Benzene was added to the aqueous layer and water was removed by azeotropic distillation. A suspension of saltlike, white crystals, mp 163–178°, remained in the benzene.

Reaction of 2-(N,N-Dimethylamino)-1-phenylpropanol (XVIII)[19] with Hydrochloric Acid.—A solution of the amino alcohol (1.02 g, 5.69 mmol) in concentrated hydrochloric acid (30 ml) was refluxed 3 hr, cooled, diluted with water, and extracted three times with ether. The ether extract was washed with water and saturated sodium chloride solution and then dried, and the solvent was evaporated. The crude product (15 mg, 1.8%), a nearly colorless liquid, was identified as phenyl-2-propanone by comparison of ir spectra and by literature analogies[4,20] in which reaction of the same amino alcohol with phosphoric acid or sulfuric acid gave phenyl-2-propanone.

Reaction of 2-(N,N-Dimethylamino)-4-phenyl-1-tetralol with Hydrochloric Acid.—A solution of the cyclic amino alcohol (500 mg, 1.87 mmol) in concentrated hydrochloric acid was refluxed for 2 hr and then cooled on ice. The oil-containing mixture was extracted three times with ether and the combined ether extracts were washed twice with water. Drying followed by evaporation of ether under reduced pressure left a light yellow oil (365 mg, 88%). The ir spectrum of the crude product was superimposable with a spectrum of authentic 4-phenyl-2-tetralone.[2a] A portion of the product was reduced with sodium borohydride to 4-phenyl-2-tetralol, identical in every respect with an authentic sample.[2a]

Determination of Rates of Reaction of Amino Alcohols I and X with 6 *M* Sulfuric Acid.—A series of 50-ml flasks, each containing 6 *M* sulfuric acid (25.0 ml), were placed in an oil bath and the bath was heated slowly to the desired temperature. After 1 hr the amino alcohol was introduced into each flask and timing was begun with a stopwatch. During the reaction the flasks were swirled occasionally and the temperature of the oil bath was maintained within 0.5° of the desired value. At the end of the reaction, ice–water (15 ml) was added and the flask was immersed in ice–water immediately. The cooled reaction mixture was poured into a 60-ml separatory funnel and extracted with ether (two 20-ml portions followed by a 10-ml portion). The combined ether extracts were washed with water (10 ml) and saturated sodium chloride solution (10 ml) and dried ($MgSO_4$). The ether solution was filtered into a tared flask (filter paper and $MgSO_4$ were washed thoroughly with ether) and evaporated under reduced pressure, ultimately at 60–70°, until the weight of the flask remained constant. The results of the experiments and a representative run are tabulated in Tables I and II.

TABLE I

REPRESENTATIVE RUN. RAW KINETIC DATA FROM THE REACTION OF 2-(N,N-DIMETHYLAMINO)-4-PHENYL-1-TETRALOL (X) WITH 6 *M* H_2SO_4

Amino alcohol, mg	Temp, °C ± 0.5°	Reaction time, min	Isolated 4-phenyl-2-tetralone, mg
350	110	15	16.4
350	110	30	36.9
350	110	60	105.9
350	110	90	152.4
350	110	120	191.1

TABLE II

GRAPHICALLY DETERMINED PSEUDO-FIRST-ORDER RATE CONSTANTS AND ACTIVATION PARAMETERS FOR THE REACTIONS OF AMINO ALCOHOLS I AND X WITH 6 *M* H_2SO_4

Amino alcohol	Temp, °C	k, sec^{-1}
I	118	1.65×10^{-4}
I	110	8.56×10^{-5}
I	105	5.38×10^{-5}
X	110	1.74×10^{-4}

It follows that $(k_X/k_I)_{110°} = 2.03$. These data allow the graphical calculation[21] of activation parameters: $E_a = 26$ kcal/mol; $\Delta S^{\ddagger}_{\circ} = -11$ eu.

Registry No.—I, 14195-36-9; II, 14195-35-8; V, 19236-31-8; VI, 23885-33-8; X, 23885-34-9; XV, 23885-00-9; XVII, 23885-01-0.

(19) S. Sugasawa, T. Yamazaki, M. Kawanishi, and J. Iwao, *J. Pharm. Soc. Jap.*, **71**, 530 (1951).

(20) H. Takamatsu, *ibid.*, **76**, 1244 (1956).

(21) A. A. Frost and R. G. Pearson, "Kinetics and Mechanism," 2nd ed, John Wiley & Sons, Inc., New York, N. Y., 1953, p 98 ff.

Titanium Chloride Catalyzed Addition of Aziridine to Ketones. A Route to N-Aziridinylenamines[1]

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Addition of aziridine to a series of cyclic ketones from C_5–C_8 in the presence of $TiCl_4$ and triethylamine produced 1,1-bis(aziridinyl)cycloalkanes, 1-N-aziridinylcycloalkenes, 1-N-(β-chloroethyl)cycloalkylimine, and 1-N-(β-aziridinylethyl)cycloalkylimine. The product ratio was dependent upon the ketone ring size and the ketone/$TiCl_4$ mole ratio. 1-N-Aziridinyl-1-cycloheptene (**10**) and 1-N-aziridinyl-1-cyclooctene were prepared in ~20% yield but no enamine could be isolated from cyclopentanone or cyclohexanone. 1,1-Bis(aziridinyl)cyclopentane (**2**) and cyclohexane (**3**) were synthesized for the first time; previously reported bisaziridinyl derivatives were shown to be 1-N-(β-aziridinylethyl)cycloalkylimines. 3-N-Aziridinyl-1-cyclohexene (**17**) was prepared by the addition of aziridine to 3-bromo-1-cyclohexene in the presence of potassium hydroxide; treatment of this derivative with strong bases at temperatures up to 150° failed to effect an isomerization to 1-N-aziridinyl-1-cyclohexene. All of the aziridine compounds decomposed at room temperature to yield low molecular weight polyaziridines. The structures of the derivatives were assigned on the basis of infrared, nmr, and mass spectral data.

Enamines are generally prepared by condensing aldehydes or ketones with secondary amines in aromatic solvents and removing the water evolved by azeotropic distillation. An alternate technique, which is more applicable to reaction mixtures containing low-boiling components, is to remove the water with an inorganic drying agent such as $CaCl_2$ or $MgSO_4$.[2] Recently White and Weingarten reported that titanium tetrachloride is a more effective drying agent for this reaction; it appears to enhance the reactivity of the carbonyl as well as scavenge the water.[3] We have utilized the activating influence of $TiCl_4$ to prepare enamines derived from aziridine; *i.e.*, we have prepared

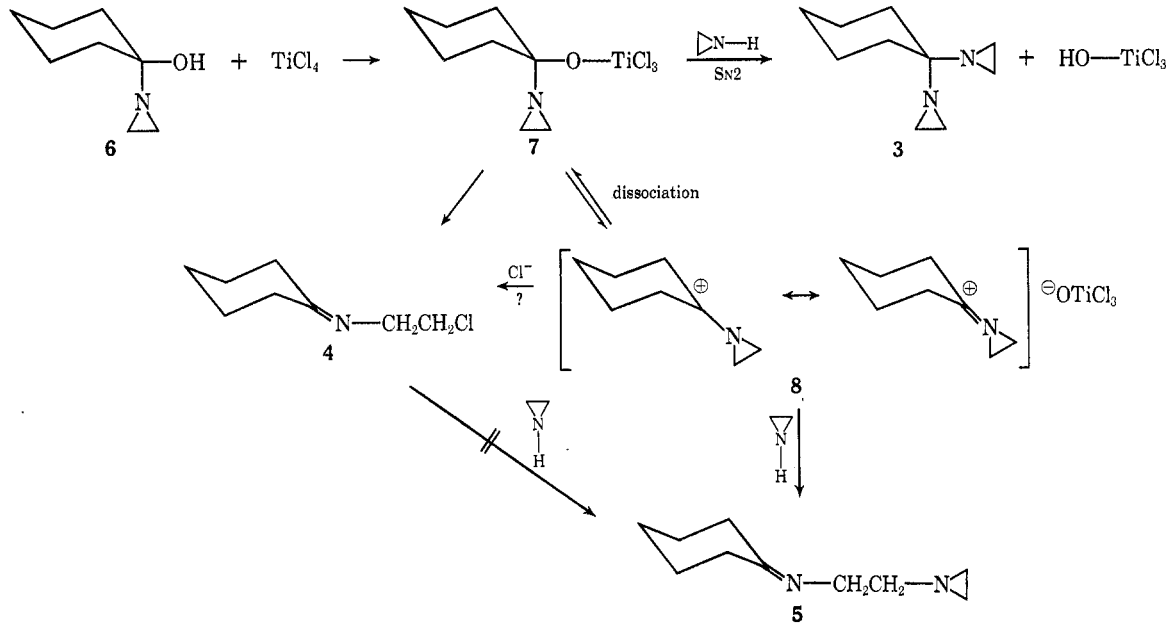
(1) Presented in part at the 158th National Meeting of the American Chemical Society, New York, N. Y., Sept 1969.

(2) L. W. Haynes, "Enamines," A. G. Cook, Ed., Marcel Dekker, Inc., New York, N. Y., 1969, Chapter 2.

(3) R. A. White and H. Weingarten, *J. Org. Chem.*, **32**, 213 (1967).

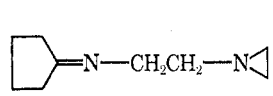
SCHEME I

PROPOSED MECHANISM FOR ADDITION OF AZIRIDINE TO CYCLOHEXANONE



1-N-aziridinylcycloheptene and -cyclooctene from the corresponding ketones. Although we could not isolate the enamines derived from cyclopentanone or cyclohexanone, this procedure enabled us to prepare 1,1-bis(aziridinyl)cyclopentane and -cyclohexane.

The reaction of aziridine with cyclic ketones was initially studied by Dornow and Schacht.[4] They reported that cyclohexanone yielded 1-N-aziridinylcyclohexanol when the two reagents were combined at room temperature. After standing for several days, a mixture of cyclopentanone and aziridine afforded a low yield of a diadduct, which was postulated to be 1,1-bis(aziridinyl)cyclopentane on the basis of elemental analysis. The aminohydrin structure of the cyclohexanone derivative has been confirmed,[5] but the structure of the diadduct has not been challenged. We have prepared the diadduct according to the procedure of Dornow and Schacht and characterized the compound more completely. The nmr spectra exhibits a pair of triplets between δ 2.5 and 3.5 which is indicative of a β-(N-aziridinylethyl)cyclopentylimine (**1**) rather than the 1,1-bis(aziridinyl)cyclopentane (**2**)



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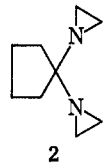


2

initially proposed. Recently, the diadduct derived from benzaldehyde was assigned a β-(N-aziridinylethyl) structure similar to **1**.[6] Apparently the imine form of the diadduct is also favored when aromatic aldehydes are treated with excess aziridine. Thus, 1,1-bis(N-aziridinyl) derivatives of ketones have not been reported to date.

A few aziridinyl enamines have been prepared by addition of aziridine to activated acetylenes[7] or by displacement of an activated vinyl chloride.[8] Both of these procedures yield compounds with electron-withdrawing substituents conjugated with the double bond which reduce the nucleophilic character of the enamines. Since we are interested in the nucleophilicity of enamines, the preparation of unsubstituted aziridinyl enamines was undertaken.

Results and Discussion

The reaction of aziridine with cyclic ketones in the presence of titanium tetrachloride is complicated by the susceptibility of the aziridine ring to nucleophilic attack. We have found that at least three types of low-molecular-weight products as well as polymeric aziridine derivatives can be isolated from the reaction mixture. For example, treatment of cyclohexanone with excess aziridine yields 1,1-bis(aziridinyl)cyclohexane (**3**), N-(β-chloroethyl)cyclohexylimine (**4**), and N-(β-aziridinylethyl)cyclohexylimine (**5**) (see Scheme I). The nature of the products and the product distribution is dependent upon the ketone to $TiCl_4$ mole ratio, the ring size of the ketone, and the presence of an efficient acid acceptor.

The reaction of water with titanium tetrachloride produces hydrogen chloride which must be scavenged. In most cases, an excess of the amine component is added to neutralize the HCl. However, aziridine polymerizes in the presence of acids, and compound **4** is the only low-molecular-weight component formed when $TiCl_4$ is added to a mixture of cyclohexanone and aziridine. Obviously, neither aziridine nor polyethyl-

(4) A. Dornow and W. Schacht, *Chem. Ber.*, **82**, 464 (1949).

(5) R. G. Kostyanovoskii, *Dokl. Akad. Nauk SSSR*, **135**, 853 (1960); *Chem. Abstr.*, **55**, 12380*a* (1961). W. J. Rabourn and W. L. Howard, *J. Org. Chem.*, **27**, 1039 (1962). M. Lidaks and S. Hillers, *Latv. PSR Zinat. Akad. Vertis*, 99 (1961). *Chem. Abstr.*, **56**, 4706*i* (1962).

(6) Y. Oshiri, K. Yamamoto, and S. Komori, *Yuki Gosei Kagaku Kyokai Shi*, **24**, 945 (1966); *Chem. Abstr.*, **66**, 37706*y* (1967). M. Lidaks and S. Hillers, *Puti Sin. Izyskaniya Protivoopukholevykh Prep. Tr. Simp. Khim. Protivoopukholevykh Veshchestv, M*, 193 (1960); *Chem. Abstr.*, **58**, 4531*c* (1963).

(7) J. E. Dolfini, *J. Org. Chem.*, **30**, 1298 (1965); A Padwa and L. Hamilton, *Tetrahedron Lett.*, 4363 (1965); B. Giese and R. Huisgen, *ibid.*, 1889 (1967).

(8) H. W. Whitlock, Jr., and G. L. Smith, *ibid.*, 1389 (1965).

TABLE I

REACTION OF AZIRIDINE WITH CARBONYL COMPOUNDS

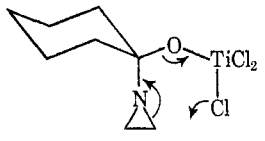
Run	Ketone	Mol of ketone/mol of $TiCl_4$	Product mixt bp, °C (mm)	Composition of mixt, %[a] Bis	Imine	Cl	Enamine	Wt of mixt/10 g of ketone	Yield[b] of bis adduct
1	Cyclohexanone	1/1	75–78 (6.2)	68	17.5	14.5	0	7.9	37
2	Cyclohexanone	1/0.5	91–100 (4.4)	44.4	55.5	0	0	4.9	13.3
3	Cyclohexanone	1/0.25	89–95 (3.0)	19	81	0	0	5.1	5.2
4	Cycloheptanone	1/1	90–95 (3.3)	29.2	0	37.2	33.6[c]	6.1	11
5	Cycloheptanone	1/0.5	88–94 (2.8)	0	23.6	24.2	52.2	2.2	
6	Cyclooctanone	1/1	76–111 (2.5)	0	0	56.8	43.2[d]	6.0	
7	3,3,5,5-Tetramethylcyclohexanone	1/1	100–106 (3.0)	24	0	61	17	1.6	3
8	Cyclopentanone	1/1	82–81 (5.3)	68	0	32	0	11.5	43
9	Benzaldehyde	1/1	100–110 (3.1)	23	34	43	0	8.2	11
10	Benzaldehyde[e]	1/1	103 (2.2)	0	0	100	0	2.3	
11	Benzaldehyde[f]	1/0	136 (9.5)	0	100	0	0	3.7	
12	Cyclopentanone[f]	1/0	85 (4.5)	0	100	0	0	0.15	

[a] The weight percentages were based on nmr analysis of volatile product mixture. [b] Based on ketone or benzaldehyde used. [c] A yield of 17% based on the ketone used. [d] A yield of 21.5% based on the ketone used. [e] No triethylamine present. [f] Aziridine and aldehyde or ketone stirred at room temperature without catalyst.

enimine is basic enough to completely scavenge the HCl. We have found that the addition of triethylamine to the initial ketone–aziridine mixture enables us to isolate a mixture of low-molecular-weight compounds as the major product, but the polymerization cannot be completely inhibited. We surveyed several other acid acceptors including pulverized sodium hydroxide, sodium carbonate, and pyridine; triethylamine was judged to be the most effective and most convenient.

The ketone to titanium tetrachloride mole ratio is an important factor in controlling the product distribution. The data in Table I show that equimolar ketone to $TiCl_4$ ratios (run 1) favor the formation of the bis-aziridinyl derivatives as well as the N-(β-chloroethyl)-imines. As the $TiCl_4$ concentration is decreased, the concentration of N-(β-aziridinylethyl)imines in the product mixture increases until they become the predominant compound of the distillate (run 3). There is a corresponding decrease in the overall yield of low-molecular-weight products as the ketone to $TiCl_4$ mole ratio is increased, so an equimolar stoichiometry of ketone and $TiCl_4$ is considered necessary for optimum yields of low-molecular-weight products.

Mechanism of Aziridine Addition.—The data in Table I can be rationalized by the following mechanism (Scheme I). When cyclohexanone is mixed with aziridine in benzene, 1-aziridinylcyclohexanol (**6**) precipitates. Addition of titanium tetrachloride converts the hydroxyl group to the more labile titanium alkoxide derivative **7**. A second mole of aziridine can then displace the titanate leaving group to produce 1,1-bis(aziridinyl)cyclohexane (**3**). High concentrations of $TiCl_4$ relative to the aminohydrin substrate will produce a minimum concentration of **7** and thus favor SN2 displacement by aziridine. Since the formation of N-(β-chloroethyl)cyclohexylimine (**4**) is also enhanced by high $TiCl_4$ concentrations, a concerted displacement by a chloride atom attached to titanium is probably the predominant reaction pathway leading to **4**.[9] As a first approximation $[Cl^-]/[aziridine]$ in runs 1–3 remains constant; *i.e.*, in run 1, the formation of $ROTiCl_3$ (1 mol) produces 1 mol of $Et_3NH^+Cl^-$, and, in run 3, 1 mol of $Et_3{}^+NHCl^-$ would be produced if the formation of $(RO)_4Ti$ were sterically possible. Under these conditions one would expect the relative concentration of **4** to remain constant if free chloride attack on either intermediate **7** or **8** were the major source of **4**.



The titanate complex **7** could dissociate to produce a resonance-stabilized carbonium ion **8**. Nucleophilic attack on the activated aziridine ring of **8** by aziridine would yield **5**. The dissociation process would be favored sterically if more than one aminohydrin molecule were complexed with a molecule of titanium tetrachloride. This explains the increase in the carbonium ion derived product **5**, as the concentration of titanium tetrachloride is reduced. We have shown that **4** cannot be converted to **5** in the presence of excess aziridine under these reaction conditions. Carbonium ion **8** need not react solely at an aziridinyl carbon with concomitant cleavage of the ring. Attack by aziridine on the cyclohexyl ring may contribute to the formation of **3**. Chloride ions may also attack the tertiary carbonium ion, but reionization of the α-chloramine formed precludes the isolation of the product. Since enamines could be isolated from this reaction only when the more sterically hindered cycloheptanone and cyclooctanone substrates were employed, we believe that the carbonium ion intermediate is also required for enamine formation. This hypothesis is supported by the presence of an enamine component in the low molecular-weight products derived from 3,3,5,5-tetramethylcyclohexanone (run 7), which should exhibit a strong steric interaction between the titanate and aziridinyl substituents of the intermediate analogous to **7** and the two axial methyl groups in the 3 and 5 positions.

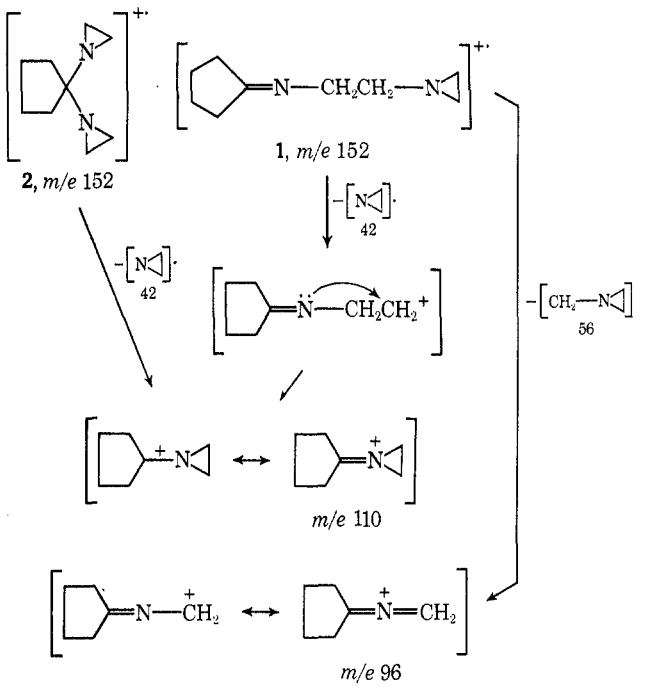
Spectral Characterization of the Aziridine Derivatives.—The structures were assigned to the products on the basis of infrared, nmr, and mass spectral data. The infrared spectra indicated the presence of the aziridine ring in compounds **3** and **5**; the sharp C–H stretch at 3080 cm^{-1} along with strong bands at 1260, 840, and 810 cm^{-1} are consistent with the values reported for

(9) We are grateful to a referee for suggesting this mechanism for the formation of **4**.

N-substituted aziridines.[10] Further, the imine derivatives **4** and **5** exhibited strong C=N stretching bands at 1660 and 1670 cm^{-1}, respectively.

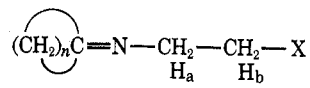
The mass spectra provide further support for the structure of **3** and **5**. Thus, bisaziridinyl derivatives fail to yield molecular ions, but the cracking patterns are similar to those observed for the N-(β-aziridinylethyl)imines. The major ions observed in the mass spectra of 1,1-bis(aziridinyl)cyclopentane (**2**) and N-(β-aziridinylethyl)cyclopentylimine (**1**) are assigned in Scheme II. The facile elimination of one aziridine

SCHEME II



ring from compound **2** would be expected for a bisaziridinyl derivative, for this produces a stabilized tertiary carbonium ion and probably relieves some steric strain. This effect is amplified in the cyclohexyl derivative. The principle peak in the spectrum of compound **3** occurs at *m/e* 124 (M − 42), and no larger ions can be observed. Compound **1** was prepared by the procedure of Dornow and Schacht to avoid contamination by the β-chloroethyl derivative. The spectrum of this compound clearly indicates the stability of the linear diadduct. The molecular ion as well as the ions produced by a stepwise loss of methylene groups are present in relatively high concentrations. A similar cracking pattern was observed for N-(β-aziridinylethyl)benzalimine. The mass spectrum of 1-N-aziridinylcycloheptene was consistent with the enamine structure. A strong molecular ion at *m/e* 137 confirms the stability of the monosubstituted cycloalkane. The cracking pattern indicated that initial decomposition occurred by loss of either ethylene or aziridine followed by a complex fragmentation, leading to a series of ions from 79 to 83 with similar intensities. These were probably generated by the loss of several hydrogen atoms from the cycloheptene ring. The principle peak was found at *m/e* 42, which corresponds to the aziridinyl cation.

The most conclusive evidence for the structure of the low-molecular-weight products was obtained from the nmr spectra. The aziridine rings in the bisaziridinyl derivatives **2** and **3** do not undergo rapid inversion; therefore, two signals corresponding to the *syn* (δ 1.12–1.32) and *anti* (δ 1.60–1.80) protons[11] are observed. The cycloalkane protons appear as a complex multiplet centering around δ 1.45. No absorptions above δ 1.10 or below δ 1.8 were observed. In contrast to the spectra of the bisaziridinyl derivatives, the spectra of both the N-(β-chloroethyl)imines and the N-(β-aziridinylethyl)imines exhibited complex multiplets below δ 1.8. These multiplets were assigned to the protons in the ethylene group bridging the cycloalkane and aziridine rings (**9**). By comparing the spectra of several similar derivatives, the low-field absorption (δ ~3.5–3.7) was assigned to H_a. The higher field absorptions of H_b



9, X = Cl, -N

were assigned to δ 2.45–2.5 for X = aziridinyl and to δ ~3.5 for X = Cl. These assignments are consistant with those reported for N-(β-chloroethyl)aziridine.[12]

The nmr spectra of the 1-N-aziridinylcycloalkenes exhibited a triplet δ 5.0, which is characteristic of the ethylenic proton on the enamine structure. This is one of the lowest downfield absorptions we have observed for an enamine ethylenic proton; it probably reflects a minimal interaction of the electron pair on the aziridinyl nitrogen with the olefinic π electrons. It is also interesting to note that the absorption of the protons on the aziridine ring appears as a singlet, which coincides with the cycloalkane protons. The nitrogen inversion is occurring too rapidly at room temperature to observe *syn* and *anti* conformers. The broad multiplet δ ~2.10 is due to the allylic protons on the cycloalkene ring.

Reactivity of the Aziridine Derivatives.—All of the compounds decomposed when stored at room temperature. The initial distillates darkened rapidly, and low-molecular-weight polyaziridine derivatives began to precipitate. The polymerization is probably initiated by the quaternary ammonium salt formed by the addition of N-(β-chloroethyl)cycloalkylimine to the bisaziridine component. Most of the polymers were insoluble in polar as well as acidic solvents which indicates that a cross-linked network had formed. Efforts to remove the N-(β-chloroethyl)cycloalkylimines by distillation and chromatography failed. However, when piperazine was added to the reaction mixture to convert the β-chloro derivative to a piperazinium salt, pure bis(aziridinyl)cycloalkane could be isolated. The purification of 1-N-aziridinyl-1-cycloheptene was effected by the same technique.

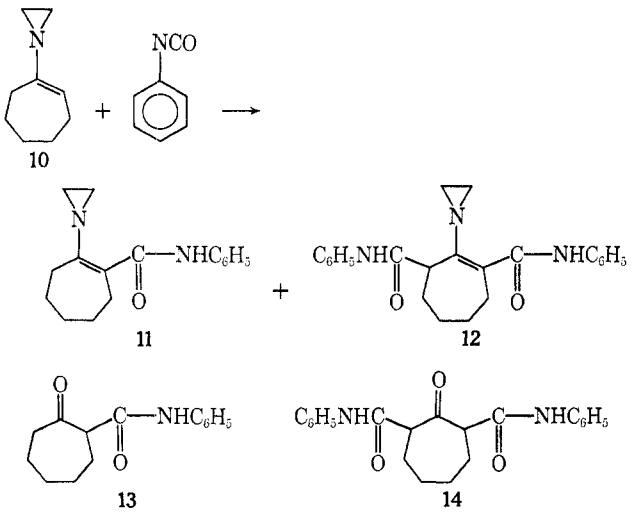
The nucleophilic character of the aziridinyl enamines was ascertained by allowing them to react with phenyl isocyanate in acetone. 1-N-Aziridinyl-1-cycloheptene (**10**) yielded a mixture of 2-aziridinyl-1-cycloheptene-1-carboxanilide (**11**), 2-aziridinyl-1-cycloheptene-1,3-dicarboxanilide (**12**), cycloheptan-2-one-1-carboxanilide (**13**), and cycloheptan-2-one-1,3-dicarboxanilide

(10) H. T. Hoffman, Jr., G. E. Evans, and C. Glockler, *J. Amer. Chem. Soc.*, **73**, 3028 (1951). R. W. Hitchell, J. C. Burr, Jr., and J. A. Merritt, *Spectrochim. Acta*, **23A**, 195 (1967). J. Tempe, *C. R. Acad. Sci., Paris*, **259**, 1717 (1964); *Chem. Abstr.*, **62**, 1204 (1965).

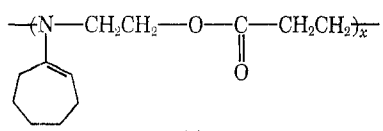
(11) S. J. Brois, *J. Amer. Chem. Soc.*, **89**, 4242 (1967).

(12) P. L. Levins and Z. B. Papanastassiov, *ibid.*, **87**, 826 (1965).

(14). The reaction mixture was hydrolyzed with ethanolic hydrochloric acid to yield **13** and **14**, which were identical with the compounds obtained from the addition of phenyl isocyanate to 1-N-pyrrolidino-1-cycloheptene followed by acid hydrolysis. Treatment of 1-N-aziridinyl-1-cyclooctene with phenyl isocyanate afforded a mixture of mono- and diadducts as well as three minor components which were not identified.



The reactivity of the aziridine substituent on the enamines is demonstrated by their polymerization when treated with β-propiolactone. An equimolar mixture of 1-N-aziridinyl-1-cycloheptene and β-propiolactone in acetonitrile yielded a low-molecular-weight yellow oil which was assigned structure **15** on



the basis of nmr and infrared evidence. The oil darkened rapidly when exposed to air as would be expected for a copolymer containing residual unsaturation. Recently, the reaction of N-phenylethylenimine and β-propiolactone under these conditions was reported to yield copolymers with a similar structure.[13]

Attempted Preparation of 1-N-Aziridinyl-1-cyclohexene.—The isolation and characterization of 1-N-aziridinyl-1-cycloheptene and -1-cyclooctene demonstrates the stability and bifunctionality of unsubstituted enamines containing an aziridine substituent. Since the titanium tetrachloride catalyzed addition of aziridine to cyclohexanone failed to afford 1-N-aziridinyl-1-cyclohexene (**16**), we attempted to prepare **16** *via* a base-catalyzed isomerization of 3-N-aziridinyl-1-cyclohexene. Isomerization of allylamines to enamines has been successfully employed in the synthesis of several N,N-dialkylenamines[14] and represents a technique for preparing *cis* isomers of monosubstituted aliphatic enamines.[15] The isomerization is catalyzed by potassium *t*-butoxide in dimethyl sulfoxide, sodium amide in liquid ammonia, or sodium metal. Since the aziridine ring is known to be resistant to strong bases, we did not anticipate any problems in isomerizing aziridine derivatives. We prepared 3-aziridinyl-1-cyclohexene (**17**) by allowing aziridine to react with 3-bromo-1-cyclohexene in the presence of powdered potassium hydroxide. Initially, we attempted to run the reaction at 0° in methanol, but no reaction occurred. Nonprotic solvents, such as nitrobenzene or chlorobenzene, produced low yields of the desired product, but the best solvent for the reaction proved to be tetralin. Although complete removal of the tetralin is extremely difficult, 60% yields of 3-aziridinyl-1-cycloheptene containing 15–20% tetralin could easily be obtained. Unfortunately, all attempts to isomerize this mixture to 1-N-aziridinyl-1-cyclohexene failed. The compound was essentially inert to potassium *t*-butoxide in dimethyl sulfoxide, sodium amide in liquid ammonia, and sodium metal at room temperature. Sodium amyloxide in benzene catalyzed a rapid decomposition. Prolonged heating of **17** in bulk or in *o*-chlorotoluene in the presence of sodium metal produces a low-molecular-weight polymer with residual unsaturation. However, no evidence for the characteristic ethylenic proton of an enamine structure could be detected in the nmr.

Experimental Section

Melting and boiling points are uncorrected. Analyses were by Galbraith Laboratories, Inc., Knoxville, Tenn. Ir spectra were determined using a Beckman IR-8 spectrometer. The nmr spectra were determined at 60 and 100 Mc with Varian Model A-60A and Varian HR-100 nmr spectrometers, respectively. The chemical shift values are expressed in δ values (parts per million) relative to a tetramethylsilane internal standard. The mass spectra were obtained with a Varian M-66 mass spectrometer operating at 70 eV. All reactions involving aziridine were performed under a nitrogen atmosphere. Thin layer chromatograms were obtained on 0.25-mm silica gel G plates developed by exposure to iodine vapor.

Preparation of Starting Materials.—Commercial samples of the starting carbonyl compounds were available. The aziridine was donated by the Dow Chemical Co. Benzene was distilled from calcium hydride. Reagent grade titanium tetrachloride was diluted with benzene to produce a solution which was 1 *M* in titanium tetrachloride. Phenyl isocyanate and β-propiolactone were purified by distillation immediately prior to use. 3-Bromo-1-cyclohexene was prepared by treating cyclohexene with N-bromosuccinimide in CCl_4.[16]

Illustrative Procedure for the Preparation of Bis(aziridinyl)-cycloalkanes.—A solution of 12 g (0.12 mol) of cyclohexanone in 100 ml of benzene was charged into a 1 l., four-necked, round-bottom flask equipped with a mechanical stirrer, nitrogen inlet, thermometer, and a pressure-equalizing dropping funnel. The dropping funnel was connected to a mercury pressure release valve; the system was purged and then placed under a positive pressure of nitrogen. The flask was immersed in an ice bath at 5° and 50 ml (0.36 mol) of triethylamine followed by 20 ml (0.44 mol) of aziridine were added. 1-N-Aziridinylcyclohexanol precipitated immediately. The slurry was stirred vigorously at 5–10° while 120 ml of 1 *M* $TiCl_4$ in benzene was added dropwise. Addition of the $TiCl_4$ required 1.5–2 hr. The reaction was stirred an additional 2–3 hr at 5°, and then the temperature was allowed to rise to 25°. The reaction mixture was allowed to stand overnight at room temperature. The volatile products were isolated from the mixture by filtering off the triethylamine hydrochloride, which had precipitated, evaporating the solvent and excess aziridine at reduced pressure, and distilling the residue through a short Vigreux column. A total of 9.5 g of volatile material, bp 75–78° (6 mm), was obtained. The composition

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of this product mixture was analyzed by tlc and nmr before further purification. A brown tar (4.2 g) remained in the distillation flask; this residue appeared to be an aziridine polymer. The relative concentrations of the volatile products (Table I) were determined by comparing the integrated areas of the δ 3.5, 2.5, and 1.12 absorptions. The value for bis(aziridinyl)cycloalkane was corrected for the overlapping aziridinyl absorption of **5**. Tlc on silica G with acetone as the eluent did not indicate the presence of components other than those reported in Table I.

Pure bis(aziridinyl)cyclohexane was obtained by stirring the distillate with 5.0 g of piperazine dissolved in 20 ml of benzene at room temperature overnight to remove **4**, filtering the precipitated salt, and fractionally distilling the filtrate *in vacuo*. After two distillations through a Vigreux column, 2.1 g of **3**, bp 58–60° (1.4 mm), was isolated: ir (neat) 3080, 1255, 805 cm^{-1} (aziridinyl); nmr (benzene) δ 1.12 (4.5 H triplet, *syn*-aziridinyl **H**), 1.43 (9 H singlet, cyclohexyl **H**), 1.80 (4.5 H triplet, *anti*-aziridinyl **H**); mass spectrum, no molecular ion, abundant fragment peaks at *m/e* 125, 124 (principal peak), 123, 122, 110, 96, 95, 94, 81, 80, 79, 77, 69, 68, 67, 56, 55, 54, 53, 43, 42, 41, and 39. *Anal.* Calcd for $C_{10}H_{18}N_2$: C, 72.23; H, 10.92; N, 16.85. Found: C, 72.53; H, 11.14; N, 16.44.

A similar purification procedure afforded pure **2**: bp 63° (3.0 mm); nmr (benzene) δ 1.32 (3.5 H, multiplet, *syn*-aziridinyl **H**), 1.45 (8.5 H, broad singlet, cyclopentyl **H**), 1.60 (4.0 H, multiplet, *anti*-aziridinyl **H**); mass spectrum, no molecular ion, fragmentation peaks at *m/e* 124, 110, 96, 67, 55, 54, 53, 52, 51, 44, 43, and 41 (principal peak). *Anal.* Calcd for $C_9H_{16}N_2$: C, 71.06; H, 10.52; N, 18.42. Found: C, 70.92; H, 10.18; N, 18.14.

β-(N-Aziridinylethyl)cyclopentylimine (1).—A mixture of cyclopentanone (50 ml, 0.6 mol) and aziridine (52 g, 1.2 mol) was allowed to stand at 30° for 1 week.[4] The excess aziridine was distilled from the light orange reaction mixture and the residue fractionally distilled under reduced pressure to yield cyclopentanone and 0.75 g of **1**: bp 85° (4.5 mm); ir (neat) 3080, 1250, 815 cm^{-1} (aziridinyl), 1710 cm^{-1} (C=N); nmr (benzene) δ 0.95 (2 H, triplet, *syn*-aziridinyl **H**), 1.51 (6 H, multiplet, *anti*-aziridinyl **H** and cyclopentyl $-CH_2-$ in the 3 and 4 positions), 2.00 (4 H, multiplet, allylic cyclopentyl $-CH_2-$), 2.52 (2 H, triplet, J = 7.0 cps, CH_2 adjacent to aziridinyl substituent), 3.48 (2 H, triplet, J = 7.0 cps, CH_2 adjacent of imine linkage); mass spectrum, 152 (molecular ion), 151, 137, 124, 123, 110 (principal peak), 96, 78, 77, 66, 56, 52, 51, 50, 42, and 41.

1-N-Aziridinyl-1-cycloheptene (10).—A mixture of cycloheptanone (34 ml, 0.3 ml) and triethylamine (150 ml, 1.1 mol) dissolved in 120 ml of benzene was allowed to react with 60 ml (1.5 mol) of aziridine for 30 min at 10°. A solution of 0.3 mol of titanium tetrachloride in 300 ml of benzene was added dropwise over a 3-hr interval while the temperature was maintained below 10° with an ice bath. When the $TiCl_4$ addition was completed, the reaction mixture was allowed to warm to room temperature (~35°) and stirred overnight. The product mixture, 18.5 g, bp 75–90° (3.3 mm), was isolated and analyzed by nmr as described above. Fractional distillation of the product mixture through a short Vigreux column yielded 7.8 g of a fraction, bp 56–59° (3.3 mm), which contained at least 70% **10** along with cycloheptanone and N-(β-chloroethyl)cycloheptylimine. This fraction was dissolved in 20 ml of benzene and treated with 1.0 g of piperazine at room temperature for 4 hr. Vacuum distillation of the benzene solution yielded 3.5 g of pure **10**: bp 69–71° (4.5 mm); ir (neat) 3080, 1280 cm^{-1} (aziridinyl), 1670, 763 cm^{-1} (C=C), nmr (benzene) δ 1.50 (10 H broad singlet, aziridinyl CH_2 and CH_2 at the 4, 5, and 6 positions of cycloheptenyl ring), 2.10 (4 H multiplet, allylic CH_2), 5.00 (1 H, triplet, ethylenic proton); mass spectrum, 137 (molecular ion), 136, 109, 108, 95, 94, 83, 82, 81, 80, 79, 68, 67, 56, 55, 54, 53, 42, and 41 (principal peak). *Anal.* Calcd for $C_9H_{15}N$: C, 78.76; H, 10.94; N, 10.21. Found: C, 78.53; H, 10.92; N, 10.51.

Reaction of 1-N-Aziridinyl-1-cycloheptene with Phenyl Isocyanate.—The enamine (1.54 g, 6 mmol) in 2 ml of acetone was allowed to react with 0.83 g (7 mmol) of phenyl isocyanate under nitrogen at 30° for 12 hr. Evaporation of the acetone yielded 1.55 g of a solid, mp 130–135°. Thin layer chromatography of this solid on silica gel G using a mixture of benzene–cyclohexane–absolute ethanol (25:60:10) revealed the presence of at least five components (R_f value): diphenylurea (0.00), **14** (0.21), **13** (0.32), **12** (0.47), and **11** (0.72). The mass spectrum of this mixture contained the molecular ions for **14**, **13**, and **11** at *m/e* 350, 231, and 256, respectively. Although a molecular ion for **12** was not observed, an ion at *m/e* of 333 was present which would correspond to the loss of aziridine (375 − 42) from this compound. The ir spectrum of the mixture had bands at 3080 (aziridinyl) and 1680 and 1660 cm^{-1} (-CONH-). Hydrolysis of 1.0 g of the mixture with 25 ml of 10% ethanolic HCl simplified the mixture to three components (tlc). These were identified as diphenylurea, **13**, and **14** by comparison with samples of these compounds prepared from 1-N-pyrrolidino-1-cycloheptene under the same conditions. Compound **14** (mp 193°) precipitated from the hydrolysis mixture; a mixture melting point with **14** prepared *via* the 1-N-pyrrolidino-1-cycloheptene showed no depression.

Reaction of 1-N-Aziridinyl-1-cycloheptene with β-Propiolactone—A solution of 1.4 g (2 mmol) of β-propiolactone in 10 ml of anhydrous acetonitrile was added to a glass ampoule and cooled to −78°. The enamine (0.8 g, 3 mmol) was injected through a serum cap after the ampoule had been filled with nitrogen. The ampoule was allowed to warm to 4°, and within 1 hr a yellow oil began to separate from the acetonitrile solution. After 2.5 days at 4°, the acetonitrile solution was decanted from the oil which was dried to constant weight (0.58 g) *in vacuo:* ir (neat) 1740 (-OOC-), 1670 cm^{-1} (C=C); nmr ($CDCl_3$) δ 4.65 (1 H, broad singlet, ethylenic proton), 4.30 (2 H, multiplet, COO-CH_2), 2.80 (10 H, multiplet, allylic CH_2, CH_2NCH_2-, $CH_2C=O$), 1.60 (6 H, broad singlet, CH_2 in the 4, 5, and 6 positions of the cycloheptene substituent). The polymer darkened rapidly upon exposure to air and the ethylenic proton disappeared.

Preparation of 3-N-Aziridinyl-1-cyclohexene (17).—3-Bromocyclohexene (21 g, 0.13 mol) was added to a mixture of 50 g (0.9 mol) of potassium hydroxide slurried in 200 ml of tetralin. The reaction mixture was cooled to 5° in an ice bath and stirred while 21 ml (0.4 mol) of aziridine was added dropwise. The addition required 0.5 hr; the mixture was stirred for 6 hr and then filtered. The yellow filtrate was fractionally distilled through a short Vigreux column under reduced pressure: fraction I, 15.0 g, bp 49–57° (7.0 mm); fraction II, 15.5 g, bp 62–67° (7.0 mm); fraction III, 75 g, bp 70–73° (7.0 mm). Fraction I contained 85.5% **17** (by nmr analysis), fraction II contained 28% **17**, and fraction III is essentially pure tetralin. Distillation of fraction I through a 30-cm spinning-band column failed to increase the purity of **17**. However, pure **17** could be obtained in much lower yield [3.0 g., bp 51–53° (11 mm)] by changing the solvent to chlorobenzene and isolating the 3-N-aziridinyl-1-cyclohexene as described above: ir (neat) 3050, 1280 (aziridinyl), 1660 cm^{-1} (C=C); nmr (CCl_4) δ 1.05 (2 H, broad doublet, *syn*-aziridinyl **H**), 1.58 (6.5 H, multiplet, cyclohexenyl CH_2), 1.96 (2.5 H, broad singlet, *anti*-aziridinyl **H**) 5.61 (2 H, broad singlet, ethylenic **H**). *Anal.* Calcd for $C_8H_{13}N$: C, 78.05; H, 10.57; N, 11.38. Found: C, 78.20; H, 10.87; N, 11.11.

Attempted Isomerization of 17 to 1-N-Aziridinyl-1-cyclohexene.—A solution of 0.3 ml of **17** in 3 ml of *o*-chlorotoluene was treated with 0.2 g of sodium metal and heated to 150°. The solution darkened rapidly, but nmr analysis showed that no enamine had formed after 24 hr at 150°. When N-allylmorpholine was treated under the same conditions, 60% isomerized within 1 hr to N-propenylmorpholine.[14] Treatment of **17** with a 20% solution of potassium *t*-butoxide in dimethyl sulfoxide at room temperature for 4 days or at 60° for 12 hr failed to effect isomerization.

Registry No.—Aziridine, 151-56-4; **1**, 23924-14-3; **2**, 23924-15-4; **3**, 23924-16-5; **10**, 23924-17-6; **17**, 23924-18-7.