxygen from the samples a relatively stable signal was obtained which showed at least 27 lines with separation of approximately 1 gauss (G). Although analysis of the hyperfine splitting in this signal is not complete, the signal is considered to be due to III-91d. Addition of DMAD to hot (100-140°) solutions containing the radical species reduce the spectrum to an approximate 1:5:10:10:5:1 pattern, A_1 = 12.2 G, in which each line is further split into a 1:2:1 triplet, A_2 = 3.6 G. This

pattern is consistent with III-95.



III-95

Heating III-25d in naphthalene with or without dimethyl maleate gave the same initial esr signal. Within five minutes, however (at 140°) if dimethyl maleate was present, the initial complex signal was transformed into a clean 1:2:3:2:1 quintet (A = 6.6 G). This latter signal decayed within 1 hr to concentrations below the range of detection of the spectrometer ($\approx 10^{-8}$ M). Although the structure of the species giving rise to this latter signal is still not identified, it has been established that it is formed only when III-25d and III-38 are heated together or when the latter is added to hot solution of III-25d.

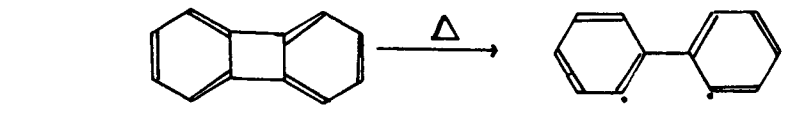
The quite obvious question as to the intermediacy of III-91c and particularly III-91d in the cycloaddition reaction of the bicyclic aziridines III-25a-f with alkenes and alkynes is thus raised.

The possibility that cycloadditions proceed via biradical intermediates has been raised previously by

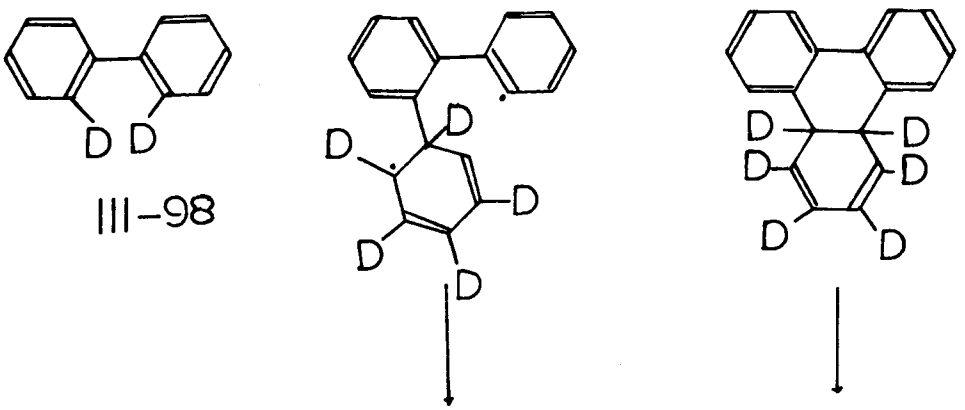
several investigators. A survey of the literature reveals that the presence of a biradical intermediate has been associated with stereo-random cycloadditions, hydrogen abstraction and polymerization. Thus, biphenylene, III-96, undergoes reactions consistent with initial homolytic cleavage of a C,C single bond to give biphenyl radicals III-97.[93] The pyrolysis of III-96 in the presence of benzene-d_6 gave biphenyl, III-98; triphenylene, III-99; and o-terphenyl, III-100.[94] The III-98 consisted of mainly d_2 and d_{10}. Biphenyl d_2 was formed from the biradical, generated on decomposition of III-96 and benzene-d_6 by deuterium abstraction, while d_{10} arose from pyrolytic coupling of benzene-d_6. III-99 and III-100 contained mainly six and four deuterium atoms per molecules, respectively. The reaction sequence is shown below.

Similarly, Reich and Cram[95] observed that thermolysis of 2,2-para-cyclophane, III-101, resulted in hydrogen abstraction from 1,4-diisopropylbenzene to afford 4,4'-dimethyldibenzyl, III-102. Furthermore, the thermal decomposition of III-101 in either III-34 or III-38 afforded identical reaction mixtures of III-103 and III-104. These data have been interpreted in terms of biradical intermediates.

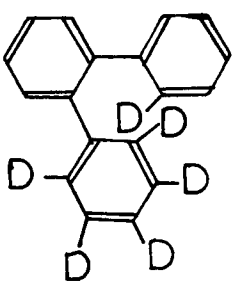
Other strained systems where biradical intermediates have been posulated are those of 3-methylbicyclo(1.1.0)-butanecarbonitrile,[96] III-105, and bicyclo(2.1.0)pentane,[97] III-106. In both cases, the C,C bond was cleaved and added



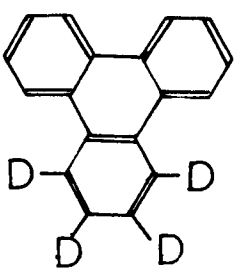
III-96 III-97



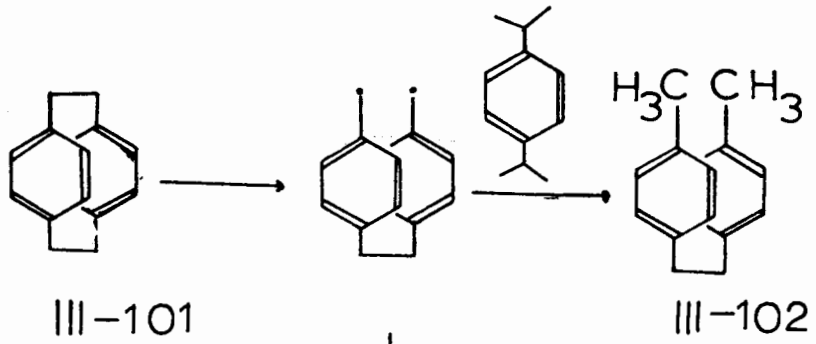
III-98



III-99

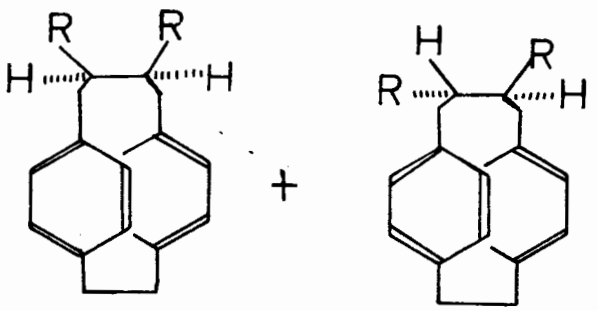


III-100



III-101 III-102

III-34 or III-38



III-103 III-104

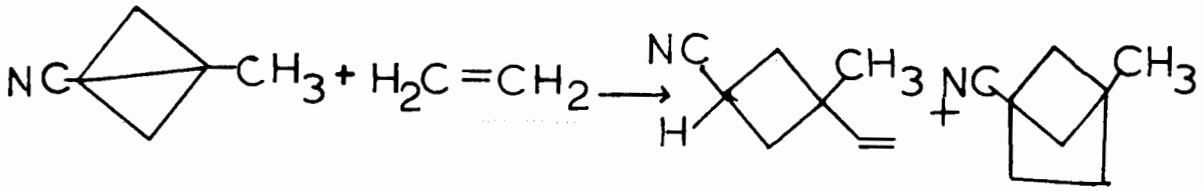
R= $COOCH_3$

Yield in

III-34	34%	30%
III-38	30%	29%

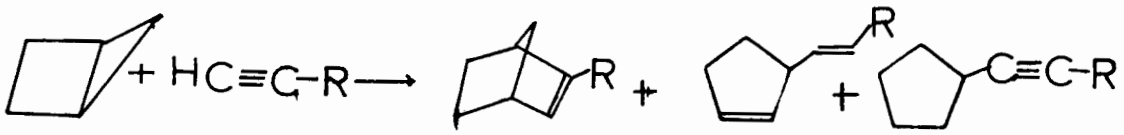
to alkynes and alkenes. In both reactions products of hydrogen abstraction were observed; and stereorandomization

took place, where possible.



III-105.

+unidentifiable polymer.



III-106 $R=COOC_2H_5$

Further information regarding stereorandomization in cycloaddition involving biradical intermediates is found in the elegant work of Bartlett and co-workers.[98] They observed that 1,2-cycloaddition of 1,1-dichloro-2,2-difluoroethylene with the geometrical isomers of 2,4-hexadiene afforded non-stereospecific products.

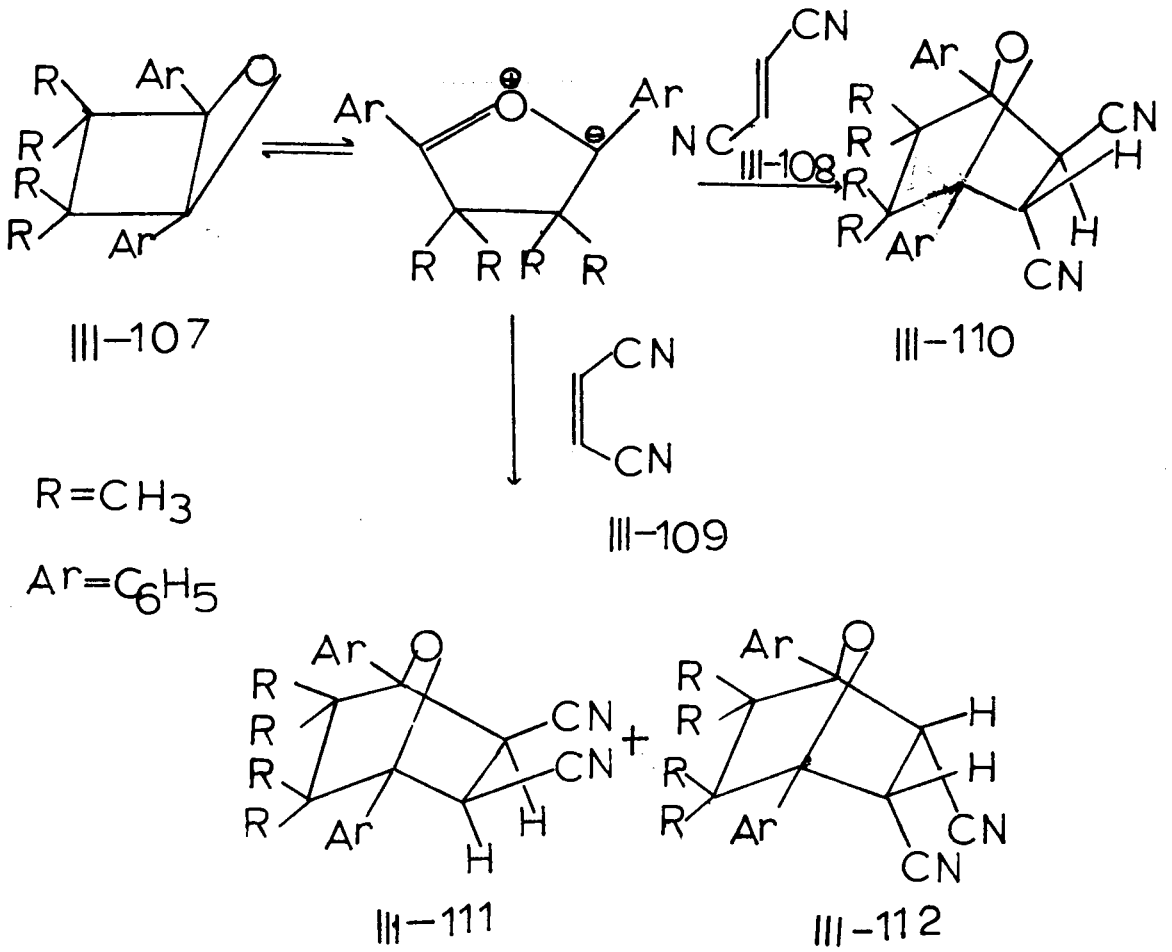
Since the cycloaddition reactions of III-25a-f failed to show any stereorandomization and we failed to observe any alkene polymerization or hydrogen abstraction, we do not consider III-91c or III-91d as reactive intermediates. We hold the view that III-91e (and III-91f) are the reactive ($_3p$-$_4$) intermediates in the 1,3-cycloaddition reactions. The substituent effect observed in the ring opening reaction indicates they are formed via III-91c which is capable of undergoing spin inversion to give III-91d. The biradical III-91d is considered to be equilibrium with III-91e and III-91f and although it is capable of reactions with

alkenes, this reaction does not represent a detectable path to products.

Evidence for this equilibrium comes from the observation of the intensity of the esr signal attributed to III-91d as a function of temperature. Thus heating III-25d in xylene to 140° established the signal. Cooling the sample gradually decreased the signal intensity while reheating the sample increased the signal intensity. Further evidence in this regard is being sought by studying the intensity of the signal at a given temperature as a function of aziridine concentration. A linear relationship should be observed if III-91d is in equilibrium with III-91c,e,f.

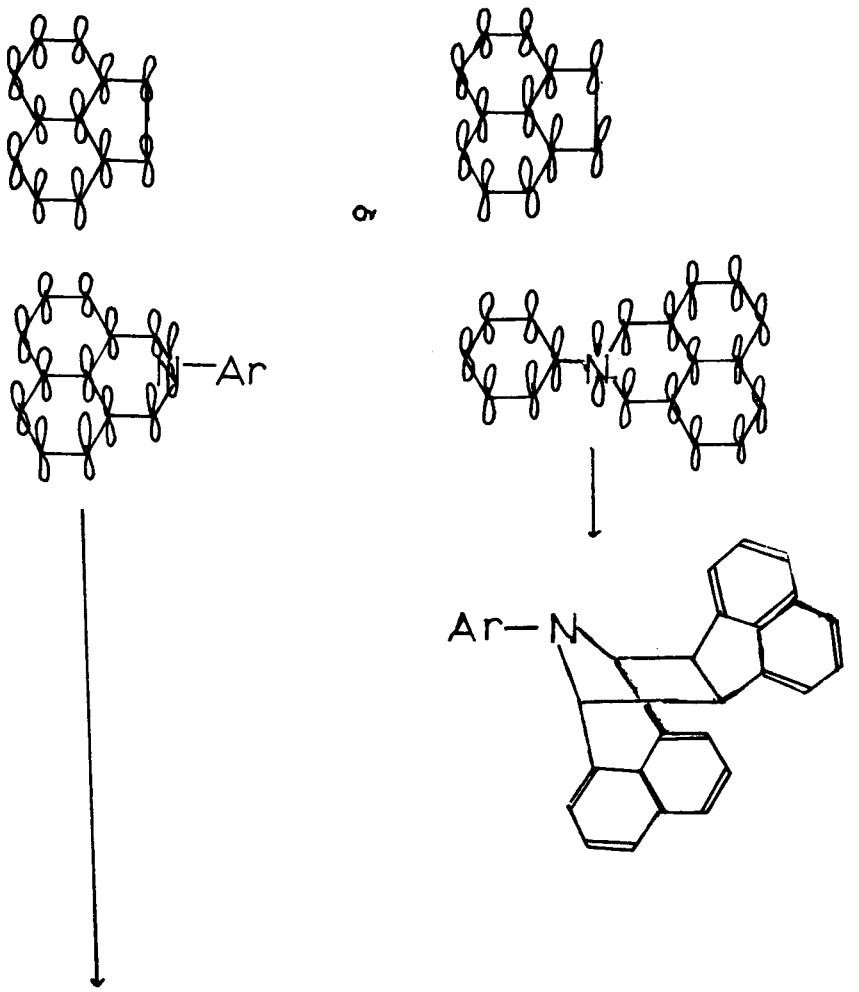
A similar interpretation could be advanced for the stereospecific addition of III-107 to III-108 and III-109 to give III-110 and III-111, III-112, respectively. Thermolysis of III-105 in inert solvent gave a stable radical species.[99]

The formation of exo and endo products in nearly equal amounts from the reaction of aziridine III-25a with maleic anhydride, dimethyl maleate, trans-methyl crotonate and with itself indicates that the reacting intermediate 4πe system is almost planar. The reaction with acenaphthylene, 1,3-cyclohexadiene, trans-trans, 2,4-hexadiene, and dimethyl trans-trans-1,3-butadiene-1,4-dicarboxylic acid resulted in compounds in which the electron rich portion of the groups attained the endo-configuration. This result is consistent with a planar intermediate and points to the stabilization



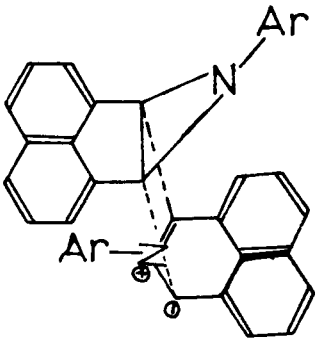
of the transition by π-interaction between the olefinic substituents and the naphthalene ring of III-25a-f. The reaction of 7a with acenaphthylene is diagramatically represented below. A similar phenomenon is expected for other systems which can have π-interaction with the naphthalene ring.

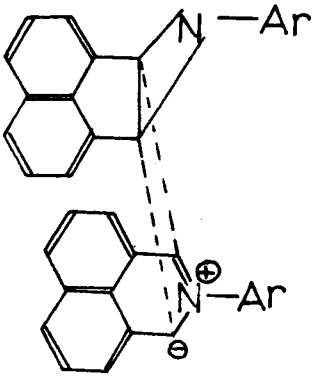
The dimerization of aziridines to give piperazin derivatives are known. The dimerization of aziridine III-25a to give two adducts can be best explained as a



major product III-57 (not isolated)

4 + 2 cycloaddition reaction. The possibility of dimerization of two reacting species such as III-91e(f) is not considered likely, since 4 + 4 thermal cycloaddition is forbidden by symmetry.[32]





trans-dimer

III-54

cis-dimer

III-55

Summary

The kinetic evidence presented indicates the reaction of monocyclic and bicyclic aziridines with alkenes and alkynes is a two step process. The first step is the cleavage of the C,C bond of the aziridines and the second step is the addition of the ring opened species to alkenes. The lone pair on the aziridinyl nitrogen participates in the conrotatory opening of the monocyclic aziridines to give directly a 3p-4 π electron dipolar intermediate, isoelectronic with an allyl anion, which adds to the alkenes in a stereospecific fashion. The disrotatory cleavage of carbon-carbon bond of the bicyclic aziridines studied is aided by electronegative substituents on the aziridinyl nitrogen. The initially formed ring opened species is considered to resemble either an allyl cation (3p-2π system) or an allyl radical (3p-3 π system). However, the product obtained indicates that the species behave as a 3p-4 π system during the addition with alkenes and dienes.

The reaction of either cis and trans-1-cyclohexyl-2-benzoyl-3-phenylaziridine (III-31a,b) afforded products in which the phenyl and the benzoyl groups were trans to each other. It seems probable that in these recations the cyclo-addition is stereospecific, but in the case of cis-adduct a post isomerization to the more stable trans-adduct occurs. Alternatively this observation could also result from prior isomerization of III-31a to III-31b. Under the conditions of the reaction these aziridines were found to isomerize to an

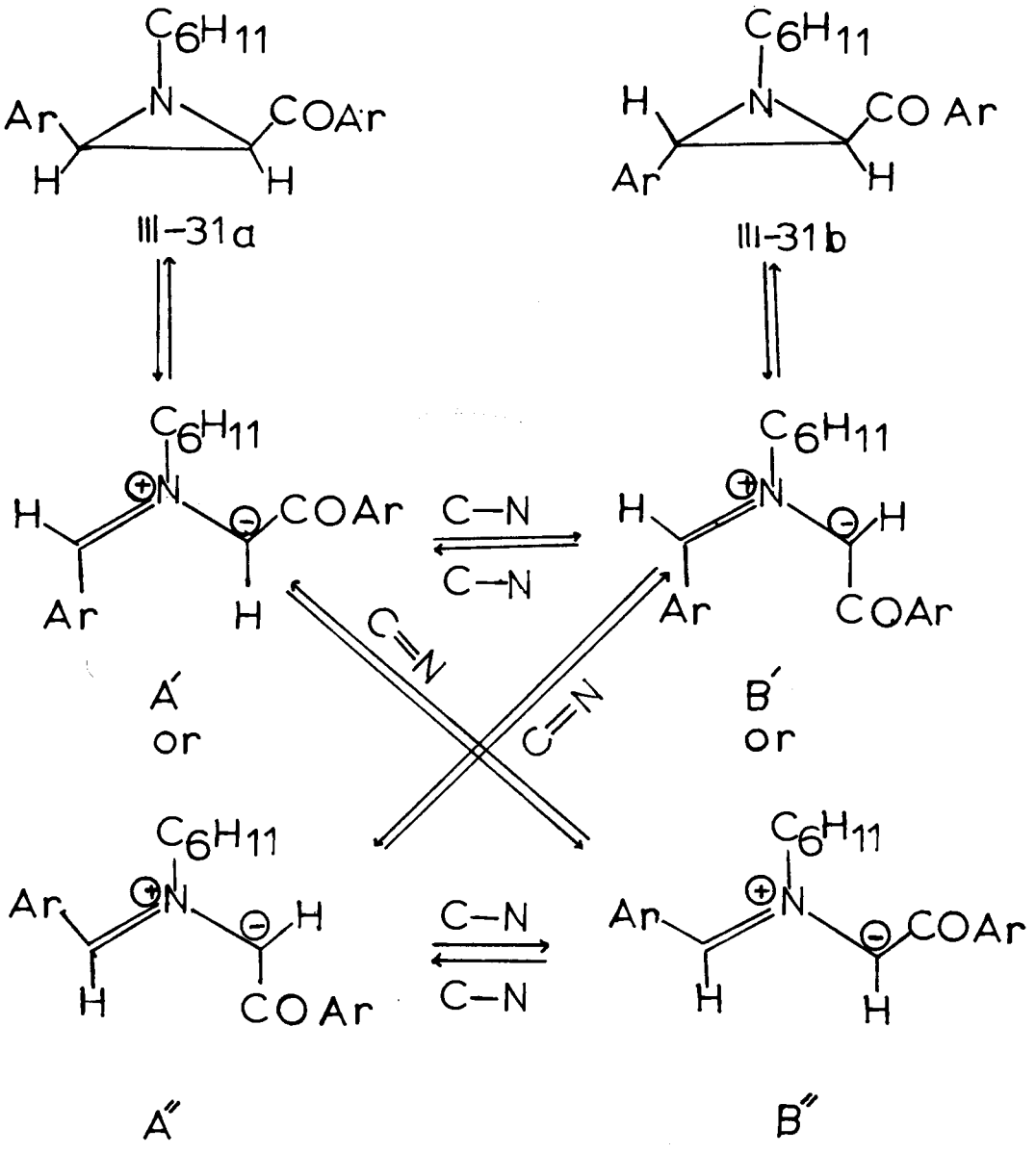
equilibrium mixture of 75% III-31b and 25% III-31a. This isomerization presumably occurs via C,C bond cleavage rather than the epimerization of the hydrogen to the benzoyl groups in these aziridines.

In theory the ring opening of III-31a in a conrotatory fashion may give two distinct open chain species A' or A" of which the former is more stable for steric reasons. Likewise conrotatory opening of III-31b may give B' or B" of which the latter clearly possesses less steric interactions. The stereochemistry observed in the cycloaddition products from both III-31a and III-31b indicates that the cycloaddition proceeds via either A' or A" and since A' is the more stable of the two, it is considered to be the likely reactive species.

In order for III-31b to react via A' or A" isomerization of the initially formed ring species must occur. There are four distinct processes by which direct isomerization of the B series may be converted to those of the A series. These are shown diagramatically in Scheme 3. In order to determine which of these operate, it is suggested that the thermal isomerization of the closely related aziridine pairs C and D should be carried out, and compare the rates of isomerizations with that of III-31a and III-31b under the identical conditions.

The opening of <u>cis</u> aziridines of series C and D can give rise to open species of type A' or A". If these

Scheme 3


C6H11
Ar
N
COAr
H
H
III-31a
C6H11
H
N
CO Ar
Ar
H
III-31b
C6H11
H
N
COAr
Ar
H
C—N
C—N
C6H11
H
N
H
Ar
COAr
A´
or
B´
or
C=N
C=N
C6H11
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COAr
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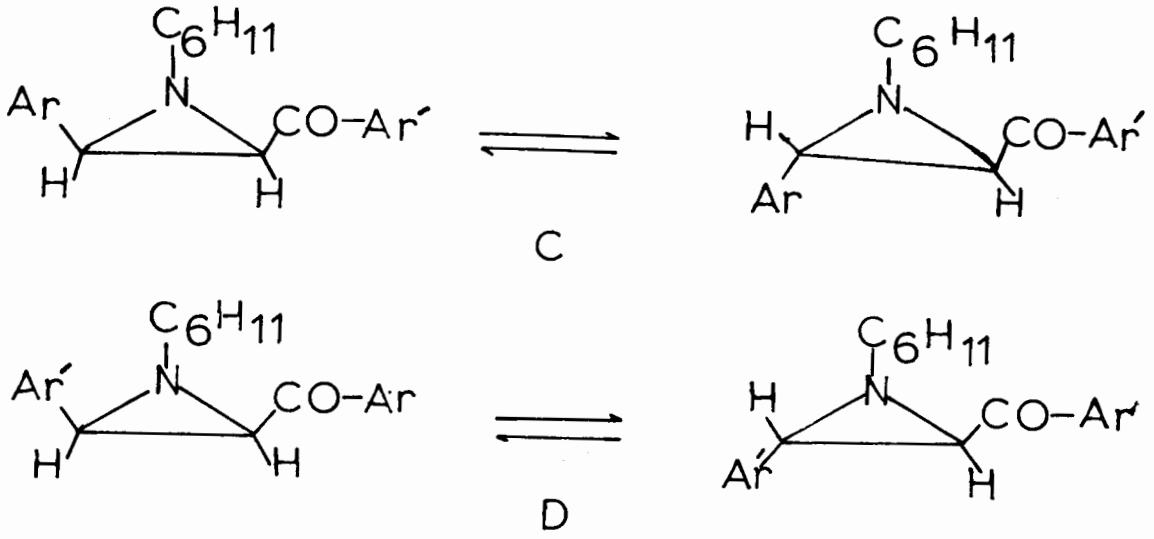
H
A´´
B´´



Ar'= $C_6H_4-NO_2$

aziridines open to give species of type A', then the rotation of C-N bond leading to species of type B' will be faster for the species derived from cis C aziridine than the one obtained from cis D aziridine, since the negative charge on carbon bearing p-nitrobenzoyl group is minimized by the electron withdrawing property of p-nitrobenzoyl group. On the other hand, the C=N rotation (high energy) will be faster in species of type A' derived from cis D than that of type A' of cis C since the double bond character between nitrogen and the carbon bearing p-nitrophenyl group will be lowered by inductive effect. A similar reasoning can be advanced for the isomerization of the species of type A".

The expected observations on these assumptions are summarized below.

cis C or D		NO_2-benzoyl	NO_2-phenyl
Type A'	$\overset{C-N}{\rightleftharpoons}$ Type B' $\rightleftharpoons$ *trans*	faster	slower
Type A'	$\overset{C=N}{\rightleftharpoons}$ Type B" $\rightleftharpoons$ *trans*	slower	faster
Type A"	$\overset{C-N}{\rightleftharpoons}$ Type B" $\rightleftharpoons$ *trans*	faster	slower
Type A"	$\overset{C=N}{\rightleftharpoons}$ Type B' $\rightleftharpoons$ *trans*	slower	faster

The consideration of orbital symmetry control of concerted organic reactions is relatively new concept. The basic reason for undertaking the present study was to learn more about the influence of orbital symmetry control in those reactions in which the polarity of the transition states could be changed by polar substituents. Of several lines of investigation that could be persued further in this area, the study of the cycloaddition of charged intermediates such as allyl anions and cations to alkenes, 1,3-dienes, and trienes appear attractive. There are several classes of cycloaddition reactions which have not been investigated, and are potentially synthetically useful. For example the photochemical cyclo-addition of allyl anion analoges to dienes (4+4 addition).

Experimental

Preparation of 7-phenyl-6a,7a-dihydro-acenaphtha [1,2-b -] aziridine, III-25a.

A solution of acenaphthylene (3.0 g) and phenyl azide (2.4 g) in dichloromethane (15 ml) was allowed to react at room temperature, in dark, for $2\frac{1}{2}$ months, during which time granular product had deposited. Removal of the solvent, and dilution of reddish semi-solid with ether-pet ether mixture gave III-25a as a white solid, 3.7 g (76%), mp 168-171°. It was recrystallized from boiling cyclohexane: mp 171-172.5°; ir (KBr) 3030 (C-H), 1600, 1510, 1453 (aromatic), 755, 745 (naphthyl ring), and 695 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ4.27 (s, 2H), and 6.51-7.51 (m, 11H, aromatic).

Anal. Calc. for $C_{18}H_{13}N$: C, 88.85; H, 5.37 mol.wt. 243.
Found: C, 88.67; H, 5.42; mol.wt. 243.

The aziridines III-25b-f were synthesised by reaction of 1.5-2 molar excess of appropriately substituted azide with acenaphthylene at 60 to 70° in benzene solution. The yield of aziridine depends on the reactivity of the azide. If excess azide is not used, the thermal dimerization of acenaphthylene becomes an undesirable side reaction. Similarly, a higher concentration of acenaphthylene and a higher temperature results in adduct formation with

TABLE XVIII

YIELDS, MELTING POINTS, AND ANALYSES OF N-ARYL-6b,7a-DIHYDRO-ACENAPHTHA[1,2-b]AZIRIDINES

Aziridines	Yield(%)	m.p.(°C)	Analysis			
			Calculated		Found	
			C	H	C	H
III-25a	75	171-172.5	88.85	5.37	88.67	5.42
III-25b	69	167-168.5	88.68	5.88	88.54	5.73
III-25c	57	145-146.5	83.49	5.55	83.35	5.64
III-25d	81	188-190	67.08	3.75	66.97	3.91
III-25e	83	225-227	74.98	4.16	75.21	4.13
III-25f	80	139.5-141	69.21	3.55	69.08	3.43

acenaphthylene and the dimerization of the aziridine, respectively.

The yield and the physical properties of aziridines III-25a-f are collected in Table XIX and XX

Preparation of aziridines III-29a-d, III-30a,b, and III-31a,b.

These aziridines were prepared using procedures prescribed in the literature[73-75]. Their physical data are recorded in Table XXI and are in agreement with the reported values, where applicable.

Preparation of III-33.

A benzene solution (10 ml) of III-25a (500 mg) and dimethyl acetylendicarboxylate (290 mg) was heated at 140° for 8 hr in a sealed tube. Removal of the solvent in vacuuo gave III-33 as a pale yellow solid which was washed with methanol, filtered and dried to yield 685 mg (93%), mp 210-212°. An analytical sample was obtained by recrystallization from benzene-pet ether: mp 211-212.5°; ir (KBr) 3050, 2950 (C-H), 1720 (conjugated ester), 1645 (tetrasubstituted double bond conjugated with a carbonyl group), 1605, 1510, 1450 (aromatic), 1300-1200 (C-O stretching), 794, 770 (naphthyl ring), and 705 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.73 (s, 6H, methyl ester at C_3, C_4), 5.78 (s, 2H, C_2, C_5), and 6.61-7.71 (m, 11H, aromatic).

TABLE XIX

SPECTRAL DATA OF N-ARYL-6b,7a-DIHYDRO-ACENAPHTHA[1,2-b]-AZIRIDINES

Aziridines	nmr(δ)	$\lambda_{max}(\log_{10}\varepsilon)$ (CH_3CN)
III-25a	4.33(s,2H) 6.67-7.63(m,11H)	229(4.66), 242(4.13) 281(3.90), 292(3.96), 306(3.76)
III-25b	2.10(s,3H) 4.30(s,2H) 6.70-7.65(m,10H)	230.5(4.60), 243(4.19) 281(3.86), 291(3.93), 306(3.74)
III-25c	3.43(s,3H) 4.16(s,2H) 6.40-7.57(m,10H)	228(4.62), 240(4.18) 281(3.91), 292(3.97), 307(3.74)
III-25d	4.36(s,2H) 6.65-7.60(m,10H)	226(4.60), 250(4.25), 282(3.50) 292(3.95), 306(3.76)
III-25e	4.59(s,2H) 6.58-7.77(m,10H)	229(4.78), 262(4.34), 282(3.24) 306(4.15), 327(4.32)
III-25f	4.29(s,2H) 6.42-7.67(m,9H)	226(4.60), 251(4.18), 282(3.87) 292(3.93), 306(3.78)

TABLE XX

PHYSICAL PROPERTIES OF AZIRIDINES III-29a-d, III-30a,b and III-31a,b

Aziridine	mp	nmr(δ)
III-29a	98-99.5° (Lit.[73] 99°)	3.43(s,2H), 6.95-7.36(m,15H)
III-29b	113-114.5°	2.25(s,3H), 3.51(s,2H), 6.93-7.26(m,14H)
III-29c	92-93.5°	3.50(s,2H), 6.80-7.22(m,14H)
III-29d	114-155°	3.73(s,2H), 6.74-7.26(m,13H)
III-30a	59-61° (Lit.[74] 59-62°)	3.05(AB quart.,2H,J_{AB}=6.8Hz), 3.65(AB quart.,-CH_2-,2H, J_{AB}=14.1Hz), 6.95-7.84(m,15H)
III-30b	107-108.5° (Lit.[75] 108°)	3.28(s,2H), 3.85(AB quart.,2H,J_{AB}=14.0Hz) 6.97-7.92(m,15H)
III-31a	108-109° (Lit.[74] 107-109°)	1.02-2.76(b,11H), 3.17(AB quart.,2H, J_{AB}=7.0Hz), 7.13-8.16(m,10H)
III-31b	99-100° (Lit.[74] 99-101°)	1.01-2.76(b,11H), 3.57(AB quart.,J_{AB}=2.9Hz) 7.13-8.16(m,10H)

Anal. Calc. for $C_{24}H_{19}NO_4$: C, 74.79; H, 4.96; mol.wt. 385.
Found: C, 74.96; H, 4.68; mol.wt. 385.

Hydrogenation of III-33.

A solution of III-33 (245 mg) in toluene (10 ml) and methanol (50 ml) using 50 mg of 5% Pt on charcoal was allowed to react under hydrogen at 50 psig for 24 hr. The removal of the solvent gave III-39, mp 201-203°, 232 mg (94%). The nmr and the ir spectra of III-39 prepared in this manner were identical to those III-39 prepared by reaction of dimethyl maleate with III-25a described below. The mixed melting points of III-39 from these two sources were undepressed.

Preparation of III-35.

A benzene solution (10 ml) of III-25a (500 mg) and dimethyl fumarate (291 mg) was heated at 140° for 14 hr in a sealed tube. Removal of the solvent under reduced pressure gave red liquid which crystallized from methanol-pet ether to afford III-35, 683 mg (89%), mp 144-146.5°. An analytically pure sample was obtained by further crystallization from methanol-pet ether: mp 145-146.5°; ir (KBr) 3010, 2875 (C-H), 1730, 1718 (unconjugated ester), 1602, 1515, 1462 (aromatic), 1300-1180 (C-O stretching), 780, 760 (naphthyl ring), and 700 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.46 (s, 3H, *endo* methyl ester at C_4), 3.75 (s, 3H, *exo* methyl ester at C_3),

3.66 (d, 1H, C_3, $J_{3,4}$ = 5.7 Hz), 4.28 (d of d, 1H, C_4, $J_{3,4}$= 5.7 Hz, $J_{4,5}$ = 7.0 Hz), 5.49 (d, 1H, C_5, $J_{4,5}$ = 7.0 Hz), 5.55 (s, 1H, C_2), and 6.52-7.66 (m, 11H, aromatic).

Anal. Calc. for $C_{24}H_{21}NO_4$: C, 74.40; H, 5.46; mol.wt. 387.
Found: C, 74.24; H, 5.55; mol.wt. 387.

Preparation of III-39 and III-40.

A benzene solution (10 ml) of III-25a (750 mg) and dimethyl maleate (450 mg) was heated in a sealed tube at 140° for 14 hr. Removal of the solvent left a red oil which was taken up in 75-80 ml of boiling ethanol. Standing at room temperature for 6-8 hr gave a thick layer of III-39, 340 mg, mp 201-203°. The filtrate was concentrated to half its volume. On standing this concentrate gave another 150 mg of III-39 (43%). An analytical sample was obtained by recrystallization from hot mathanol: mp 202-203°; ir (KBr) 3030, 2850 (C-H), 1730 (unconjugated ester), 1605, 1510, 1467 (aromatic), 1205, 1180 (C-O stretching), 785, 770 (naphthyl ring), and 700 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.29 (s, 6H, endo methyl ester at C_3 and C_4), 3.86 (2d, 2H, C_3, C_4, $J_{2,3}$ = 7.2 Hz, $J_{4,5}$ = 2.0 Hz), 5.41 (2d, 2H, C_2, C_5, $J_{2,3}$ = 7.2 Hz, $J_{4,5}$ = 2.0 Hz), and 6.36-7.63 (m, 11H, aromatic).

Anal. Calc. for $C_{24}H_{21}NO_4$: C, 74.40; H, 5.46; mol.wt. 387.
Found: C, 74.31; H, 5.42; mol.wt. 387.

Further concentration of the mother liquor from the last operation and the repeated procedure gave 137 mg of a mixture of III-39 and III-40; mp 180-195°. The filtrate was concentrated and treated with pet ether which on standing for overnight yielded III-40, 390 mg; mp 188-190.5°. Evaporation of the solvent to dryness gave III-40, 70 mg (40%), mp 187-190°. An analytical sample of III-40 was prepared by recrystallization from benzene-pet ether: mp 189-190.5°; ir (KBr) 3025, 2820 (C-H), 1740 (unconjugated ester), 1603, 1507, 1454 (aromatic), 1310, 1270, 1220, 1170 (C-O stretching), 795, 760 (naphthyl ring), and 695 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.73 (s, 6H, exo methyl ester at C_3, C_4), 3.47 (s, 2H, C_3, C_4), 5.56 (s, 2H, C_2, C_5), and 6.62-7.53 (m, 11H, aromatic).

Anal. Calc. for $C_{24}H_{21}NO_4$: C, 74.40; H, 5.46; mol.wt. 387.
Found: C, 74.68; H, 5.28; mol.wt. 387.

The nmr analysis of the crude mixture indicated the isomers III-39 and III-40 to be present in 54 and 46% yield, respectively.

Preparation of III-43 and III-44.

A solution of III-25a (500 mg) and maleic anhydride (200 mg) in benzene (15 ml) was heated in a sealed tube at 140° for 8 hr. Removal of the solvent gave a semi-solid which was washed with ether to yield III-43 as a solid. The solid was

filtered, washed with ether and dried to give 400 mg (60%); mp 255-257°. Recrystallization from hot toluene afforded a pure sample of III-43: mp 256-257.5°; ir (KBr) 3010 (C-H), 1841, 1775 (anhydride), 1603, 1505, 1447 (aromatic), 1280, 1230, 1210 (C-O stretching), 785, 760 (naphthyl ring), and 695 cm^{-1} (monosubstituted benzene ring); nmr (DMSO-d_6) δ3.84 (s, 2H, C_3, C_4), 5.76 (s, 2H, C_2, C_5), and 6.83-7.83 (m, 11H, aromatic).

Calc. for $C_{22}H_{15}NO_3$: 341 (M^+). Found: 341 (M^+).

Evaporation of the filtrate gave a beige oil, III-44, which resisted crystallization. Its ir spectrum (thin film) showed absorption due to anhydride moiety at 1853 and 1776 cm^{-1}, and the nmr ($CDCl_3$), though not well defined, had two sets of doublets centred at δ4.19 (2H), and another two sets of doublets centred at δ5.42 (2H).

Conversion of III-44 to III-39

The oil in 10 ml of methanol was treated with an excess of ethereal diazomethane. Evaporation of the solvent at 50° left a semi-crystalline material which was treated with methanol to give III-39, 210 mg (28%); mp 202-204°. The nmr and ir spectra of III-39 prepared in this manner were identical to those of III-39 prepared upon reaction of III-38 with III-25a. The mixed melting point of III-38 from the two sources was undepressed.

Conversion of III-43 to III-40.

A suspension of anhydride adduct III-43 (200 mg) in ether-methanol solution (20 ml) was treated with an excess of ethereal diazomethane solution at -70° and was allowed to warm to room temperature. The usual work up procedure afforded needles, 200 mg (90%), mp 188-190°. The nmr and ir spectra of this dimethyl ester were identical to those recorded for the diester III-40 obtained from reaction of III-38 with III-25a.

In a separate experiment, the entire mixture obtained after evaporation of the solvent, from III-25a (245 mg) and III-42 (101 mg) was treated with an excess of diazomethane until the yellow color persisted. The usual work up procedures gave a mixture of dimethyl esters III-39 and III-40, 324 mg (87%). The integral analysis of the nmr spectrum of the mixture of III-39 and III-40 revealed that the two esters were present in the ratio of 42 to 58.

Preparation of III-52 and III-53.

A benzene solution (15 ml) of III-25a (750 mg) and trans- methyl crotonate (750 mg) was heated in a sealed tube at 140° for 16 hr. Removal of the solvent gave red oil. Treatment of the crude reaction mixture with benzene-pet ether gave a ppt of III-52 which was filtered and dried to yield 510 mg (50%), mp 174-177.5°. Recrystallization from benzene-pet ether gave white needles: mp 176-177.5°;

ir (KBr) 3010, 2945 (C-H), 1735 (unconjugated ester), 1603, 1510, 1450 (aromatic), 1280, 1200, 1180 (C-O stretching), 790, 770 (naphthyl ring), and 705 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ1.43 (d, 3H, exo methyl at C_3, $J_{3\text{-}CH_3}$ = 7.0 Hz), 2.84 (quintet, 1H, C_3, $J_{3\text{-}CH_3}$ = 7.0 Hz, $J_{3,4}$ = 6.5 Hz), 3.37 (d of d, 1H, C_4, $J_{3,4}$ = 6.5 Hz, $J_{4,5}$ = 6.5 Hz), 3.37 (s, 3H, endo methyl ester at C_4, 4.70 (s, 1H, C_2), 5.46 (d, 1H, $J_{4,5}$ = 6.5 Hz), and 6.41-7.61 (m, 11H, aromatic).

Anal. Calc. for $C_{23}H_{21}NO_2$: C, 80.44; H, 6.16; mol.wt. 343.
Found: C, 80.25; H, 6.21; mol.wt. 343.

Removal of the solvent from the filtrate to dryness gave a red oil which was taken up in hot pet ether. On cooling III-52 deposited, 407 mg (41%); mp 155-157°. Further purification from charcoal treatment gave III-53: mp 158-159.5°; ir (KBr) 3015 (C-H), 1728 (unconjugated ester), 1590, 1495, 1437 (aromatic), 1260, 1190, 1170, 1135 (C-O stretching), 780, 745 (naphthyl ring), and 685 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ0.83 (d, 3H, endo methyl at C_3, $J_{3\text{-}CH_3}$ = 6.7 Hz), 2.57 (d, 1H, C_4, $J_{3,4}$ = 6.5 Hz), 3.25 (m, 1H, C_3, $J_{3\text{-}CH_3}$ = 6.7 Hz, $J_{3,4}$ = 6.5 Hz, $J_{2,3}$ = 6.2 Hz), 3.70 (s, 3H, exo methyl ester at C_4), 5.07 (d, 1H, C_2, $J_{2,3}$ = 6.2 Hz), 5.49 (s, 1H, C_5), and 6.50-7.61 (m, 11H, aromatic).

Anal. Calc. for $C_{23}H_{21}NO_2$: C, 80.44; H, 6.16; mol.wt. 343.
Found: C, 80.38; H, 6.19; mol.wt. 343.

Preparation of III-54 and III-55.

A benzene solution (10 ml) of III-25a (250 mg) was heated at 140° in sealed tube for 14 hr. On cooling the reaction mixture III-54 precipitated which was filtered, washed with benzene and dried to yield 117 mg (47%), mp 318-321° (dec). A pure sample was obtained by crystallization from boiling toluene: mp 322-324° (dec); ir (KBr) 3050, 2900 (C-H), 1600, 1510, 1450 (aromatic), 792, 762 (naphthyl ring), and 698 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ5.09 (s, 4H), 6.30-7.01 (m, 10H, 2 phenyl); 7.33-7.83 (m, 12H, 2 naphthyl); nmr (CF_3COOH) δ5.54 (s, 4H), 6.12-6.63 (m, 10H, 2 phenyl), and 7.12-7.64 (m, 12H, 2 naphthyl).

Anal. Calc. for $C_{36}H_{26}N_2$: C, 88.85; H, 5.38; mol.wt. 486.
Found: C, 88.61; H, 5.47; mol.wt. 486.

Evaporation of the solvent gave III-55, 102 mg (41%), mp 278-281° (dec). Recrystallization from benzene-pet ether gave: mp 280-282° (dec); ir (KBr) 3030, 2900 (C-H), 1603, 1510, 1420 (aromatic), 797, 760 (naphthyl ring), and 705 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ5.79 (s, 4H), and 6.63-7.03 (m, 22H, aromatic).

Anal. Calc. for $C_{36}H_{26}N_2$: C, 88.85; H, 5.38; mol.wt 486.
Found: C, 88.57; H, 5.52; mol.wt. 486.

Preparation of III-57.

A benzene solution (10 ml) of III-25a and purified acenaphthylene (155 mg) was heated at 140° in a sealed tube for 14 hr. On cooling III-54 separated which was collected, washed with benzene and dried to yield 22 mg (8%).

Evaporation of the solvent gave red oil which on standing at room temperature solidified. The solid was washed with ether to afford III-57, 305 mg (77%), mp 225-228°. An analytical sample was obtained from benzene-pet ether: mp 227-228.5°; ir (KBr) 3050, 2950 (C-H), 1605, 1510, 1440 (aromatic), 795, 775 (naphthyl ring), and 700 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ5.07 (2d, 2H, C_3, C_4, $J_{2,3}$ = 7.5 Hz, $J_{4,5}$ = 3.0 Hz), 5.69 (2d, 2H, C_2, C_5, $J_{2,3}$ = 7.5 Hz, $J_{4,5}$ = 3.0 Hz), and 6.96-7.28 (m, 17H, aromatic).

Anal. Calc. for $C_{30}H_{21}N$: C, 91.11; H, 5.35; mol.wt. 395.
Found: C, 90.82; H, 5.56; mol.wt. 395.
C, 91.01; H, 5.45;.

Preparation of III-62 and III-63.

A benzene solution (15 ml) of III-25a (500 mg) and dimethyl muconate, III-61, (340 mg) was heated in a sealed tube at 140° for 14 hr. The reaction mixture on cooling at room temperature gave white needles of unreacted diester, 70 mg (19%), mp 155-157° (Lit.[101] mp 156-157°)

Evaporation of the filtrate afforded an oil which was crystallized from hot methanol. The crystalline product was filtered, washed with cold methanol, and dried to yield III-63, 210 mg (31%), mp 296-299°. Further crystallization from benzene-pet ether gave III-63: mp 298-300°; ir (KBr) 3050, 2950 (C-H), 1737 (unconjugated ester), 1603, 1510, 1444 (aromatic), 1280-1180 (C-O stretching), 790, 783 (naphthyl ring), and 695 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.25 (d, 2H, C_3, $C_{3'}$, $J_{3,4} = J_{3',4'} = 6.5$ Hz), 3.51 (s, 6H, exo methyl ester at C_3, $C_{3'}$), 3.80-4.21 (b, 2H, C_4, $C_{4'}$), 5.28 (s, 2H, C_2, $C_{2'}$), 5.50 (d, 2H, C_5, $C_{5'}$, $J_{4,5} = J_{4',5'} = 6.5$ Hz), and 6.48-7.67 (m, 22H, aromatic).

Anal. Calc. for $C_{44}H_{36}N_2O_4$: C, 80.48; H, 5.48; mol.wt. 656.
Found: C, 80.57; H, 5.65; mol.wt. 656.

The mother liquor was evaporated and treated with hot pet ether to give III-62, 520 mg (63%), mp 146-149°. An analytical sample was obtained by recrystallization from benzene-pet ether: mp 148-149.5°; ir (KBr) 3050, 2950 (C-H), 1733 (unconjugated ester), 1710 (conjugated ester), 1658 (double bond conjugated with a carbonyl group), 1603, 1505, 1437 (aromatic), 1220, 1170 (C-O stretching), 787, 767 (naphthyl ring), and 695 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ2.93 (d, 1H, C_3, $J_{3,4} = 6.2$ Hz), 3.53 (s, 3H, exo methyl ester at C_3), 3.70 (s, 3H, methyl ester at C_7), 3.98 (m, 1H, C_4, $J_{3,4} = 6.2$ Hz, $J_{4,5} = 6.0$ Hz, $J_{4,6} = 8.0$ Hz), 5.20 (d, 1H, C_5, $J_{4,5} = 6.0$ Hz), 5.52 (s, 1H, C_2), 5.86

(d, 1H, C_7, $J_{6,7}$ = 15.5 Hz), 6.17 (d of d, 1H, C_6, $J_{4,6}$ = 8.0 Hz, $J_{6,7}$ = 15.5 Hz), and 6.51-7.63 (m, 11H, aromatic).

Anal. Calc. for $C_{26}H_{23}NO_4$: C, 75.53; H, 5.61; mol.wt. 413.
Found: C, 75.48; H, 5.52; mol.wt. 413.

Conversion of III-62 to III-63.

Heating a benzene (10 ml) solution of III-62 (100 mg) and III-25a (68 mg) in a sealed tube at 140° for 14 hr gave a red oil. Dilution of the oil with ether deposited a small amount of III-54 which was removed by filtration. The filtrate was concentrated to dryness and treated with hot methanol to yield III-63, 120 mg (75%), mp 297-300°.

Preparation of III-66.

A benzene solution (10 ml) of III-25a (500 mg) and 1,3-cyclohexadiene (200 mg) was heated at 140° for 14 hr in a sealed tube. On cooling the reaction mixture III-54 deposited which was removed by filtration, washed twice with benzene, and dried to yield 120 mg (24%), mp 318-322° (dec).

The filtrate was evaporated to dryness and on treatment with methanol to give III-55 which was washed with methanol, and dried to yield 97 mg (20%), mp 278-282° (dec).

The methanolic solution was evaporated to dryness to give an oil which was then dissolved in warm benzene-pet ether (1:10). On cooling III-66 deposited which was filtered, washed with benzene-pet ether (1:20), and dried to yield 207

mg (32%), mp 172-176°. An analytical sample was obtained by recrystallization from hot benzene-pet ether: mp 175-176.5°; ir (KBr) 3020, 2950 (C-H), 1607, 1520 (aromatic), 797, 763 (naphthyl ring), and 695 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ1.11-1.81 (b, 4H, cyclohexyl methylene), 2.92-3.51 (b, 2H, C_3, C_4), 5.20 (d, 2H, C_2, C_5, $J_{2,3} = J_{3,4} = 6.5$ Hz), 5.51 (AB quart., 2H, $J_{AB} = 10.0$ Hz), and 6.41-7.59 (m, 11H, aromatic).

Anal. Calc. for $C_{24}H_{21}N$: C, 89.13; H, 6.54; mol.wt. 323.
Found: C, 88.97; H, 6.63; mol.wt. 323.

Preparation of III-68.

A benzene solution (10 ml) of III-25f (315 mg) and 1,3-cyclohexadiene (400 mg) was heated in a sealed tube at 140° for 16 hr. On cooling a small amount of solid deposited which was removed by filtration. Evaporation of the solvent and treatment with ether deposited the dimer, III-69, which was washed with ether, and dried to yield 40 mg (13%), mp > 300°. Removal of the solvent to dryness gave a semi-solid compound which on dilution with benzene-pet ether (1:10) deposited III-68 which was filtered and dried to yield 280 mg (72%), mp 193-196°. A pure sample was obtained by crystallization from hot benzene-pet ether: mp 197-198.5°; ir (KBr) 2990, 2900 (C-H), 1595, 1495 (aromatic), 840 (1,2,4-trisubstituted benzene ring), 795, 780 (naphthyl ring), and 660 cm^{-1} (C-Cl stretching); nmr ($CDCl_3$) δ1.21-1.81

(b, 4H, cyclohexyl methylene), 2.90-3.45 (b, 2H, C_3, C_4), 5.05 (d, 2H, C_2, C_5, $J_{2,3} = J_{4,5} = 6.2$ Hz), 5.44 (AB quart. $J_{AB} = 10.0$ Hz), and 6.45-7.61 (m, 9H aromatic).

Anal. Calc. for $C_{24}H_{19}Cl_2N$: C, 73.45; H, 4.88; mol.wt. 391.
Found: C, 73.33; H, 4.79; mol.wt. 391.

Catalytic hydrogenation of III-68.

A solution of III-67 (70 mg) in distilled methanol (25-30 ml) containing 20 mg of 5% Pt on charcoal was placed in a hydrogenator under 45 psig of hydrogen. Hydrogen uptake was completed in 3 hr. After reaction for an additional 2 hr the catalyst was removed and the solvent evaporated to yield III-7**o**, 68 mg (96%), mp 180-182°. A pure sample was prepared by recrystallization from warm pet ether: mp 181-182.5°; ir 2910 (C-H), 1595, 1495 (aromatic), 824 (1,2,4-trisubstituted benzene ring), and 795, 780 cm^{-1} (naphthyl ring); nmr ($CDCl_3$) δ1.01-1.51 (b, 8H, cyclohexyl methylene), 2.51-2.94 (b, 2H, C_3, C_4), 5.03 (d, 2H, C_2, C_5, $J_{2,3} = J_{4,5} = 6.2$ Hz), and 6.51-7.72 (m, 9H, aromatic).

Calc. for $C_{24}H_{21}Cl_2N$: 393 (M^+). Found: 393 (M^+).

An admixture of this hydrogenated product, mp 181-182.5°, with III-7**o** from reaction of III-25f with cyclohexene, mp 180-182°, gave mp 180-182°.

Preparation of III-73.

A benzene solution of III-25d (650 mg) and 2,4-

trans, trans- hexadiene (400 mg) was allowed to react at 140° for 16 hr in a sealed tube. Removal of the solvent afforded a red liquid which on dilution with ether gave III-74 (dimer) which was filtered, washed with ether, and dried to yield 142 mg (22%); mp >300°; ir (KBr) 3050, 2940 (C-H), 1575, 1480 (aromatic), 822 (1,4-disubstituted benzene ring), 805, 770 (naphthyl ring), and 670 cm^{-1} (C-Br stretching).

Calc. for $C_{36}H_{24}Br_2N_2$: 642 (M^+). Found: 642 (M^+).

The ethereal mother liquor was evaporated and treated with hot methanol-pet ether to give on cooling III-73, 469 mg (58%), mp 197-199.5°. Recrystallization from benzene-pet ether gave: mp 198-199.5°; ir 3050, 2950 (C-H), 1590, 1490 (aromatic), 965 (alkene, trans disubstituted), 815 (1,4-disubstituted benzene ring), and 785 (naphthyl ring); nmr ($CDCl_3$) δ1.31 (d, 3H, exo methyl at C_3, $J_{3\text{-}CH_3}$ = 6.5 Hz), 1.47 (d of d, 3H, methyl at C_7, $J_{7\text{-}CH_3}$ = 6.5 Hz, $J_{6\text{-}CH_3}$ = 1.0 Hz), 1.98 (quintet, 1H, C_3, $J_{3,4}$ = 6.5 Hz = $J_{3\text{-}CH_3}$), 2.89 (m, 1H, C_4, $J_{3,4}$ = 6.5 Hz, $J_{4,5}$ = 6.0 Hz, $J_{4,6}$ = 9.0 Hz), 4.57 (s, 1H, C_2), 4.96 (d, 1H, C_5, $J_{4,5}$ = 6.0 Hz), 4.96 (m, 1H, C_6, $J_{4,6}$ = 9.0 Hz, $J_{6,7}$ = 15.0 Hz, $J_{6\text{-}CH_3}$ = 1.0 Hz), 5.50 (m, 1H, C_7, $J_{7\text{-}CH_3}$ = 6.5 Hz, $J_{6,7}$ = 15.0 Hz), and 6.50-7.66 (m, 10H, aromatic).

Anal. Calc. for $C_{24}H_{22}BrN$: C, 71.29; H, 5.48; mol.wt. 403.
Found: C, 71.13; H, 5.59; mol.wt. 403.

Catalytic hydrogenation of III-73.

To a suspension of 50 mg of 5% Pt on charcoal in

methanol (50 ml) was added III-73 (110 mg). Reaction under hydrogen at 50 psig for 8 hr followed by filtration and evaporation of the solvent yielded III-75 as a oil which solidified on standing, 107 mg (97%), mp 134-137°. A pure sample was obtained by crystallization from methanol-pet ether mixture: mp 136-137.5°; ir (KBr) 2950, 2900, 2850 (C-H), 1585, 1495 (aromatic), 822 (1,4-disubstituted benzene ring), and 795 cm^{-1} (naphthyl ring); nmr ($CDCl_3$) δ0.78 (t, 3H, methyl of propyl moiety in endo position at C_4, J = 6.5 Hz), 0.95-2.53 (m, 6H, $-CH_2-CH_2-$, C_3, C_4), 1.33 (d, 3H, exo methyl at C_3, J_{3-CH_3} = 6.0 Hz), 4.53 (s, 1H, C_2), 5.05 (d, 1H, C_5, $J_{4,5}$ = 6.5 Hz), and 6.45-7.61 (m, 10H, aromatic).

Calc. for $C_{24}H_{24}BrN$: 405 (M^+). Found: 405 (M^+).

Lithium aluminium hydride reduction of III-25a.

To a suspension of LAH (200 mg) in anhydrous ether (75 ml) was added dropwise a solution of III-25a (250 mg) in anhydrous ether (50 ml) over a period of 30 min. The reaction mixture was allowed to reflux overnight then treated with an ice-ether mixture to deposit aluminium salts which were removed by filtration, and washed twice with ether. The ethereal portions were combined, washed with cold water, and dried over anhydrous $MgSO_4$. Removal of the solvent gave 212 mg (86%) of III-76 as a red oil which failed to crystallize; ir (thin film) 3450 (N-H), 3080, 2930 (C-H), 1610, 1505, 1434 (aromatic), 785, 755 (naphthyl ring), and 695 cm^{-1}

(monosubstituted benzene ring); nmr ($CDCl_3$) δ2.85 (d of d, 1H, H_2, $J_{1,2}$ = 16.5 Hz, $J_{2,3}$ = 3.3 Hz), 3.53 (d of d, 1H, H_1, $J_{1,2}$ = 16.5 Hz, $J_{1,3}$ = 7.0 Hz), 3.53 (b, 1H, N-H, D_2O exchangeable), 5.10 (d of d, 1H, H_3, $J_{1,3}$ = 7.0 Hz, $J_{2,3}$ = 3.3 Hz), and 6.20-7.51 (m, 11H, aromatic).

The red oil was then treated with 12N HCl to convert the free amine into a HCl salt, III-77, mp 187-191° (dec).

Calc. for $C_{18}H_{15}N \cdot HCl$: 281 (M^+); $(M-36)^+$ = 245. Found: $(M-36)^+$ = 245.

Catalytic hydrogenation of III-25a.

A solution of III-25a (250 mg) in benzene (5 ml) and methanol (25 ml) using 50 mg of 5% Pt on charcoal was allowed to react under hydrogen at 50 psig for 24 hr. Removal of the catalyst and evaporation of the solvent in vacuo afforded a red oil, 242 mg (97%) which failed to solidify. The ir and nmr spectra of this compound were identical to that obtained for compound III-76, N-acenaphthylaniline. The mixed melting point of hydrochloride salts was undepressed.

Preparation of III-78.

A toluene solution (25 ml) of III-29a (276 mg) and dimethyl fumarate (147 mg) was refluxed for 15 hr, after removal of solvent, a pale yellow was obtained. Dilution of the oil with methanol gave III-78, 392 mg (94%), mp 218-

221°. Recrystallization from hot methanol gave an analytical sample: mp 221-222°; ir (KBr) 3030, 2850 (C-H), 1725 (unconjugated ester), 1603, 1505, 1458 (aromatic), 1340, 1325, 1220 (C-O stretching), 785, and 707 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.40 (s, 6H, methyl ester at C_3 and C_4), 4.09 (d, 1H, C_3, $J_{2,3}$ = 2.5 Hz), 4.17 (d, 1H, C_4, $J_{4,5}$ = 2.5 Hz), 5.50 (d, 1H, C_5, $J_{4,5}$ = 2.5 Hz), 5.59 (d, 1H, C_2, $J_{2,3}$ = 2.5 Hz), and 6.25-7.29 (m, 15H, aromatic).

Anal. Calc. for $C_{26}H_{25}NO_4$: C, 75.16; H, 6.06; mol.wt. 415.
Found: C, 75.25; H, 6.20; mol.wt. 415.

Preparation of III-79.

A sample of III-29a (273 mg) and dimethyl maleate (145 mg) was refluxed in toluene (25 ml) for 14 hr. Removal of the solvent in vacuo gave light yellow oil which solidified on standing to give III-79 which further precipitated by treating the reaction mixture with methanol, 385 mg (92%), mp 178-181°. An analytical sample was obtained by recrystallization from methanol: mp 180-181.5°; ir (KBr) 3010 (C-H), 1745, 1715 (unconjugated ester), 1600, 1510, 1480 (aromatic), 1350, 1270, 1220, 1180 (C-O stretching), 767, and 715 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.16 (s, 3H, methyl ester at C_4), 3.57 (s, 3H, methyl ester at C_3), 3.39 (d of d, 1H, C_3, $J_{2,3}$ = 7.3 Hz, $J_{3,4}$ = 7.5 Hz), 3.89 (d of d, 1H, C_4, $J_{3,4}$ = 7.5 Hz, $J_{4,5}$ = 7.0 Hz), 5.63 (d, 1H, C_5, $J_{4,5}$ = 7.0 Hz), 5.63 (d,

1H, C_2, $J_{2,3}$ = 7.3 Hz), and 6.21-7.32 (m, 15H, aromatic).

Anal. Calc. for $C_{26}H_{25}NO_4$: C, 75.16; H, 6.06; mol.wt. 415.
Found: C, 75.04; H, 6.24; mol.wt. 415.

The compound III-78 was also obtained in 90% yield by treating the anhydride adduct III-79 (described below) with an excess of ethereal diazomethane solution.

Preparation of III-80.

Refluxing a toluene (25 ml) solution of III-29a (275 mg) and maleic anhydride (100 mg) for 6 hr gave, after evaporation of the solvent, III-80 as a pale yellow solid which after washing with methanol yielded 342 mg (93%), mp 212-214°. Recrystallization from benzene-pet ether gave: mp 215-216° (Lit.[52] mp 214-215.5°); ir (KBr) 3020, 2880 (C-H), 1850, 1780 (anhydride stretching), 760, and 717 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.63 (d of d, 1H, C_3, $J_{3,4}$ = 8.7 Hz, $J_{2,3}$ = 1.3 Hz), 4.19 (d of d, 1H, C_4, $J_{3,4}$ = 8.7 Hz, $J_{4,5}$ = 10.0 Hz), 5.62 (d, 1H, C_5, $J_{4,5}$ = 10.0 Hz), 5.84 (d, 1H, C_2, $J_{2,3}$ = 1.3 Hz), and 6.33-7.33 (m, 15H, aromatic).

Calc. for $C_{24}H_{19}NO_3$: 369 (M^+). Found: 369 (M^+).

Preparation of III-82a and III-83a.

Refluxing a toluene solution (20 ml) of III-30a (720 mg) and dimethyl fumarate (290 mg) for 14 hr afforded,

after removal of the solvent, a pale yellow oil which was crystallized from 10-12 ml of hot methanol to give III-82a, 363 mg (40%), mp 100-102°. A pure sample was obtained by recrystallization from hot methanol: mp 101-102.5°; ir (KBr) 3000, 2920, 2850 (C-H), 1730 (unconjugated ester), 1670 (benzoyl), 1603, 1500, 1445 (aromatic), 1245, 1170 (b, C-O stretching), 770, and 715 cm^{-1} (monosubstituted benzene ring); nmr (C_6H_6) δ2.85 (s, 3H, methyl ester at C_4), 2.92 (s, 3H, methyl ester at C_3), 3.57 (AB quart., benzyl, J_{AB} = 14.0 Hz), 4.25 (d of d, 1H, C_3, $J_{2,3}$ = 7.0 Hz, $J_{3,4}$ = 10.0 Hz), 4.67 (d of d, 1H, C_4, $J_{3,4}$ = 10.0 Hz, $J_{4,5}$ = 10.0 Hz), 5.12 (d, 1H, C_5, $J_{4,5}$ = 10.0 Hz), 5.25 (d, 1H, C_2, $J_{2,3}$ = 7.0 Hz), and 7.05-7.84 (m, 15H, aromatic).

Anal. Calc. for $C_{28}H_{27}NO_5$: C, 73.51; H, 5.95; mol.wt. 457.
Found: C, 73.47; H, 5.91; mol.wt. 457.

The methanol filtrate was concentrated and diluted with pet ether. Crystallization for a week at 0° gave III-83a, mp 74-76°, 417 mg (46%). Recrystallization from methanol-pet ether afforded an analytical sample: mp 75-76.5°; ir (KBr) 3000, 2915, 2830 (C-H), 1725 (unconjugated ester), 1680 (benzoyl), 1603, 1500, 1458 (aromatic), 1230-1160 (b, C-O stretching), 780, and 710 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.63 (s, 3H, methyl ester at C_4), 3.72 (s, 3H, methyl ester at C_3), 3.50-3.63 (m, 4H, benzyl, C_3, C_4), 4.83 (d, 1H, C_5, $J_{4,5}$ = 5.5 Hz), 5.12 (d,

1H, C_2, $J_{2,3}$ = 2.0 Hz), and 7.10-7.83 (m, 15H, aromatic).

Anal. Calc. for $C_{28}H_{27}NO_5$: C, 73.51; H, 5.95; mol.wt. 457.
Found: C, 73.64; H, 5.81; mol.wt. 457.

Reaction of III-30b (355 mg) and III-34 (147 mg) under the same reaction conditions afforded a mixture of III-82a and III-83a in 38% and 47% yields, respectively. The two compounds were isolated and their identities were established by comparison of spectral data and mixed melting point with III-82a and III-83a prepared by the reaction of III-30a with III-34.

Preparation of III-82b and III-83b.

A toluene solution (25 ml) of III-31a (600 mg) and III-34 (290 mg) was refluxed for 14 hr. Evaporation of the solvent gave a semi-solid which crystallized from hot methanol to give III-82b, mp 176-177.5°, 412 mg (46%). An analytical sample was obtained by recrystallization from hot methanol: mp 177-178°; ir (KBr) 2900, 2820 (C-H), 1720 (unconjugated ester), 1672 (benzoyl), 1603, 1450 (aromatic), 1225-1165 (b, C-O stretching), 750, 705 cm^{-1} (monosubstituted benzene ring); nmr (C_6H_6) δ0.66-1.50, and 1.63-2.01 (b, 11H, cyclohexyl methylene and methine, respectively), 2.87 (s, 3H, methyl ester at C_3), 2.96 (s, 3H, methyl ester at C_4), 4.29 (d of d, 1H, C_3, $J_{2,3}$ = 7.2 Hz, $J_{3,4}$ = 11.1 Hz), 4.64 (d of d, 1H, C_4, $J_{3,4}$ = 11.1 Hz, $J_{4,5}$ = 10.0 Hz), 5.21 (d,

1H, C_5, $J_{4,5}$ = 10.0 Hz), 5.46 (d, 1H, C_2, $J_{2,3}$ = 7.2 Hz), and 7.07-8.20 (m, 10H, aromatic).

Anal. Calc. for $C_{27}H_{31}NO_5$: C, 72.14; H, 6.95; mol.wt. 449.
Found: C, 72.03; H, 6.74; mol.wt. 449.

The methanol filtrate was evaporated to dryness to give 341 mg (38%) of III-83b as an oil which resisted crystallization. The nmr analysis of III-83b indicated the absence of III-82b. The oil (300 mg) was chromotographed on silica gel (50 g). Elution with benzene gave 260 mg of a colorless oil; ir (thin film) 2950, 2850 (C-H), 1738 (unconjugated ester), 1680 (benzoyl), 1600, 1460 (aromatic), 1260-1210 (b, C-O stretching), and 720 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ0.65-2.01, and 2.57-3.02 (b, 11H, cyclohexyl methylene and methine, respectively), 3.62 (s, 3H, methyl ester at C_4), 3.72 (s, 3H, methyl ester at C_3), 3.45-3.60 (m, 2H, C_3, C_4), 5.12 (d, 1H, C_5, $J_{4,5}$ = 4.5 Hz), 5.62 (d, 1H, C_2, $J_{2,3}$ = 1.2 Hz), 7.15-8.23 (m, 10H, aromatic).

Anal. Calc. for $C_{27}H_{31}NO_5$: C, 72.14; H, 6.95; mol.wt. 449.
Found: C, 71.97; H, 7.03; mol.wt. 449.

Reaction of III-31b and III-34 gave III-82b and III-83b in 42% and 36% yields, respectively.

Preparation of III-84a.

A sample of III-30a (315 mg) and dimethyl maleate

(145 mg) in toluene (20 ml) was refluxed for 14 hr. Removal of the solvent gave an oil which solidified on standing. The solid was crystallized from hot methanol-pet ether to give III-84a, 389 mg (82%), mp 119-122°. Recrystallization from hot methanol gave: mp 121-122.5°; ir (KBr) 3010, 2810 (C-H), 1725 (unconjugated ester), 1680 (benzoyl), 1600, 1495, 1480 (aromatic), 1270-1180 (b, C-O stretching), 760, and 715 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.30 (s, 3H, methyl ester at C), 3.53 (s, 3H, methyl ester at C_3), 3.57-4.02 (m, 4H, benzyl, C_3, C_4), 4.93 (d, 1H, C_5, $J_{4,5}$ = 5.5 Hz), 5.63 (d, 1H, C_2, $J_{2,3}$ = 6.0 Hz), and 6.95-7.53 (m, 15H, aromatic).

Anal. Calc. for $C_{28}H_{27}NO_5$: C, 73.51; H, 5.95; mol.wt. 457.
Found: C, 73.28; H, 5.75; mol.wt. 457.

Reaction of III-30b and III-38 in refluxing toluene solution gave III-84a in 81% yield. The mixture melting point of III-83a obtained in this fashion with that obtained below was undepressed. The ir and nmr spectra of III-83a obtained from these sources were identical.

The adduct III-83a was also prepared by reaction of anhydride adduct III-85a (400 mg) with an excess of ethereal diazomethane solution. The solution containing the dimethyl ester was evaporated in vacuo leaving a semi-crystalline material which when washed with 10 ml of methanol yielded white needles of III-84a, 390 mg (89%), mp 119-121°.

Preparation of III-84b.

A toluene solution (20 ml) of III-31a (300 mg) and III-38 (145 mg) was refluxed for 15 hr. Removal of the solvent gave an oil which was treated with methanol-ether solution to give III-84b as a red oil, 370 mg (84%). Several recrystallizations from methanol-pet ether gave III-83b with mp 92-93°. An analytical sample was obtained by further recrystallization from methanol-pet ether: mp 93.5-94.5°; ir (KBr) 3010, 2940 (C-H), 1730 (unconjugated ester), 1670 (benzoyl), 1603, 1450 (aromatic), 1250-1170 (b, C-O stretching), 765 and 717 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ3.12 (s, 3H, methyl ester at C_4), 3.58 (s, 3H, methyl ester at C_3), $J_{2,3}$ = 4.5 Hz, $J_{3,4}$ = 8.3 Hz), 3.82 (d of d, 1H, C_4, $J_{3,4}$ = 8.3 Hz, $J_{4,5}$ = 8.0 Hz), 5.08 (d, 1H, C_5, $J_{4,5}$ = 8.0 Hz), 5.58 (d, 1H, C_2, $J_{2,3}$ = 4.5 Hz), and 7.13-8.23 (m, 10H, aromatic).

Anal. Calc. for $C_{27}H_{31}NO_5$: C, 72.14; H, 6.95; mol.wt. 449.
Found: C, 72.04; H, 7.01; mol.wt. 449.

Refluxing a toluene solution (20 ml) of III-31b (150 mg) and III-38 (73 mg) gave III-84b in 83% yield. The III-84b prepared in this manner had ir and nmr spectra identical to those obtained for III-83b prepared from reaction of III-31a and III-38.

The compound III-84b was also prepared in 91% yield by reacting the adduct III-85b with excess of diazomethane solution.

Preparation of III-85a.

A toluene solution (20 ml) of III-30a (625 mg) and maleic anhydride (200 mg) was refluxed for 6 hr. Evaporation of the solvent gave light yellow oil which solidified on standing to give III-85a. Recrystallization from hot benzene-pet ether gave 765 mg (93%), mp 168-170°. An analytical sample was obtained by an additional recrystallization from hot benzene: mp 169-170°; ir (KBr) 3030, 2980, 2885 (C-H), 1880, 1780 (anhydride), 1677 (benzoyl), 1600, 1585, 1480 (aromatic), 1277, 1220 (C-O stretching); and 710 cm^{-1} (monosubstituted benzene ring), nmr (C_6H_6) δ2.50 (d, 1H, C_3, $J_{3,4}$ = 9.5 Hz), 3.33 (t, 1H, C_4, $J_{3,4}$ = 9.5 Hz, $J_{4,5}$ = 8.2 Hz), 3.60 (AB quart., 2H, benzyl, J_{AB} = 14.1 Hz), 5.14 (d, 1H, C_5, $C_{4,5}$ = 8.2 Hz), 5.26 (s, 1H, C_2), and 7.01-8.15 (m, 15H, aromatic).

Anal. Calc. for $C_{26}H_{21}NO_4$: C, 75.89; H, 5.14; mol.wt. 411.
Found: C, 75.61, H, 5.37, mol.wt. 411.

When a toluene solution (20 ml) of III-30b (315 mg) and III-42 (101 mg) was refluxed for 7 hr, the usual work up procedure yielded, 387 mg (94%), mp 167-169°. The mixed melting point of III-85a with the compound obtained from reaction of III-30b and III-42 was undepressed. In addition the III-85a obtained from these two sources gave identical nmr and ir spectra.

Preparation of III-85b.

A toluene solution (20 ml) of III-31a (310 mg) and III-42 (98 mg) was refluxed for 6 hr. Removal of the solvent resulted in an oil which solidified on standing. The usual work up procedure yielded III-85b as pale yellow crystals, 347 mg (86%), mp 177-179.5°. Recrystallization from benzene gave: mp 179-180.5°; ir (KBr) 2900, 2830 (C-H), 1850, 1767 (anhydride), 1450 (aromatic) 1665 (benzoyl), 1450 (aromatic), 1220, 1200 (aromatic), 780, 717 cm^{-1} (monosubstituted benzene ring); nmr ($CDCl_3$) δ0.81-2.11 and 2.41-2.83 (b, 11H, cyclohexyl methylene and methine, respectively), 3.37 (d, 1H, C_3, $J_{3,4}$ = 9.5 Hz), 3.87 (t, 1H, C_4, $J_{3,4}$ = 9.5 Hz, $J_{4,5}$ = 8.5 Hz), 5.42 (d, 1H, C_5, $J_{4,5}$ = 8.5 Hz), 5.64 (s, 1H, C_2), and 7.13-8.21 (m, 10H, aromatic).

Anal. Calc. for $C_{25}H_{25}NO_4$: C, 74.42; H, 6.25; mol.wt. 403.
Found: C, 74.33; H, 6.15; mol.wt. 403.

Refluxing a toluene solution (20 ml) of III-31b (315 mg) and III-42 (100 mg) for 6 hr followed by the usual work up gave III-85b, 332 mg (82%); mp 177-180°. The admixture of III-85b obtained in this manner with III-84b obtained from reaction of III-31a and III-42 melted at 178-180°. The ir and nmr spectra of III-85b obtained from these two sources were identical.

Kinetic Studies.

Materials. The aziridines III-25a-f and III-

29a-d were purified by at least three recrystallizations from appropriate solvents followed by drying at 70-75°C (0.1mm- Hg). The dimethyl acetylenedicarboxylate (III-14) and dimethyl fumarate (III-34) were prepared by published procedures [102-103]; III-14 was distilled twice, bp 130-131° (10mm- Hg) and stored at 0° until use. Similarly, III-34 was recrystallized by sublimation at 80° (0.5mm- Hg), mp 101-102°. Spectroscopic grade benzene was distilled over LAH prior to use.

Kinetic analysis

The requisite amounts of aziridine, toluene (internal standard) and ester (dimethyl acetylenedicarboxylate, or dimethyl fumarate) were weighed into a 10 ml volumetric flask, and made up to volume with solvent. The nmr tubes were filled with samples of the reaction mixture using a hypodermic syringe and sealed under N_2 atmosphere. The tubes were withdrawn at appropriate intervals, and the reaction was quenched by cooling to -70°. The tubes were allowed to warm to room temperature, and the nmr spectra were recorded.

The concentration of aziridines, products and esters were calculated by comparison of areas of respective peaks with those of known concentrations of toluene (internal standard). However, in the case of III-29b, the area of methyl signals were used in calculating the concentration of reactants and product. Nmr spectra were

recorded using sweep width of 250 Hz and sweep time of 250 sec.

The yield of products from the kinetic runs was obtained by placing the tubes in oil, after recording the spectra, for varying lengths of time. The reaction mixtures were then transfered to a flask. The solvent was removed at 50-55^{o} and the residue was diluted with methanol (10 ml) to precipitate, which was filtered, washed, dried and weighed.

The yield of adducts and their physical properties are collected in Tables XXI and XXII.

TABLE XXI

PHYSICAL PROPERTIES OF ADDUCTS OF III-33b-f, and III-35b

Adduct	Yield	mp	nmr($CDCl_3$)	ir(KBr) cm^{-1}(C=O)	Mass Spectra M^+	$\frac{M^+ + 1}{M^+}$	$\frac{M^+ + 2}{M^+}$
III-33b	87	295-297	2.13(s,3H) 3.74(s,6H) 5.72(s,2H) 6.59-7.56(m,10H)	1707	Calc: 399	0.278	0.0458
					Found: 399	0.291	0.0491
III-33c	81	225-227	3.16(s,3H) 3.73(s,6H) 5.68(s,2H) 6.71-7.64(m,10H)	1717	Calc: 415	0.278	0.0478
					Found: 415	0.292	0.0492
III-33d	89	286-288	3.75(s,6H) 5.70(s,2H) 6.52-7.71(m,10H)	1710	Calc: 463	0.267	1.017
					Found: 463	0.262	1.000
III-33e	93	255-257	3.76(s,6H) 5.84(s,2H) 6.51-7.91(m,10H)	1702	Calc: 430	0.267	0.0468
					Found: 430	0.281	0.049
III-33f	91	243-245	3.74(s,6H) 5.75(s,2H) 6.65-7.82(m,9H)	1700	Calc: 453	0.281	0.688
					Found: 453	0.279	0.691

TABLE XXII

PHYSICAL PROPERTIES OF ADDUCTS III-113a-d

Adduct	Yield %	mp	nmr	ir(KBr) cm^{-1}(C=O)		Mass Spectra M^+	$\frac{(M+1)^+}{M^+}$	$\frac{(M+2)^+}{M^+}$
III-113a	92	164-66°	3.59(s,6H) 6.25(s,2H) 6.30-7.50(m,15H)	1710	Calc: Found:	413 413	0.289 0.283	0.0489 0.0493
III-113b	91	214-215°	2.09(s,3H) 3.57(s,6H) 6.18(s,2H) 6.37-7.43(m,14H)	1720	Calc: Found:	427 427	0.333 0.330	0.052 0.059
III-113c	89	197-199°	3.63(s,6H) 6.25(s,2H) 6.28-7.37(m,14H)	1720	Calc: Found:	447 447	0.289 0.295	0.368 0.338
III-113d	90	178-180°	3.60(s,6H) 6.18(s,2H) 6.24-7.41(m,13H)	1717	Calc: Found:	481 481	0.289 0.297	0.695 0.641

APPENDIX

Description of Equipment and Services

Infrared spectra were recorded with either Unicam SP 200 or Beckman IR-12 spectrophotometer. The nmr spectra were taken on a Varian A-56-60 spectrometer, with tetramethylsilane as an internal standard. The esr spectra were obtained on a Varian E-3 spectrometer equipped with a modified Varian 6040 variable temperature controller. Ultraviolet spectra were recorded on either Unicam SP 800 or Cary spectrometer.

Mass spectra were obtained on a Perkin-Elmer Hatachi spectrometer using an ionization voltage of 70 ev and an inlet temperature of 175-200°.

Gas-liquid partition chromotography was performed on Varian Aerograph Autoprep and HiFi gas chromotography Units. The following columns were used:

Column A: 5 ft. x 0.125 in, 20% SE-550 silicon oil Stationary phase on 100-200 mesh Chromosorb W support.

Column B: 5 ft. x 0.125 in, 25% of 30% silver nitrate in triethylene glycol Stationary phase on 100-200 mesh Firebrick.

Column C: 5 ft. x 0.125 in, containing 20% XF-1150 Cyanosilicon Stationary phase on 100-120 mesh Chromosorb W support.

Elemental analyses were performed either by Alfred Bernhardt, Microanalysiches Laboratorium, Mulhein, Germany or in this laboratory.

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