(b) To about 200 ml. of concentrated sulfuric acid was added 22 g. (0.1 mole) of freshly prepared potassium 3-benzoyldithiocarbazate. The temperature rose rapidly to about 50°. After standing at room temperature for 4 hours the mixture was added to 1 l. of ice-water, and the solid that separated was collected and washed with cold water. The crude product weighed 10 g. and was recrystallized from acetic acid or ethyl alcohol to give 6 g. (31% yield) of bis-(2-phenyl-1,3,4-thiadiazole-5) disulfide (V), m.p. 163°; λ_{max} 286 mμ, log ε 4.40; mol. wt., 406 (cryoscopic).

Anal. Calcd. for $C_{16}H_{10}N_4S_4$: C, 49.71; H, 2.61; N, 14.50. Found: C, 49.53; H, 2.53; N, 14.44.

Compound V also was prepared from a sample of 2-phenyl-Δ^2-1,3,4-thiadiazoline-5-thione (III) and concentrated sulfuric acid heated at 50° for two minutes. A sample of III was dissolved in 1 *N* sodium hydroxide solution and was treated with iodoform reagent. The solid that separated was identified as compound V.

(c) Air was bubbled for 1 hour into a mixture of 10 g. of potassium 3-benzoyldithiocarbazate and 100 ml. of concentrated sulfuric acid warmed at 40°. The mixture was poured into ice-water and the resulting solid was collected and washed with water. The solid was treated with 100 ml. of saturated sodium carbonate solution and then was filtered. The insoluble material was recrystallized from ethyl acetate–petroleum ether and 2 g. (23% yield) of V was obtained. The sodium carbonate extract was neutralized with concentrated hydrochloric acid and 0.2 g. of III was obtained.

When the reaction was repeated using a nitrogen atmosphere in place of air the yields of the two products were the same.

Basic Cleavage of Bis-(2-phenyl-1,3,4-thiadiazole-5) Disulfide (V).—About 2 g. (0.005 mole) of bis-(2-phenyl-1,3,4-thiadiazole-5) disulfide and 20 ml. of 1 *N* sodium hydroxide was warmed on a steam-bath for 1 hour during which time it dissolved and formed a yellow colored solution. Hydrochloric acid was added until the solution was acidic and sulfur dioxide was evolved. The solution was made basic and was extracted with ethyl acetate. The ethyl acetate was evaporated and the residue was shown by infrared analysis to be 2-phenyl-1,3,4-thiadiazole. The basic layer was made acidic with hydrochloric acid and the solid that separated was identified as 2-phenyl-Δ^2-1,3,4-thiadiazoline-5-thione (III). The yields were almost quantitative.

INDIANAPOLIS 6, IND.

[CONTRIBUTION NO. 2306 FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY]

Nuclear Magnetic Resonance Spectra. Nitrogen Inversion Rates of N-Substituted Aziridines (Ethylenimines)[1]

BY ALBERT T. BOTTINI[2] AND JOHN D. ROBERTS

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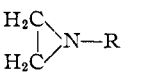
The nuclear magnetic resonance spectra of various cyclic imines ranging in ring size from three to six have been examined. The spectra of N-substituted aziridine (ethylenimine) derivatives were found to be strongly temperature dependent as would be expected if the nitrogen atoms and attached groups do not lie in a plane and inversion occurs rather slowly. It has been possible to evaluate some factors which affect the inversion rates of non-planar nitrogen atoms in cyclic imines. As would be expected, attachment of unsaturated groups to non-planar nitrogen increases the inversion rate as the result of conjugation with the nitrogen unshared electron pairs. The rates are also increased by bulky groups whether attached to nitrogen or to the carbons of the imine ring. Substitution of alkyl groups for one hydrogen or for two *cis*-hydrogens attached to carbon appears to make the molecules assume preferred configurations with the N-substituent *trans* to the ring substituent(s). The inversion rates most probably are decreased in hydroxylic solvents because of stabilization of the separate configurations by hydrogen bonding between the solvent and the imino nitrogen. The data so far obtained indicate that substituted aziridines with molecular asymmetry due to trivalent nitrogen are likely only to be resolvable into reasonably stable optical antipodes at temperatures below −50°. The nitrogen inversion rates of N-substituted azetidines (trimethylenimines) and larger-ring imines appear to be too great to be measurable by nuclear magnetic resonance techniques at temperatures above −77°.

Introduction

Considerable effort has been expended in attempts to resolve substances into optical isomers which would owe their asymmetry solely to non-planar trivalent nitrogen.[3] Failure to obtain such compounds in optically active forms indicates that the molecules of the type NRR′R″ readily undergo optical inversion.

In 1939, several groups of workers[4] postulated independently that suitably substituted aziridines (ethylenimines) might be favorably constituted to permit existence of stable, optically active antipodes. This idea was given support by Kincaid and Henriques[5] through calculations of the magnitude of the energy barrier for inversion of the nitrogen in 1-methylaziridine (Ia). With the aid



Ia, R = CH_3–	Ie, R = C_6H_{11}–
Ib, R = C_2H_5–	If, R = t-C_4H_9–
Ic, R = $C_6H_5CH_2$–	Ig, R = C_6H_5–
Id, R = $C_6H_5CH_2CH_2$–	Ih, R = H–

of Wall and Glockler's expression for the potential energy of ammonia,[6] they first estimated an activation energy (ΔE) of 38 kcal./mole for inversion of Ia. Since the same method gave 11 kcal./mole for the barrier height in ammonia, as compared to the "more reasonable" value of 8 kcal./mole, Kincaid and Henriques reduced their estimated ΔE for Ia to 25 kcal./mole. They noted that resolution would be practically impossible unless the above rate constant for inversion is less than 10^{-5} sec.$^{-1}$. From the Arrhenius equation (1) and assumption of a normal preexponential factor of 10^{13}, ΔE must be greater than 25 kcal./mole if the rate constant for inversion is to be less than 10^{-5} sec.$^{-1}$ at room temperature.

$$k' = 10^{13} e^{-\Delta E/RT} \quad (1)$$

(1) Supported in part by the Office of Naval Research.

(2) National Science Foundation Predoctoral Fellow, 1954–1957.

(3) (a) R. L. Shriner, R. Adams and C. S. Marvel in H. Gilman, "Organic Chemistry, An Advanced Treatise," John Wiley and Sons, Inc., New York, N. Y., second edition, 1943, Vol. I, pp. 402–413; (b) V. Prelog and P. Wieland, *Helv. Chim. Acta*, **27**, 1127 (1944).

(4) (a) R. Adams and T. L. Cairns, THIS JOURNAL, **61**, 2464 (1939); (b) P. Maitland, *Ann. Rept. Chem. Soc. London*, **36**, 239 (1939); (c) J. Meisenheimer and L.-H. Chou, *Ann.*, **539**, 70 (1939); (d) J. D. C. Mole and E. E. Turner, *Chemistry & Industry*, **17**, 582 (1939).

(5) J. F. Kincaid and F. C. Henriques, Jr., THIS JOURNAL, **62**, 1474 (1940).

(6) F. T. Wall and G. Glockler, *J. Chem. Phys.*, **5**, 314 (1937).

Kincaid and Henriques also calculated an uncorrected activation energy of 15 kcal./mole for inversion of trimethylamine. The effects of other nitrogen substituents on the activation energy were considered and it was pointed out that increase in weight of a group would have little effect compared to that expected from steric repulsions. Thus, branched groups, such as the *t*-butyl group, were expected to lower the activation energy much more than larger straight-chain groups. Kincaid and Henriques concluded that cyclic compounds with nitrogen incorporated in unstrained five- or six-membered rings would undergo inversion with practically the same ease as the analogous open-chain compounds and would almost certainly be unresolvable even at −80°.

So far, all attempts to resolve substituted ethylenimines have been unsuccessful.[4a,c,7]

Results and Discussion

In an earlier communication,[8] we described the temperature-dependent nuclear magnetic resonance (n.m.r.) spectra of 1-ethylaziridine (Ib) and 1-ethyl-2-methylene-aziridine (II) (Fig. 1). At room temperature, Ib shows the characteristic resonances of the ethyl group[9] and two triplet resonances separated by 27 c.p.s. at 40 mc. The latter resonances are best interpreted as being due to the two groups of non-equivalent ring hydrogens which are either *cis* or *trans* to the 1-ethyl group and split by their mutual spin–spin interaction. It is less likely

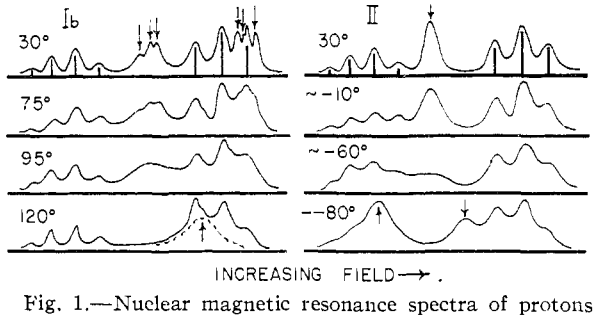
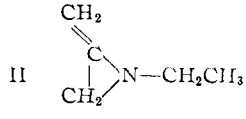


Fig. 1.—Nuclear magnetic resonance spectra of protons of 1-ethylaziridine (Ib) and 1-ethyl-2-methyleneaziridine (II) as a function of temperature. Heavy vertical lines mark characteristic resonance lines of the ethyl group while vertical arrows indicate absorption of the ring hydrogens. The temperature-invariant absorption of the double-bond methylene protons of II is off scale on the left.



that the splitting is due to interaction with the ^{14}N in the manner observed for tetramethylammonium ion.[10] On heating to 120°, the ring hydrogens of Ib appear to lose their identity with respect to the position of the ethyl group. At room temperature, II shows only one resonance line for the ring methylene group. However, at and below −77°, this line is split into two components separated by about 30 c.p.s. Gutowsky and coworkers,[11] through application of the equations derived by Bloch[12] to describe the shape of n.m.r. absorption lines, have shown that when exchange of nuclei between two individual chemical environments occurs at a sufficiently rapid rate, such exchange is capable of collapsing a complex n.m.r. pattern into a simpler one. As t, the average lifetime of a proton, or group of equivalent protons, in either of two equally probable environments, decreases, the observed line separation, $\delta\omega_e$, decreases from $\delta\omega$ to 0. If the line widths at half-maximum intensity for the absorption lines in the complex spectrum are small with respect to $\delta\omega$, a particularly simple expression results[11c]

$$\delta\omega_e = (1 - 2/(t/2)^2\delta\omega^2)^{1/2}\delta\omega \text{ if } t/2\ \delta\omega > 2^{1/2}$$
$$\delta\omega_e = 0 \text{ if } t/2\ \delta\omega \leq 2^{1/2} \qquad (2)$$

Thus, at 108 ± 5°, the temperature, T_c where the two ring-hydrogen resonances of Ib coalesce (*i.e.*, $\delta\omega_e$ becomes 0), the mean lifetime t of a given molecule before nitrogen inversion occurs is about 0.017 sec. The corresponding value of T_c for II was found to be −65 ± 10°, at which point the mean configurational lifetime is about 0.015 sec.

The spectra of a number of substituted aziridines were examined at various temperatures. For each, T_c was determined with samples in either a vacuum-jacketed probe insert or a probe insert so constructed that the temperature of the sample was controlled by a flow of preheated air.[13] At T_c, t was taken as equal to $2 \times 2^{1/2}(2\pi\delta\omega)^{-1}$ (with $\delta\omega$ expressed in c.p.s.), and the first-order rate constant, k', for the nitrogen inversion was obtained from the equality, $k' = 1/t$.

It is possible to compute activation energies, ΔE, for nitrogen inversion in the substances investigated by using the expression[14]

$$k' = K(kT/h)e^{-\Delta E/RT} \qquad (3)$$

provided K, the transmission coefficient, is assumed to be as unity. This assumption might be expected to be valid for a kinetic process as simple as nitrogen inversion but, nonetheless, K is reported by Gutowsky and Holm[11c] to be far different from unity for rotation around C–N bonds. Consequently, detailed discussion of this point will be deferred until experimental measurements of the activation energies are completed. However, if K is close to unity, even the most slowly inverted imine so far measured (Ib) would have at or above −50° a rate constant greater than the 10^{-5} sec.$^{-1}$ value believed to limit successful resolution into optical antipodes.

The results given in Table I show that conjugation with nitrogen either produces essentially planar molecules with equivalent imine ring-hydrogens or else greatly increases the nitrogen inversion rates.

(7) (a) T. L. Cairns, THIS JOURNAL, **63**, 871 (1941); (b) H. M. Kissman and D. S. Tarbell, *ibid.*, **74**, 4817 (1952).

(8) A. T. Bottini and J. D. Roberts, *ibid.*, **78**, 5126 (1956).

(9) B. P. Dailey and J. N. Shoolery, *ibid.*, **77**, 3977 (1955).

(10) E. Grunwald, A. Lowenstein and S. Meiboom, *J. Chem. Phys.*, **27**, 641 (1957).

(11) (a) H. S. Gutowsky, D. W. McCall and C. P. Slichter, *J. Chem. Phys.*, **21**, 279 (1953); (b) H. S. Gutowsky and A. Saika, *ibid.*, **21**, 1688 (1953); (c) H. S. Gutowsky and C. H. Holm, *ibid.*, **25**, 1228 (1956).

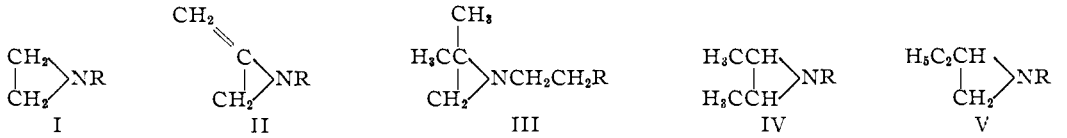
(12) F. Bloch, *Phys. Rev.*, **70**, 460 (1946).

(13) J. N. Shoolery and J. D. Roberts, *Rev. Sci. Instruments*, **28**, 61 (1957).

(14) S. Glasstone, K. J. Laidler and H. Eyring, "The Theory of Rate Processes," McGraw-Hill Book Co., Inc., New York, N. Y., 1941, p. 295.

TABLE I

THE NITROGEN INVERSION RATES OF SUBSTITUTED AZIRIDINES

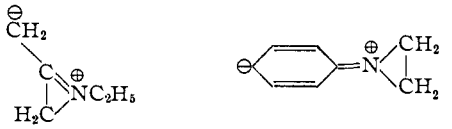


I II III IV V

Compound	R	T_c, °C.	t, sec.	k', sec.$^{-1}$
Ib	C_2H_5	108[a]	0.017	60
Ib	C_2H_5	>145[b]	>.017	<60
Ic	$CH_2C_6H_5$	105[a]	.017	60
Id	$CH_2CH_2C_6H_5$	96[a]	.014	69
Ie	C_6H_{11}	95[c]	.020	51
If	t-C_4H_9	<−77[d]	...	..
Ig	C_6H_5	<−77[e]	...	..
Ig	C_6H_5	−60[c]	.024	42
II	C_2H_5	−65[c]	.015	67
II	C_2H_5	−25[c,f]	.015	67
IIIa	CH_2OH	55[a,g]	.11	8.9
IIIb	$CO_2C_2H_5$	55[a,g]	.075	13
IV, *cis*	C_2H_5	140[h]	...	..
IV, *trans*	C_2H_5	58(?)[a,g]	.064(?)	16(?)
V	C_2H_5	140[h]	...	..

[a] ±5°. [b] In deuterium oxide solution. [c] ±10°. [d] As the pure liquid and in 0.01 *N* methanolic sodium hydroxide. [e] As the pure liquid and in toluene. [f] In 0.01 *N* methanolic sodium hydroxide. [g] Determined by observing the resonances of the *gem*-dimethyl group. [h] No marked change in ring hydrogen resonances up to 140° probably due to N-substituent group being preferentially *trans* to the ring substituents.

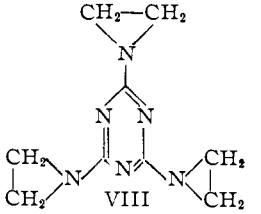
Adopting the latter hypothesis, we expect that the tremendously faster inversion rate of II compared with Ib arises from contributions of electron delocalization involving the nitrogen and double bond as indicated by structure VI. Such delocalization



VI VII

would markedly aid attainment of a planar inversion transition state. At present, it is not easy to decide whether the decrease in transition state energy brought about by electron delocalization is greater for II or the N-phenyl derivative Ig (*cf.* VII). This is because the net increase in energy due to bond angle strain in going from ground to transition states is expected to be somewhat greater for II than for Ig.

Triethylenemelamine (2,4,6-tris-(1-aziridinyl)-*s*-triazine, VIII) also was prepared and its n.m.r. spectra in chloroform and in water were examined. At −40° and at −10°, where VIII began to crystallize from chloroform and water, respectively, there was no indication that T_c was approached.



VIII

The observed effects of bulky substituents on the inversion rates of cyclic imines were found to be in accord with the predictions of Kincaid and Henriques.[5] 1-Benzylaziridine (Ic) and 1-(β-phenethyl)-aziridine (Id) exhibited only slightly greater nitrogen inversion rates than the 1-ethyl derivative Ib. The spectrum of the cyclohexyl derivative Ie has one of the two ring-hydrogen resonances overlapping with the broad cyclohexyl resonance so that exact determination of T_c was difficult. The fine structure did not disappear until the temperature was raised to above 80° and T_c was thus estimated to be 95 ± 10°.

The largest bulk effect was observed with 1-*t*-butylaziridine (If). Examination of models of If reveals that there can be no conformation of the molecule with pyramidal nitrogen wherein the steric interactions of the *t*-butyl hydrogens and the ring-hydrogens are substantially minimized. If one allows that the non-steric potential energy contribution of the substituent is the same in the ground and transition states, then the lower inversion barrier for If as compared to Ib might well result from the non-bonded hydrogen–hydrogen repulsions in the ground state of If.[15]

The above considerations also account for the increase in nitrogen inversion rates when two alkyl groups are attached to carbon on opposite sides of the imine ring of N-substituted aziridines. The increase is about the same when the groups are on the same or different carbon atoms.

The n.m.r. spectra of the aziridine derivatives substituted on the ring with either one alkyl group or two *cis*-alkyl groups, *e.g.*, V and *cis*-IV, were found to be essentially temperature independent

(15) W. D. Emmons, THIS JOURNAL, **79**, 5739 (1957), and private communication, reports two bands for the ring hydrogens in the high resolution n.m.r. spectrum of 2-*t*-butyloxazirane at room temperature and up to 60° (the highest temperature employed). The slow inversion of *t*-butyloxazirane compared to 1-*t*-butylaziridine may well be due to diminished substituent–ring hydrogen–hydrogen repulsions in the former compound.

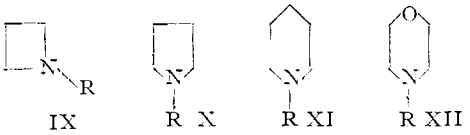
even up to 140°. One interpretation of this is that the molecules have preferred orientations with the N-substituent *trans* to the ring substituent(s).

Several nitrogen inversion frequencies for ethylenimine derivatives were found to be substantially decreased in hydroxylic solvents because of stabilization of the ground-state configurations through hydrogen bonding of the solvent with the imino nitrogen. For example, 1-ethylaziridine (Ib) in the pure liquid exhibits an inversion rate constant of 60 sec.$^{-1}$ at 108 ± 5°. The same inversion rate is not reached in deuterium oxide solution even up to 145°. If this stabilization affects only the energy of activation for inversion then it must amount to at least 2 kcal./mole and should increase the average lifetime of a particular configuration at room temperature by at least 25 times. 1-Ethyl-2-methyleneaziridine (II) has an inversion rate constant of about 67 sec.$^{-1}$ at −65 ± 10° in the pure liquid, but in 0.01 *N* methanolic sodium hydroxide solution, this rate is not reached until −25 ± 10°. On the assumption that only ΔE is affected the stabilization energy due to hydrogen bonding is calculated to be about 2 kcal./mole.

The n.m.r. spectra of pure 1-phenylaziridine (Ig) and pure 1-*t*-butylaziridine (If) at −77° possess only single sharp lines for the ring hydrogens indicating that inversion occurs too rapidly for measurement. In 0.01 *N* methanolic sodium hydroxide solution, the inversion rate of Ig was decreased sufficiently to cause two ring-hydrogen bands to appear in the spectrum and permit determination of the rate constant as about 40 sec^{-1} at −60 ± 10°. It should be noted that this behavior of the n.m.r. spectra of Ig provides evidence for a pyramidal configuration about nitrogen in aromatic amines[16] (at least in hydroxylic solvents). Dissolution of If in alkaline methanol did not change the character of its n.m.r. spectrum even at −77°.

Surprisingly, no evidence was obtained for significant stabilization of configuration in 3-(2,2-dimethyl-1-aziridinyl)-propanol (IIIa) from intramolecular hydrogen bonding in the pure liquid.

The n.m.r. spectra of a number of azetidine (IX), pyrrolidine (X), piperidine (XI) and morpholine



IX R X R XI R XII

(XII) derivatives were examined. The spectra of these compounds were temperature independent above −77° indicating that inversion was too rapid for measurement. The spectrum of a methanol solution of 1-ethylazetidine (IXa, R = C_2H_5), which was initially cooled to −196° and then allowed to warm, showed fine structure for spin–spin coupling of the ring-hydrogen bands after the fine structure of the ethyl resonances appeared. However, no reasonably accurate estimate of T_c could be made.

The n.m.r. Spectra of Cyclic Imines.—The resonance frequencies of the ring hydrogens of a number of cyclic imines were determined with respect to the benzene proton resonance. The results are summarized in Table II.

The aziridine-hydrogen bands in spectra of compounds undergoing slow nitrogen inversion, *i. e.*, $t/2 >> 2^{1/2}/\delta\omega$, were split into triplets with J, the separation due to spin-spin coupling, about 1.8 c.p.s. In the spectra of aziridine derivatives, undergoing rapid nitrogen inversion, *i. e.*, $t/2 << 2^{1/2}/\delta\omega$, the ring-hydrogen resonance was a sharp singlet. Therefore, *if* the triplet patterns of the ring-hydrogen resonances arise from coupling with ^{14}N, then rapid inversion must either cause the coupling constants to be substantially decreased or else cause the ^{14}N relaxation rate to be markedly increased. It seems more likely that the splitting arises from spin–spin interactions between the ring hydrogens.

The splitting due to spin–spin coupling was found to be pronounced in the azetidine derivatives. The α- and β-hydrogen resonances were triplets and quintets, respectively, with J = 7.4 c.p.s. Less well-defined structure was observed for the resonances of the ring-hydrogens of pyrrolidine (X) and morpholine (XII) derivatives and their hydrochlorides. The two ring-hydrogen bands of piperidine (XI) derivatives and their hydrochlorides were broad with no fine structure. 1-*t*-Butylpyrrolidine (Xc, R = *t*-C_4H_9) and 1-*t*-butylpiperidine (XId, R = *t*-C_4H_9) were prepared to allow examination of the α-hydrogen resonances, since the exocyclic α-hydrogen lines in the other N-alkyl derivatives overlapped with their α-ring-hydrogen lines.

The resonance positions of the various ring-hydrogen bands in cyclic imine hydrochlorides are shifted to lower fields compared to the corresponding bands in the respective free bases. As expected, the shift is more pronounced for the hydrogens closest to the nitrogen. The resonance positions for the hydrochlorides, with the exception of the water line, were found to be essentially independent of the acid concentration. The splitting of the exocyclic α-hydrogen resonances observed in the spectra of the hydrochlorides in excess acid and the broadening of the water resonance observed in the spectra of some hydrochlorides is accounted for by the slowness of proton exchange between amine hydrochlorides and water.[17a,b]

Acknowledgment.—We wish to thank Prof. H. J. Lucas and Dr. R. Ghirardelli for generous samples of IV (*cis* and *trans*) and V.

Experimental

Melting points are corrected unless stated otherwise. Boiling points are uncorrected. The n.m.r. spectra were obtained at 40 mc. with the Varian Associates high resolution spectrometer (V-4300B) with 12-in. magnet equipped with super-stabilizer using samples contained in 5-mm. o.d. tubes. Infrared spectra were obtained with a Perkin–Elmer model 21 Spectrophotometer. Microanalyses were performed by Dr. A. Elek.

2-*t*-Butylaminoethanol was prepared by a modification of Biel's synthesis of the isopropylamino analog.[18] To a cooled, stirred mixture of 219 g. (3.0 moles) of *t*-butylamine, 5.0 g. of concentrated hydrochloric acid and 10.4 g. of water in a one-l., three-necked flask equipped with a stirrer,

(16) *Cf.* B. M. Wepster, *Rec. trav. chim.*, **72**, 661 (1953).

(17) (a) J. D. Roberts, THIS JOURNAL, **78**, 4495 (1956); (b) E. Grunwald, A. Lowenstein and S. Meiboom, *J. Chem. Phys.*, **25**, 382 (1956).

(18) J. H. Biel, THIS JOURNAL, **71**, 1306 (1949).

TABLE II

RESONANCE FREQUENCIES OF RING-HYDROGENS IN N.M.R. SPECTRA OF CYCLIC IMINES

Compound	R	$\delta^{a,b}$		Compound	R	$\delta^{a,c}$ α-H's	β-H's
Ib	C_2H_5	5.60	6.28	Xa	H	4.1	5.3
Ib[d]	C_2H_5	5.25	5.92	Xa·HCl[g]	H	3.1	4.5
Ic	$C_6H_5CH_2$	5.58	6.25	Xb	CH_3	4.7	5.4
Id	$C_6H_5CH_2CH_2$	5.85	6.62	Xb·HCl[g]	CH_3	2.8	4.3
Ie	C_6H_{11}	5.32	5.90	Xc	t-C_4H_9	4.2	5.2
If	t-C_4H_9	5.55		Xc·HCl[g]	t-C_4H_9	3.1	4.5
If[e]	t-C_4H_9	5.42		Xd	CHO	3.5	5.1
Ig	C_6H_5	5.38		XIa	H	4.2	5.4[i]
Ig[e]	C_6H_5	5.22		XIa·HCl[g]	H	3.2	4.8[i]
Ig[f]	C_6H_5	5.60		XIb	CH_3	4.8	5.6[i]
Ih	H	5.45		XIb·HCl[g]	CH_3	3.0	4.7[i]
Ih[g]	H	5.12		XIc	C_2H_5	4.7	5.5[i]
II	C_2H_5	5.25		XIc·HCl[g]	C_2H_5	3.2	4.8[i]
II	C_2H_5	5.15		XId	t-C_4H_9	4.3	5.4[i]
IV, *cis*	C_2H_5	5.9[e]		XId·HCl[k]	t-C_4H_9	3.1	4.9[i]
VIII[h]	..	3.40		XIe	CHO	3.4	5.3[i]
VIII[e]	..	4.18		XIIa	H	4.2	3.3
IXa	C_2H_5	3.92[i]	5.0[e]	XIIa·HCl[g]	H	3.2	2.5
IXa[e]	C_2H_5	3.88[i]	5.0[e]	XIIb	CH_3	4.6	3.2
IXb	n-C_4H_9	3.82[i]	5.0[e]	XIIb·HCl[g]	CH_3	3.0	2.4
IXc	t-C_4H_9	3.80	5.08				

[a] In parts per million with respect to the benzene resonance at 25–35°. Positive values represent resonances at higher fields than the C_6H_6 resonance. [b] Unless otherwise indicated, ±0.06. [c] ±0.1. [d] In deuterium oxide. [e] In 0.01 *N* methanolic sodium hydroxide. [f] In toluene. [g] In water. [h] In chloroform. [i] α-Hydrogen resonance. [j] Resonances for β- and γ-hydrogens. [k] In hydrochloric acid solution.

dropping funnel and reflux condenser was added 44 g. (1.0 mole) of ethylene oxide in 5-ml. portions over one hour. The mixture was allowed to warm to room temperature and a mild exothermic reaction took place which maintained the mixture at a gentle reflux for 30 min. The stirred mixture was then heated gently under reflux for 10 hours. Most of the *t*-butylamine was removed by distillation through a 500-ml. Claisen flask modified so that the distilling arm carried a 25 × 250-mm. section packed with glass helices. The remainder of the *t*-butylamine and the water were removed by distillation at reduced pressure through an 8 × 600-mm. Podbielniak-type column[19] packed with a tantalum wire coil. 2-*t*-Butylaminoethanol (80.5 g., 69%) was collected at 74–76° (8 mm.); lit.[20] b.p. 80–83° (12 mm.). The colorless product solidified when cooled in an ice-bath, m.p. 44–46° (uncor.); lit.[20] m.p. 43–45°.

2-Cyclohexylaminoethanol.—The modification of Biel's procedure[18] was used. From 200 g. (2.02 moles) of cyclohexylamine and 30 g. (0.68 mole) of ethylene oxide was obtained 95.6 g. (79%) of 2-cyclohexylaminoethanol, b.p. 87–89° (1 mm.), m.p. 37–39° (uncor.); lit.[21] b.p. 122–123.5° (13 mm.), m.p. 40–41°.

2-Benzylaminoethanol.—The following is a modification of the procedure of Wedekind and Bruck.[22] A mixture of 214 g. (2.0 moles) of benzylamine, 80 g. (1.0 mole) of ethylene chlorohydrin and 30 g. of water was heated on a steam-bath for five hours. Sixty grams (1.5 moles) of sodium hydroxide was added to the cooled solution and the resulting mixture was heated on a steam-bath for 30 min. Water (400 ml.) was added to dissolve the inorganic salts and the two-phase mixture was extracted twice with 200- and 100-ml. portions of benzene. The extracts were combined and the water was removed by co-distillation with benzene through the modified Claisen flask. Most of the benzene then was removed by distillation through the modified Claisen flask at atmospheric pressure. Distillation of the residue through the Podbielniak column yielded 100.2 g. of benzylamine, b.p. 89° (40 mm.), and 86.1 g. (57%) of 2-benzylaminoethanol, b.p. 112–114° (1 mm.), $n^{25.2}$D 1.5418; lit.[23] b.p. 148–149° (13 mm.). 2-Benzylaminoethanol, b.p. 113–114° (1 mm.), also was obtained in 15% yield from 61 g. (1.0 mole) of ethanolamine and 122 g. (1.15 moles) of benzaldehyde by the general procedure of Cope and Hancock[21] for the preparation of 2-alkylaminoethanols.

3-*n*-Butylaminopropanol.—The following procedure was found to be the most satisfactory. Trimethylene chlorohydrin (142 g., 1.5 moles) was added to a solution of 385 g. (5.0 moles) of *n*-butylamine and 165 ml. (9.1 moles) of water. The reaction mixture was allowed to stand at room temperature for 18 hours and was then heated at reflux on a steam-bath for 4 hours. The mixture was cooled in an ice-bath and 80 g. of solid sodium hydroxide was added cautiously. About 200 ml. of water was added to dissolve the inorganic salts and the mixture was extracted three times with 300-ml. portions of ether, the extracts combined, dried over sodium carbonate and the ether and most of the *n*-butylamine were removed by flask distillation through a Claisen head. The residue was distilled through the Podbielniak column and 3-*n*-butylaminopropanol (121 g., 61%) was collected at 83–86° (1.5 mm.), n^{22}D 1.4488; lit.[24] b.p. 106–108° (16 mm.), n^{25}D 1.4474. The product had the same b.p., n^{22}D, infrared and n.m.r. spectra as a sample prepared from trimethylene bromohydrin and *n*-butylamine.[25]

3-*t*-Butylaminopropanol. A. From Trimethylene Chlorohydrin and *t*-Butylamine.—The procedure described for the preparation of 3-*n*-butylaminopropanol was used. After most of the ether had been removed, the residue was allowed to cool to room temperature. Long, white needles of 3-*t*-butylaminopropanol (53.2 g.) separated and were collected by suction filtration, m.p. 73.5–75.3°; lit.[26] m.p. 67–69°. A second crop of 20.2 g., m.p. 66–71°, was taken from the filtrate and the mother liquor was distilled. The aminoalcohol (19.2 g.), which solidified in the receiver, was collected at 85–87° (3 mm.), m.p. 64–70°. The over-all yield was 48%.

B. From Ethyl 3-*t*-Butylaminopropionate.—Ethyl acrylate (180 g., 1.8 moles) was added with cooling to a cold

(19) J. Cason and H. Rapoport, "Laboratory Text in Organic Chemistry," Prentice-Hall, Inc., New York, N. Y., 1950, pp. 237–243.

(20) N. Bortnick, *et al.*, THIS JOURNAL, **78**, 4039 (1956).

(21) A. C. Cope and E. M. Hancock, *ibid.*, **64**, 1503 (1942); from reduction of ethanolamine and cyclohexanone.

(22) E. Wedekind and E. Bruck, *Ann.*, **471**, 73 (1929).

(23) H. Schotte, German Patent 442,413 (1927); *Chem. Zentr.*, **98**, II, 636 (1927); from β-chloroethyl N-benzylcarbamate and alkali.

(24) S. Searles and V. P. Gregory, THIS JOURNAL, **76**, 2789 (1954); from trimethylene oxide and *n*-butylamine.

(25) S. D. Goldberg and W. F. Whitmore, *ibid.*, **59**, 2280 (1939).

(26) F. Wille and L. Saffer, *Ann.*, **568**, 34 (1950); from trimethylene bromohydrin and *t*-butylamine.

TABLE III

YIELDS, PHYSICAL PROPERTIES AND ELEMENTAL ANALYSES OF IMINES $[(CH_2)_{2-3}NR]$ FROM AMINOALCOHOLS

R	Yield, %	B.p. °C.	B.p. Mm.	n^tD	t, °C.	Elemental analyses, % Calcd. C	Calcd. H	Calcd. N	Found C	Found H	Found N
Ic, $C_6H_5CH_2$	65	86–88[a]	12	1.5298[a]	22.0	...	...	...	...	...	...
Ie, C_6H_{11}	32	89–90	66	1.4592	26.0	76.74	12.08	11.18	76.91	12.18	10.94
If, t-C_4H_9	27	91–92	745	1.4110	22.0	72.67	13.21	14.12	72.84	13.22	14.26
IXa, C_2H_5	13	74–75	743	1.4090	25.5	70.53	13.03	16.44	70.65	13.14	16.56
IXb, n-C_4H_9	24	128–129[b,c]	748	1.4241	25.6	...	...	...	...	...	...
IXc, t-C_4H_9	47	116.5–117.3[d]	747	1.4241	25.6	74.27	13.36	12.37	74.56	13.30	12.46

[a] W. S. Gump and E. J. Nikawitz, THIS JOURNAL, **72**, 1309 (1950), reported b.p. 84–87° (8 mm.), n^{20}D 1.5300. [b] Lit.[30] b.p. 127–128°. [c] The methiodide derivative had dec. pt. 150°. *Anal.* Calcd. for $C_8H_{18}NI$: C, 37.66; H, 7.11. Found: C, 38.19; H, 7.12. [d] The methiodide derivative had dec. pt. 227°. *Anal.* Calcd. for $C_8H_{18}NI$: C, 37.66; H, 7.11. Found: C 37.84; H, 7.05.

and stirred 6 *M* solution of *t*-butylamine in absolute ethanol.[27] The mixture, which developed a red color, was allowed to stand at room temperature for two days and then distilled. Ethyl 3-*t*-butylaminopropionate (324 g., 84%) was collected at 91–93° (6 mm.), n^{23}D 1.4244.

Anal. Calcd. for $C_9H_{19}O_2N$: C, 62.39; H, 11.05; N, 8.09. Found: C, 62.31; H, 11.02; N, 8.40.

Reduction of 240 g. (1.4 moles) of the aminoester with 42 g. (1.1 moles) of lithium aluminum hydride yielded 44.3 g. (24%) of crude 3-*t*-butylaminopropanol, m.p. 69–73°.

3-Ethylaminopropanol.—Following the method described for the preparation of 3-*n*-butylaminopropanol, 3-ethylaminopropanol was prepared in 29% yield from 2.0 moles of trimethylene chlorohydrin and 600 ml. of 70% aqueous ethylamine solution. The product had b.p. 90–91° (12 mm.), n^{25}D 1.4463; lit.[28] b.p. 181°, n 1.4550 (no temperature or wave length given). The infrared and n.m.r. spectra of the product were in agreement with the 3-ethylaminopropanol structure. Elemental analysis indicated that the product contained 5% trimethylene chlorohydrin.

Reduction of 52 g. (0.36 mole) of ethyl 3-ethylaminopropionate,[28] b.p. 74–76° (30 mm.), $n^{31.4}$D 1.4231, with 11.0 g. (0.29 mole) of lithium aluminum hydride yielded only 6.0 g. of 3-ethylaminopropanol, b.p. 96–99° (34 mm.), which was contaminated with a small amount of unreacted ester as shown by its infrared spectrum.

Cyclic Imines from Aminoalcohols.—The aminoalcohols were converted through their sulfonate esters to the imines by the method described by Elderfield and Hageman[29] for 1-*n*-butylaziridine (I, R = *n*-C_4H_9). The sulfonate ester of 2-benzylaminoethanol was prepared with sulfuric acid[30] and the others were prepared with chlorosulfonic acid.[29] The yields, physical properties and elemental analyses of new compounds are given in Table III.

Other Aziridine Derivatives.—Following the modification of Morsch's procedure, **ethyl 3-(2,2-dimethyl-1-aziridinyl)-propionate** (IIIb) was obtained in 71% yield from 40 g. (0.56 mole) of 2,2-dimethylaziridine and 54 g. (0.54 mole) of ethyl acrylate. The colorless oil had b.p. 95–97° (11 mm.), n^{25}D 1.4312.

Anal. Calcd. for $C_9H_{17}O_2N$: C, 63.13; H, 10.01; N, 8.18. Found: C, 63.10; H, 9.93; N, 8.14.

Compound IIIb (20.5 g., 0.12 mole) was reduced to 3-(2,2-dimethyl-1-aziridinyl)-propanol (IIIa) with 2.9 g. (0.077 mole) of lithium aluminum hydride (in an ether solution) by the method described[7b] for the methyl ester. The product (10.6 g., 68%) had b.p. 101–102° (20 mm.), n^{22}D 1.4547; lit.[7b] b.p. 110° (24 mm.), n^{25}D 1.4535.

Following Heine, Kapur and Mitch's procedure,[31] 40 g. (0.11 mole) of 2-anilinoethyl bromide hydrobromide was converted in 60% yield to 1-phenylaziridine (Ig), b.p. 73–74° (18 mm.), n^{23}D 1.5518; lit.[31] b.p. 70° (13 mm.), n^{25}D 1.5498.

Following Bestian's procedure,[32] 17.2 g. (0.40 mole) of aziridine and 20.8 g. (0.20 mole) of styrene were converted in 94% yield to 1-(β-phenethyl)-aziridine (Id), b.p. 78–79° (3 mm.), $n^{21.8}$D 1.5220; lit.[32] b.p. 89° (8 mm.).

Cyanuric chloride (18.4 g., 0.10 mole) and 14.0 g. (0.32 mole) of aziridine were converted to 15.9 g. (78%) of triethylenemelamine (VIII) by the method of Wystrach, Kaiser and Schaefer,[33] dec. pt. 138°; lit.[33] dec. pt. 139°.

1-Ethylaziridine (Ib; Matheson, Coleman and Bell Co.) was distilled through the Podbielniak column at 51.7–52.3° (746 mm.), n^{25}D 1.3920; lit.[34] b.p. 48.5–49.0° (690 mm.). The preparations of the samples of 1-ethyl-2-methyleneaziridine (II),[35] *cis*- and *trans*-1-ethyl-2,3-dimethylaziridine, (IV)[36] and 1,2-diethylaziridine (V)[36] used in this work have been described.

Other Cyclic Imines.—**1-Formylpiperidine** (XIe) was prepared in 94% yield by heating a mixture of 30 g. (0.35 mole) of piperidine and 165 g. (2.75 moles) of ethyl formate at reflux on a steam-bath for three hours. The product had b.p. 73–75° (2 mm.), n^{25}D 1.4803; lit.[37] b.p. 104–105° (16 mm.).

1-*t*-Butylpyrrolidine (Xc) was prepared in 40% yield from 76.2 g. (0.60 mole) of 1,4-dichlorobutane, 66 g. (0.90 mole) of *t*-butylamine and 63.6 g. (0.60 mole) of sodium carbonate by the procedure described by Elderfield and Hageman[29] for the preparation of 1-*n*-butylpyrrolidine. The product had b.p. 146–147° (747 mm.), $n^{20.6}$D 1.4429.

Anal. Calcd. for $C_8H_{17}N$: C, 75.52; H, 13.47; N, 11.01. Found: C, 75.50; H, 13.51; N, 11.05.

The **methiodide** had dec. pt. 249°.

Anal. Calcd. for $C_9H_{20}NI$: C, 40.16; H, 7.49; Found: C, 40.76; H, 7.62.

In essentially the same manner, **1-*t*-butylpiperidine** (XId) was obtained in 25% yield from 84.6 g. (0.60 mole) of 1,5-dichloropentane; XId had b.p. 165–166°, $n^{20.6}$D 1.4525.

Anal. Calcd. for $C_9H_{19}N$: C, 76.53; H, 13.56; N, 9.92. Found: C, 76.40; H, 13.49; N, 9.85.

The **methiodide** had dec. pt. 225°.

Anal. Calcd. for $C_{10}H_{22}NI$: C, 42.42; H, 7.83. Found: C, 42.51; H, 7.86.

The other cyclic imines were either redistilled commercial products or were prepared by well-described literature procedures.

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(27) The procedure is a modification of that used by K. Morsch, *Monatsh.*, **63**, 220 (1933), for the preparation of methyl 3-methylaminopropionate.

(28) Prepared in the same manner as the *t*-butylaminoester in 87% yield from 180 g. (1.8 moles) of ethyl acrylate. *Anal.* Calcd. for $C_7H_{15}O_2N$: C, 57.90; H, 10.41; N, 9.65. Found: C, 58.13; H, 10.30; N, 9.99.

(29) R. C. Elderfield and H. A. Hageman, *J. Org. Chem.*, **14**, 605 (1949).

(30) P. A. Leighton, W. A. Perkins and M. L. Renquist, THIS JOURNAL, **69**, 1540 (1947).

(31) H. W. Heine, B. L. Kapur and C. S. Mitch, *ibid.*, **76**, 1173 (1954).

(32) H. Bestian, *Ann.*, **566**, 210 (1950).

(33) V. P. Wystrach, D. W. Kaiser and F. C. Schaefer, THIS JOURNAL, **77**, 5915 (1955).

(34) P. A. Laselle and S. A. Sundit, *ibid.*, **63**, 2374 (1941).

(35) A. T. Bottini and J. D. Roberts, *ibid.*, **79**, 1462 (1957).

(36) R. Ghirardelli and H. J. Lucas, *ibid.*, **79**, 734 (1957).

(37) F. F. Blicke and C.-J. Wu, *ibid.*, **74**, 3933 (1952).