Preparation and Decomposition of 1-Azidonorbornane

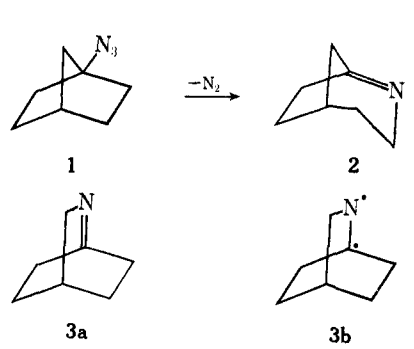
JERRY O. REED[1] AND WALTER LWOWSKI*[2]

Department of Chemistry, New Mexico State University, Las Cruces, New Mexico 88001

Received January 29, 1971

Azido group transfer from tosyl azide to the 1-norbornyl anion is a better way of preparing 1-azidonorbornane than is diazo group transfer from tosyl azide to the N anion of 1-aminonorbornane. Decomposition of 1-azidonorbornane (1) in methanol or 2-propanol leads to addition of the alcohol, probably concerted with the loss of nitrogen. Migration of the bridges, in almost statistical ratio, gives 2:1 mixtures of 1-alkoxy-2-azabicyclo[3.2.1]octanes and 1-alkoxy-2-azabicyclo[2.2.2]octanes. Decomposition in "inert" solvents led to nonvolatile products which did not contain the solvent molecule. The bicyclic α-amino ethers produced are very stable toward acid hydrolysis. Only the [3.2.1] compounds could be reduced by lithium aluminum hydride to the amines. Both the difficult acid hydrolysis and lack of reaction of the [2.2.2] compounds with lithium aluminum hydride can be explained stereochemically, since the normal course of both reactions involves C=N double bond formation, which violates Bredt's rule in our systems.

Alkyl azides decompose with loss of nitrogen predominantly by intramolecular paths to give imines: $RR'R''CN_3 \rightarrow N_2 + RR'C{=}NR''$. The migration of R'' can be concerted or be preceded by the formation of a nitrene, RR'R''CN, and the migratory aptitudes of various groups have been studied under various conditions.[3,4] Insertion of alkylnitrenes has been observed as a minor side reaction[5,6] but it is efficient with perhaloalkyl azides.[7] In general, the study of alkylnitrenes in intermolecular reactions is next to impossible because of the rapid intramolecular imine formation. Such rearrangement of a bridgehead azide (or nitrene) would expand one of the bridges by one nitrogen and put a C=N double bond on the bridgehead. In a small bicyclic system, this violation of Bredt's rule, however, should be felt already in the transition state, and should slow the rearrangement. We hoped that in 1-azidobicyclo[2.2.1]heptane the rearrangement would be retarded enough to make nitrene formation and intermolecular nitrene reactions observable. Comparison of such alkylnitrene reactions with those of carbonyl and other nitrenes would give information about the effects of substituents (such as carbonyl, sulfonyl, etc.) on the chemical properties of nitrenes. Rearranging 1-azidonorbornane would, at least on paper, give **2** and **3**, both containing a C=N double bond on the bridgehead. The azomethines **2** and **3** are highly strained by all the measures devised to make Bredt's rule[8] more quantitative,[9,10] as well as by the inspection of models. In particular, the bicyclo[2.2.2] system **3** would have little, if any, π bonding; the planes of the p orbitals on C-1 and N are orthogonal as long as the molecule is not made asymmetrical by distortion. Thus, representation **3b** would be better than **3a**. (Note, however, that the 2-quinuclidinium cation seems to be stabilized by the bridgehead nitrogen in its position 1.[11] The azomethines **2** and **3** have the same "strain number" by Fawcett's rules,[9] but **2** seems to be much less strained than **3** by Wiseman's rules.[10] In view of the observations of Ferris and Miller,[12] structure **2** seems to be acceptable for a short-lived intermediate. This contention is strengthened by the recent isolation of several bicyclononenes containing bridgehead double bonds.[13-16] Still, **2** would be severely strained.



1 **2** **3a** **3b**

Results

Preparation of 1-Azidonorbornane.—Two routes led to the desired bridgehead azide **1**: diazo group transfer from tosyl azide to the anion of 1-aminonorbornane,[17] and azide group transfer from tosyl azide to 1-norbornyl anion. The latter reaction is akin to Ito's[19] preparation of phenyl azide. Smith has independently developed a similar method for azide group transfer to carbanions, which differs from ours in that the triazene intermediate is decomposed by polyphosphoric acid, rather than by pyrolysis of the triazene salt.[20] The azide transfer method is superior here, because it requires fewer steps from norcamphor to the desired azide, affording a 12% overall yield (Scheme I). The yield, based on norcamphor, was only 4.5% when diazo group transfer to

(1) This paper is based on a part of the Ph.D. thesis by J. O. Reed, Yale University, 1968.

(2) To whom correspondence should be addressed at the Chemistry Department, New Mexico State University.

(3) F. D. Lewis and W. H. Saunders, Jr., in "Nitrenes," W. Lwowski, Ed., Interscience New York, N. Y., 1970, pp 47 ff.

(4) R. M. Moriarty and R. C. Reardon, *Tetrahedron*, **26**, 1379 (1970).

(5) F. O. Rice and C. J. Grelecki, *J. Phys. Chem.*, **61**, 830 (1957).

(6) R. A. Abramovitch and E. P. Kyba, *Chem. Commun.*, 265 (1969).

(7) R. E. Banks, D. Berry, M. J. McGlinchey, and G. J. Moore, *J. Chem. Soc. C*, 1017 (1970).

(8) E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-Hill, New York, N. Y., 1962, p 298 ff.

(9) F. S. Fawcett, *Chem. Rev.*, **47**, 219 (1950).

(10) J. R. Wiseman and W. A. Pletcher, *J. Amer. Chem. Soc.*, **92**, 956 (1970).

(11) C. A. Grob and A. Sieber, *Helv. Chim. Acta*, **50**, 2531 (1967).

(12) J. P. Ferris and N. C. Miller, *J. Amer. Chem. Soc.*, **88**, 3522 (1966).

(13) J. R. Wiseman, *ibid.*, **89**, 5967 (1967); J. A. Marshall and H. Faubl, *ibid.*, **92**, 948 (1970).

(14) W. Carruthers and M. I. Qureshi, *Chem. Commun.*, 832 (1969).

(15) J. R. Wiseman, H.-F. Chan, and C. J. Ahola, *J. Amer. Chem. Soc.*, **91**, 2812 (1969).

(16) J. R. Wiseman and J. A. Chong, *ibid.*, **91**, 7775 (1969).

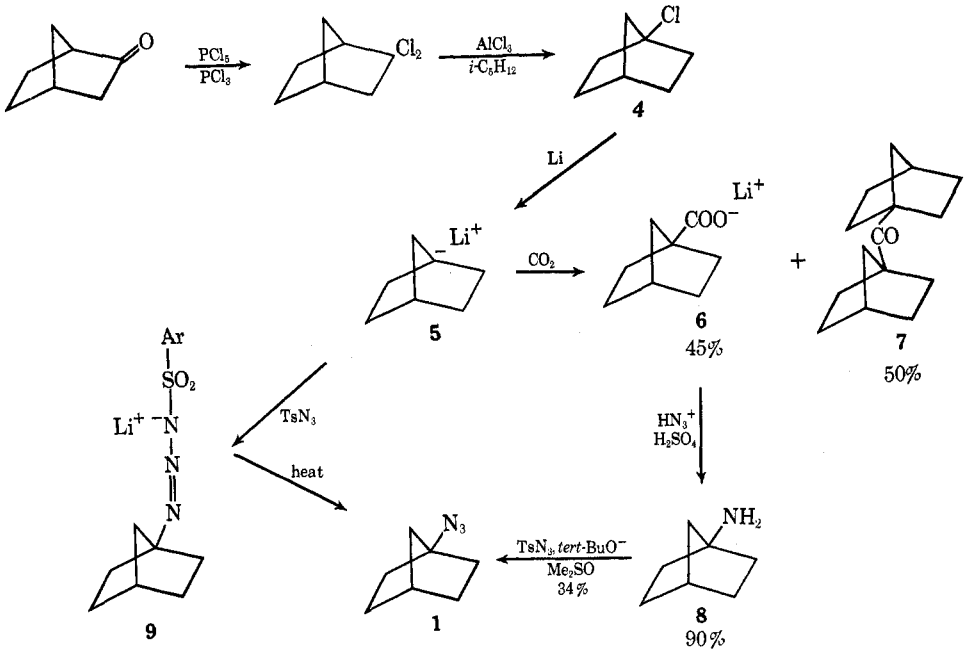
(17) Dr. G. Smolinsky kindly pointed out to us the feasibility of this reaction in Oct 1964. It was discovered independently by Fischer and Anselme.[18]

(18) W. Fischer and J.-P. Anselme, *J. Amer. Chem. Soc.*, **89**, 5284 (1967).

(19) S. Ito, *Bull. Chem. Soc. Jap.*, **39**, 635 (1966).

(20) P. A. S. Smith, C. D. Rowe, and L. B. Brunner, *J. Org. Chem.*, **34**, 3430 (1969).

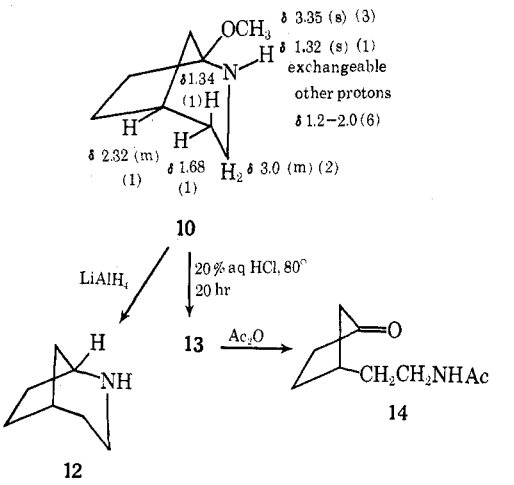
SCHEME I



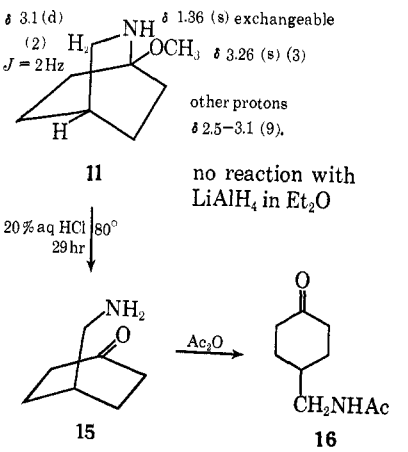
the known[21,22] 1-aminonorbornane was used, largely due to poor yields obtained in making the amine **8**. The by-product in the carbonation, 1-norbornyl ketone **7**, has, to our knowledge, not been reported previously. 1-Azidonorbornane (**1**) is a colorless liquid, bp 25° (0.1 mm), ϵ 26.2 at 290 nm, normal for an alkyl azide.[23]

Decomposition of 1-Azidonorbornane.—Photolysis of **1** with uv light (90% of the intensity between 310 and 410 nm) in methanol or 2-propanol solutions gave two products each. In methanol, **10** and **11** were produced in 54 and 24% yields, respectively, while analogous products were formed in 2-propanol in 52 (**17**) and 23% (**18**) yields, respectively. No other volatile products were found. The remaining 22% yield constituted an acid-soluble, dark glass which showed several OR signals in the nmr spectrum. While a 2% yield could have easily been found, no 1-aminonorbornane could be detected. Runs carried to only a few percent completion gave **10** and **11** in the same ratio as runs carried to completion, and no other volatiles. Analyses and mass spectra showed **10** and **11** to be isomers, $C_8H_{15}NO$. They contain NH groups, form stable hydrochlorides, and contain OCH_3 groups (nmr) which are not exchanged for other OR groups, in contrast to the behavior of open-chain α-amino ethers. The structures of **10** and **11** were assigned on the basis of spectroscopic and chemical evidence, as shown in Schemes II and III. Reduction of **10** with $LiAlH_4$ gave 2-azabicyclo[3.2.1]octane (**12**), which was synthesized independently.[24] Its structure was confirmed by its nmr spectrum, which excludes the 3-aza isomer.[25] The nmr spectrum of **12** is known.[26] Compound **10** is completely stable toward cold, dilute acid. Treatment with 10% hydrochloric acid at 80° for 15 hr resulted in about 75% hydrolysis. More vigorous acid hydrolysis converted all of the **10** into the amino ketone **13**, which was isolated as its acetyl derivative **14**, a sample of which was prepared by an independent route.

SCHEME II
STRUCTURE OF THE MAJOR METHANOL ADDUCT (10)



SCHEME III
STRUCTURE OF THE MINOR METHANOL ADDUCT (11)



(21) W. P. Whelan, Jr., Thesis, Columbia University, 1953.
(22) K. B. Wiberg, B. R. Lowry, and T. H. Colby, *J. Amer. Chem. Soc.*, **83**, 3998 (1961).
(23) W. D. Closson and H. B. Gray, *ibid.*, **85**, 290 (1963).
(24) R. C. Elderfield and E. T. Losin, *J. Org. Chem.*, **26**, 1703 (1961).
(25) *Cf.* B. L. Fox and J. E. Reboulet, *ibid.*, **33**, 3639 (1968), ref 5.
(26) A. G. Anastassiou, *ibid.*, **31**, 1131 (1966).

The structure proof for the minor product, **11**, formed in a yield of half of that of **10**, is shown in Scheme III. The nmr spectrum of the hydrochloride of **11** is very similar to that of 2-azabicyclo[2.2.2]octane hydrochloride (aside from the OCH_3 signal), the spectrum of which was kindly provided by Professor P. Gassman. Lithium aluminum hydride did not react with **11** in refluxing ether. Acid hydrolysis required 29 hr at 80° and 20% aqueous hydrochloric acid. The acetylated hydrolysis product (**16**) was synthesized independently (see Experimental Section). The mass spectra of **10** and **11** are reported in the Experimental Section.

Changes in the reaction conditions in the photolysis of **1** had almost no effect. When light of 254-nm wavelength is employed, **10** and **11** are produced in the same yields and ratio obtained with 310–410-nm light. However, 254-nm light slowly destroys **11**, and, even more slowly, **10**. The presence of acid (0.05 *M* H_2SO_4) or base (0.54 *M* $Na^+{}^-OMe$), or saturation of the methanol solution with oxygen before irradiation with light of either wavelength, did not affect product yields or the rate of nitrogen evolution. The experiments with acid and base were run because of the possibility of the intervention of a nitrenium ion. To further test for this, in view of Gassman's work,[27] *N*-chloro-1-aminonorbornane was treated with silver nitrate in methanol. In contrast to our photolyses, at least nine products were formed, none of them identical with **10** or **11**. The reaction was, therefore, not pursued further.

A methanol solution of **1** begins to decompose, in the dark, at 140°, and 14 hr at 170° are required to decompose 90% of the azide and give **10** (27% yield) and **11** (3% yield). These figures do not reflect the true product ratio, since the mixture of **10** and **11** (from the photolysis) decomposes in methanol at 170°. After 14 hr, 17% of the **10** and only a trace of the **11** were recovered; the bicyclo[2.2.2] system decomposes faster.

Irradiation of **1** in 2-propanol gave 1-isopropoxy-2-azabicyclo[3.2.1]octane (**17**) and 1-isopropoxy-2-azabicyclo[2.2.2]octane (**18**) in 52 and 23% yields, respectively. Neither 1-aminonorbornane nor acetone were formed, ruling out a radical decomposition of **1**. Lithium aluminum hydride reduction of **17** gave **12** in 91% yield, while **18** was recovered in 95% yield. Nmr and mass spectra and elemental analyses establish **17** and **18** as analogs of **10** and **11**, respectively. The only difference is the replacement of the methoxy groups in **10** and **11** by isopropoxy groups.

Irradiation of **1** in "inert" solvents produces nitrogen and a polymer which, by nmr, does not contain any significant amount of groups derived from the solvent. The solvents used were benzene, cyclohexene, cyclohexane, isopentane, *n*-butylamine, and *tert*-butyl alcohol. The polymeric (nonvolatile) compounds obtained in these solvents were all very similar to each other, had an approximate composition $(C_7H_{11}N)_x$, and were insoluble in nonpolar solvents, but soluble in acid. The nmr spectra in DCl–D_2O showed many overlapping signals between δ 1–3.2, and the ir spectra showed broad NH absorptions. Mass spectra of these compounds (or mixtures) did not show identifiable parent peaks.

(27) P. G. Gassman and B. L. Fox, *J. Amer. Chem. Soc.*, **89**, 338 (1967); P. G. Gassman and R. L. Cryberg, *ibid.*, **90**, 1355 (1968); P. G. Gassman, *Accounts Chem. Res.*, **3**, 26 (1970).

Discussion

Decomposition of 1-azidonorbornane (**1**) gave oligomeric or polymeric products, not involving solvent, unless the solvent was an alcohol capable of closely solvating the azide group. With *tert*-butyl alcohol, the bulk of the $C(CH_3)_3$ group prevents this, and the results typical for an "inert" solvent are observed. 2-Propanol, which can closely solvate **1** by turning its two CH_3 groups away from the azide function, gives an 85% yield of defined products (**17** and **18**). Both in methanol and in 2-propanol, the ratio of products is close to that expected statistically—the 1 and the 2 bridges expand with equal aptitude. This argues against involvement of the [2.2.2] and [3.2.1] azomethines **3** and *2*—the transition state leading to **3** should be considerably higher in energy than that leading to *2*. This estimate is supported by the results of the $LiAlH_4$ reductions (see below). Involvement of *2* and **3** is also unlikely because of the apparent requirement of close solvation of the azide. Such solvation should not be required for a nitrene intermediate either, and a nitrene should give some amine **8** by hydrogen abstraction,[28] none of which could be found. A nitrenium ion should also give the hydrogen abstraction product **8**.[29] Furthermore, one would expect nitrenium ion formation to be facilitated by acid and decreased by base, but acid and base did not affect the results. We prefer a mechanism in which methanol or 2-propanol solvate the azide group in such a manner that the migration of a bridge and the addition of the alcohol are concerted and the formation of any high-energy intermediate is avoided. This can readily be done, with a sterically unhindered alcohol, so that the hydrogen is close to N_α of the azide group and the oxygen close to the bridgehead of **1**. Either the 1 bridge or one 2 bridge can migrate equally well in such an arrangement, leading to the observed product ratios. Bulky or chemically inert solvents force the system into a path of higher energy, which leads to an intramolecular reaction and gives a species that readily oligomerizes or polymerizes. This species could be a diradical, formed by abstraction of the exo hydrogen on C-2, which is only 1.5 bond lengths away from N_α. Whether this hypothetical abstraction is a reaction of the excited azide or a nitrene is not known.

The chemistry of our bicyclic α-amino ethers differs drastically from that of their open-chain counterparts, just as one would predict for steric reasons. The acid hydrolysis of open-chain α-amino ethers[30] goes through an iminium ion $R_2N^+{=}CH_2$,[31] corresponding in geometry to *2* and **3** in our bicyclic systems. This explains the slow hydrolysis of **10** and the even slower hydrolysis of **11** (which must proceed *via* a different path). Such an alternative hydrolysis mechanism could involve protonation of the nitrogen in **10** or **11**, followed by nucleophilic attack of water on the carbon bound to oxygen in the alkoxy group and front-side displacement of the nitrogen from the bridgehead. The

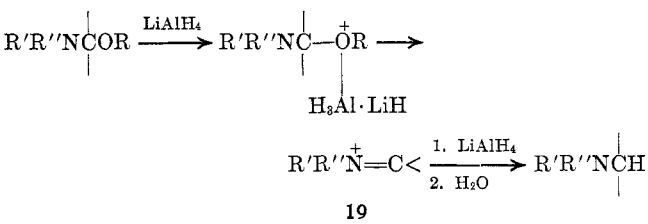
(28) *Cf.* R. M. Moriarty and M. Rahman, *Tetrahedron*, **21**, 2877 (1965); W. Pritzkow and D. Timm, *J. Prakt. Chem.*, **32**, 178 (1966); also ref 3.

(29) P. G. Gassman and R. L. Cryberg, *J. Amer. Chem. Soc.*, **91**, 5176 (1969); also ref 27.

(30) C. M. McLeod and G. M. Robinson, *J. Chem. Soc.*, **119**, 1470 (1921).

(31) T. D. Stewart and W. E. Bradley, *J. Amer. Chem. Soc.*, **54**, 4172 (1932); H. Meerwein in "Methoden der Organischen Chemie," Vol. VI/3, E. Müller, Ed., G. Thieme, Stuttgart, 1965, p 195.

front-side displacement could be avoided by ring opening of N-protonated **10** or **11**, to give an oxonium ion C=O⁺R, where C is the former bridgehead carbon, and where the oxonium ion is formed stepwise—ring opening gives a secondary carbonium ion, then an electron pair from oxygen moves in, and nucleophilic attack on R gives the ketone. A general mechanism for the reduction of α-amino ethers to amines[32,33] must accommodate the ready reduction of α-amino ethers containing a tertiary nitrogen, rather than a NH group. This makes it unattractive to coordinate the nitrogen with $LiAlH_4$. We therefore propose to coordinate the ether oxygen, and to expel it using the unshared electron pair on nitrogen. Where NH groups are present, their deprotonation would give the N anion, which would expel complexed OR (R′ = H). In our bicyclic



19

systems (**10** and **11**), the intermediate **19** would correspond to the azomethines **2** and **3**. Because of the very high energy of **3** (no π-bond stabilization), **11** should be particularly inert to $LiAlH_4$. By analogy with hydrocarbons actually obtained,[12-16] **2** should be an accessible intermediate, if one of high energy. In accord with this, **11** does not react, but **10** is reduced by $LiAlH_4$. The lack of reaction of **11** with $LiAlH_4$ seems to indicate that there is now a path of low energy which avoids the formation of a C=N double bond,[34] and indicates that **3** is indeed of high energy. The reduction of **10** indicates that, in accord with expectation (see above), the azomethine **2** is an accessible intermediate.

Experimental Section

1-Azidonorbornane (1). **A.**—Lithium sand (7.2 g, 0.53 g-atom, 50% in mineral oil) and 20.0 g (0.153 mol) of 1-chloronorbornane[21,22] in 60 ml of cyclohexane were stirred under nitrogen at 90° for 2 hr. The mixture was cooled, diluted with 60 ml of pentane, and cooled to −20°, and 30 g (0.152 mol) of *p*-toluenesulfonyl azide in 30 ml of ether was added dropwise over 0.5 hr. After stirring at −15° for 0.5 hr, the solid triazene salt **9** was filtered and washed with ether to leave a light yellow powder. This was divided into three portions, each of which was placed in a 1-l. flask attached to a vacuum system with a −70° receiver. After degassing at 25°, **9** was heated to 75° (0.1 mm) for 5 hr, and then the temperature was slowly increased to 110° to vaporize all the azide 1. Vpc analysis of the distillate showed the presence of 1, of 1-chloronorbornane, and of 1-norbornyl alcohol (column I: 6 ft × 0.25 in. 10% neopentylglycol sebacate on Anakrom ABS). Column chromatography on neutral alumina, elution with pentane, and distillation of the eluate gave 1, bp 25° (0.1 mm), still containing a trace (less than 2%) of 1-chloronorbornane, which did not interfere with the subsequent decompositions. The yield (based on 1-chloronorbornane) was 27%. *Caution:* Thermolysis of the triazene salt **9** led, in one instance, to a mild explosion. Another time, filtering the crude **9** through a Büchner funnel with rubber dam led to spontaneous ignition and burning of the whole batch of **9**.

B. 1-Azidonorbornane from 1-Aminonorbornane (**8**).—Tosyl azide (5.53 g, 0.027 mol) in 20 ml of dimethyl sulfoxide was added to a solution in 100 ml of DMSO, 4.0 g (0.027 mol) of **8**,[21,22] and 6.7 g (0.06 mol) of potassium *tert*-butoxide. Dilution with water after 12 hr, extraction with ether, and molecular distillation at 25° (0.1 mm) gave 1.12 g (32%) of 1. Vpc analysis on column I showed two impurities. The vpc purified material gave the following ir data: 2960 (s), 2920 (m), 2870 (s, CH), 2090 (s, N_3), 1447 (m), 1310 (s), 1260 (s), 1050 (m), and 910 (m) cm^{-1}. *Anal.* Calcd for $C_7H_{11}N_3$: C, 61.32; H, 8.08; N, 30.60. Found: C, 61.5; H, 8.08; N, 30.9. Nmr spectrum: CH at position 4 δ 2.22 (s, 1 H), other CH δ 1.2–1.9 (10 H). Mass spectrum: at 70 eV, *m/e* (rel intensity) parent peak 137 (2), 69 (100), 81 (78), 67 (64), 108 (49), 68 (45), 109 (33), 80 (32), 82 (28), 95 (15), 94 (13); at 13 eV, 108 becomes the base peak, and 137 (6). The uv spectrum shows a maximum at 290 nm (ε 26.2); the extinction coefficients are 11.3 at 255, 15.5 at 110, and 0.84 at 350 nm.

Irradiation of 1 in Methanol.—A solution of 0.60 g (0.0044 mol) of 1 in 70 ml of methanol was irradiated in a Pyrex tube for 24 hr in a Rayonet photochemical reactor[36] equipped with 16 fluorescent lamps (90% of the light intensity between 410 and 310 nm). Removal of the methanol, molecular distillation at 40° (0.1 mm), and vpc (column I at 120°) of the 0.46 g (75% yield) of distillate gave two components, **10** and **11**, in a ratio of 2.3:1. The peak eluted first is **10**, 1-methoxy-2-azabicyclo-[3.2.1]octane, $n^{25}D$ 1.4795. The second peak is **11**, 1-methoxy-2-azabicyclo[2.2.2]octane, $n^{25}D$ 1.4832.

Compound **10** gave the following data. *Anal.* Calcd for $C_8H_{15}NO$: C, 68.09; H, 10.64; N, 9.92. Found: C, 67.48;[37] H, 10.69; N, 10.14. Ir spectrum: NH at 3300 (w), CH at 2940 (w), 2870 (m), 2830 (w); others at 1450 (m), 1260 (m), 1150 (s), 1070 (m), 1020 (m), and 930 cm^{-1} (m). Nmr spectrum in $CDCl_3$: OCH_3 δ 3.35 (s, 3 H), CH_2 at 3 δ 3.00 (m, 2 H), CH at 5, δ 2.32 (S, 1 H), other CH δ 1.2–2.0 (8 H), NH δ 1.32 (1 H, removed by washing with D_2O); the multiplet at δ 3.0 was converted to a doublet (J = 4.5 Hz) by irradiating δ 1.33 upfield (H_{eq} at C-4), a doublet with J = 3.5 Hz resulted from irradiation of CH_{ax} at position 4 (δ 1.67 upfield), a singlet at δ 3 resulted from irradiating both (up δ 1.5 at 6 mG decoupling field). Mass spectrum: parent peak at 141 (11), p + 1 (at 142) was 10.5% of p, calcd 9.3%; base peak 112 (100); others 113 (21), 41 (21), 55 (19), 98 (14), 83 (13), 126 (11), 54 (11), 97 (8), 70 (7).

Product 11 (1-methoxy-2-azabicyclo[2.2.2]octane). *Anal.* Calcd C, 68.09; H, 10.64; N, 9.92. Found: C, 66.59;[37] H, 10.82; N, 9.73. Ir spectrum: NH at 3320 (w), CH at 2940 (vs), 2860 (s), 2923 (w); others 1410 (m), 1335 (m), 1160 (m), 1210 (s), 1110 (s), 1050 (s), and 1023 cm^{-1} (m). Nmr spectrum: OCH_3 δ 3.26 (S, 3 H), CH_2 at 3 δ 3.1 (d, J = 2 Hz, 2 H), other CH δ 1.5–2.1 (9 H), NH δ 2.36 (s, 1 H, removed by washing with D_2O). Mass spectrum: parent peak at 141 (33), p + 1 (142) 10.5% of p (calcd 9.3%); base peak 112 (100); other 98 (52), 113 (36), 55 (36), 56 (31), 41 (28), 126 (20), 70 (10), 140 (9).

Both compounds formed hydrochlorides. *Anal.* Calcd for $C_8H_{16}NOCl$ (**10**·HCl: C, 54.1; H, 9.1; N, 7.9; Cl, 20.0. Found: C, 54.29; H, 9.21; N, 7.69; Cl, 19.80. Found for **11**·HCl: C, 54.20; H, 9.28; N, 7.77; Cl, 19.80. The nmr spectra of the hydrochlorides were similar to those of the parent compounds. Melting points were 167–168° dec for **10** HCl and 163–164° dec for **11** HCl, both from methanol–ether.

The residue from the distillation of the products from irradiating 1 in methanol contained NH (3290 cm^{-1}); the nmr spectrum showed three sharp H_3CO singlets at δ 3.20, 3.27, and 3.35, and a complex of signals at δ 0.8–4.0. No 1-aminonorbornane (**8**) could be found, although its vpc retention time was known. Another vpc column (II: 2 ft × 0.25 in. 20% Carbowax 20M on Anakrom ABS) at 80° showed the same ratio of **10**:**11** and no new peaks. Compounds **10** and **11** were stable on both columns. In one irradiation of 1 in methanol, nine samples were withdrawn over 21 hr, the ratio of **10**:**11** was constant throughout the run, and 5% of the azide 1 was left after 7 hr. Irradiation of 1 in methanol with light of 254 nm wavelength gave the same results as that using 310–410 nm, except that **10** and **11** were destroyed by the 254-nm light; **11** disappeared faster (*e.g.*, after 8 hr the yields were 53 and 17%, respectively, after 21 hr 21 and 0%). Irradiation in oxygen-saturated methanol produced

(32) H. Hellman and G. Opitz, *Chem. Ber.*, **90**, 15 (1957).

(33) E. L. Eliel and R. A. Daignault, *J. Org. Chem.*, **30**, 2450 (1965).

(34) Formation of a C=N double bond in the $LiAlH_4$ reduction has been implied earlier[35] to explain the lack of reaction with $LiAlH_4$ of 2-methoxy-1-azabicyclo[3.2.1]octane, an isomer of our **10**.

(35) P. G. Gassman and B. L. Fox, *J. Amer. Chem. Soc.*, **89**, 338 (1967).

(36) The Southern New England UV Co., Middletown, Conn.

(37) Low carbon analysis values are common with bicyclic amines, *e.g.*, also with 2-azabicyclo[3.2.1]octane.[26]

no change. Irradiation (310–410 nm) of 0.0974 g (0.00071 mol) of **1** in 8 ml of methanol and 0.035 g of concentrated sulfuric acid gave **10** and **11** in 59 and 19% yields, respectively (ratio **10**:**11** = 3.1). Irradiation of 0.0950 g (0.00069 mol) of **1** in 8 ml of methanol in which 0.1 g of sodium had been dissolved gave a 56% yield of **10** and 20% of **11**. The runs with acid and base present were worked up by dilution with water, neutralization, and extraction. The greater solubility in water of **11** (compared to **10**) might account for its decreased yields. The rates of gas evolution were not affected by the addends.

Acid Hydrolysis of 10 and 11.—The reaction conditions necessary for acid hydrolysis of **10** and **11** were determined by heating samples of the mixture (from the irradiation of **1**) in D_2O–DCl in an nmr tube and following the spectral changes. Heating of **10** in concentrated HCl at 80° for 30 hr effected complete hydrolysis to 3-aminoethylcyclopentanone hydrochloride (**13**): ir (mineral oil) C=O at 1734 (vs), other at 1410 (m), 1030 (m), 890 (m); nmr spectrum in D_2O NCH_2 δ 3.1 (t, 2 H), others δ 1.5–2.5 (9.2 H). Spin decoupling of the NCH_2 triplet by irradiating upfield (1.1 to 1.3 ppm) converted the triplet to a singlet. The *N*-acetyl derivative was prepared using acetic anhydride and aqueous base[38] and purified on column II at 165°. Only one peak was observed. The **3-(2-acetylaminoethyl)cyclopentanone** had ir, nmr, and mass spectra and vpc retention time identical with those of an independently synthesized sample of **14**. Heating **11** in 10% hydrochloric acid to 80° for 15 hr hydrolyzed about 25% of the **11**. Hydrolysis with 20% hydrochloric acid at 80° for 30 hr and removal of the solvent *in vacuo* left **15** HCl: ir C=O at 1704 cm^{-1}; nmr spectrum (D_2O) NCH_2 δ 3.03 (d, 2 H), other CH δ 1.2–2.7 (8.9 H). The *N*-acetyl derivative was prepared,[38] purified on vpc column II at 165° (only one peak observed), and identified by comparison of its retention time, ir, nmr, and mass spectra with those of an authentic sample of **16**.

Lithium Aluminum Hydride Reduction of 10.—A solution of 0.299 g (0.0021 mol) of a 2.3:1 mixture of **10** and **11** (as obtained above) in 40 ml of ether was added dropwise to an excess of $LiAlH_4$ in 50 ml of ether. After the solution had boiled for 4 hr and stood overnight, dilute aqueous NaOH was added. The filtered and dried ether phase upon molecular distillation [45° (−0.1 mm)] gave 0.13 g of distillate. Analysis on vpc column I at 100° showed two products only; **11** was recovered in 85% yield and identified by its ir spectrum and the ir and nmr spectra and mixture melting point of its hydrochloride, **11** HCl. The other component (33% yield) was 2-azabicyclo[3.2.1]octane, identified by comparison of its vpc retention time and ir and nmr spectra with those of an authentic sample.[24] A mixture melting point of the picrate was undepressed, 208–209°. Mass spectrum of **12**: parent 111 (12), p + 1 10% of p (calcd 8%); others 82 (100) (loss of CH_2NH), 68 (13) (loss of CH_2CH_2NH), 83 (14) (loss of C_2H_4), 96 (loss of NH), at 70 eV. At 8-eV ionization voltage only 111 and 83 were seen. Pure **10** and $LiAlH_4$ gave **12** in 40% yield.

Thermolysis of 1 in Methanol.—No decomposition of **1** was observed upon heating at 65° for 8 hr in methanol. In sealed tubes, 90% of **1** decomposed at 170° during 14 hr, producing a 27% yield of **10** and a 3% yield of **11**. However, the 2.3:1 mixture of **10** and **11** itself is unstable at 170°; heating 0.0354 g (0.00025 mol) of the mixture in 1.3 ml of pure methanol to 170° for 14 hr led to recovery of 17% of the **10** and a trace of the **11**. The rest of the material was a dark gum. In a metal bomb, the only decomposition product of methanol solutions of **1**, at 140 and 170°, was a black oil.

Photolysis of 1 in 2-Propanol.—A solution of 0.936 g (0.0066 mol) of **1** in 60 ml of 2-propanol was irradiated with light of 310–410 nm for 21 hr. Removal of the solvent and molecular distillation [30–60° (0.1 mm)] gave 0.843 g (75% yield) of a liquid which was analyzed on vpc column I at 110°. Two components were present, **17** and **18**, in a ratio of 2.2:1. **1-Isopropoxy-2-azabicyclo[3.2.1]octane** (**17**), $n^{22}D$ 1.4695, formed in 52% yield. Ir spectrum (CCl_4): NH at 3320 (w), CH at 2970 (s), 2940 (s), 2780 (m); others at 1365 (m), 1260 (m), 1130 (s), 1145 (s), 1030 cm^{-1} (s). Nmr spectrum: *i*-PrCH δ 4.08 (septet, J = 6 Hz, 1 H), *i*-$PrCH_3$ δ 1.05 (d, J = 6 Hz), CH_2 at 2 δ 2.9 (m, 2 H), CH at 5 δ 2.28 (s, 1 H), other CH and NH δ 1–2 (m, 15 H incl *i*-$PrCH_3$ s). Mass spectrum: parent peak at 169 (14), p + 1 12% of p (calcd 11.5%) base peak 98 (100) (loss of C_2H_4 + *i*-Pr); others 110 (25) (loss of -O-*i*-Pr), 126 (26) (loss of $HNCH_2CH_2$), 140 (26) (loss of $HNCH_2$). **1-Isopropoxy-2-azabicyclo[2.2.2]octane** (**18**), formed in 23% yield. Ir spectrum (CCl_4): NH at 3325 (w), CH at 2970 (s), 2930 (s), 2865 (m), others at 1380 (m), 1250 (m), 1165 (m), 1110 (s), and 1060 cm^{-1} (m). Nmr spectrum ($CDCl_3$): *i*-PrCH δ 4.23 (septet, J = 6 Hz, 1 H), *i*-$PrCH_3$ δ 1.1 (d, J = 6 Hz, 6 H), CH_2 at 3 δ 3.1 (d, J = 2 Hz, 2 H), CH_2 at 5, 6, 7, 8 and CH at 4 δ 1.7 (0.15 ppm broad peak, 9 H), NH δ 1.38 (s, 1 H). Refractive index $n^{22}D$ 1.4710. Mass spectrum: 169 (26) (p), p + 1 12% of *p* (calcd 11.5%); base peak 98 (100) (loss of C_2H_4 + *i*-Pr); 99 (71) (loss of C_2H_4 + H_2C=$CHCH_3$), 128 (21), 110 (17) (loss of *i*-PrO), 126 (16) (loss of *i*-Pr), 127 (16), 84 (13). The hydrochlorides (from methanol–ether: **17** HCl, mp 158–159°; **18** HCl, mp 154–155°) were not obtained in sufficient quantity to be analyzed separately, but their mixture (as obtained from the mixture of **17** and **18** from photolysis) was analyzed. *Anal.* Calcd for $C_{10}H_{20}NOCl$: C, 58.50; H, 9.82; N, 6.82; Cl, 17.30. Found: C, 58.68; H, 10.65; N, 6.64; Cl, 17.14.

Reaction of 17 and 18 with Lithium Aluminum Hydride.—A mixture of **17** and **18** (2.2:1) (0.23 g, 0.00136 mol) in 50 ml of ether was added dropwise to an excess of $LiAlH_4$ in 50 ml of ether. Reflux for 2.5 hr, standing overnight, decomposition with aqueous NaOH, and removal of solvent gave a mixture, analysis of which on column I at 107° indicated recovery of 95% of the **18** and a 91% yield of **12**, both identified by their retention times and ir spectra.

Photolysis of 1 in *tert*-Butyl Alcohol.—This experiment is representative of photolyses of **1** in "inert" solvents (*tert*-BuOH, *n*-$BuNH_2$, 2-methylbutane, cyclohexane, cyclohexene, and benzene). A solution of 0.103 g (0.00075 mol) of **1** in 8 ml of *tert*-BuOH was photolyzed (310–410 nm) for 24 hr. An 84% yield of N_2 was evolved. Removal of the solvent left 0.0663 g of a red powder (assuming a molecular weight of 109, the yield is 81%). *Anal.* Calcd for $C_7H_{11}N$: C, 77.00; H, 10.15; N, 12.80. Found: C, 73.67; H, 9.97; N, 10.41. Calcd for $C_{11}H_{12}NO$ (*tert*-BuOH adduct): C, 72.2; H, 11.5; N, 7.65. The found composition is reasonably close to $C_7H_{11}N_{0.85}$. Ir spectrum (KBr): NH, broad at 3350, C=N 1640 (s), 1370, 1170 cm^{-1}. Mass spectrum (solid inlet, 100–240°: only peaks at *m/e* 39 41, 44, 55, 56, 57, and 59. The red powder was insoluble in common organic solvents, but a hydrochloride was obtained by treatment with aqueous HCl and evaporating its excess. A D_2O solution of this showed a series of broad, overlapping signals from δ 1.0–3.2 Attempted vpc analysis was unsuccessful.

4-Azabicyclo[3.2.1]octane (**12**) was prepared after Elderfield[24] and purified on column I at 75°. Ir spectrum: NH at 3350 (w), CH at 2940 (vs), 2870 (m), 2860 (m), 2805 (w); others at 1445 (m), 1300 (w), 1180 (w), and 1080 cm^{-1} (m). Nmr spectrum ($CDCl_3$): CH at 1, δ 3.4 (s, 1 H), CH_2 at 3, δ 2.9 (m, 2 H), CH at 5, δ 2.3 (s, 1 H), other CH_2 δ 1.3–1.83 (m, 8 H), NH δ 1.7 (s, 1 H, removed by D_2O). The picrate (from EtOH) had mp 208–209° (lit.[39] 203–205°); **12** HCl had mp 222–234° dec (lit.[24] 220–244°). Ir spectrum of **12** HCl (KBr): H_3N^+ 3100–2000, others at 1590 (m), 1450 (s), 1330 (m), 1185 (m), 1000 (m), and 540 cm^{-1} (m). Nmr spectrum in D_2O: CH at 1 δ 3.96 (s, 1 H), CH_2 at 3 δ 3.2 (m, 2 H), CH at 5 δ 2.52 (s, 1 H), other CH_2 δ 1.82 (m, 8 H).

3-(2-Acetylaminoethyl)cyclopentanone (**14**) was prepared from ethyl 3-oxocyclopentylacetate ethylene ketal,[40] bp 81–82° (0.3 mm) [lit.[40] 73° (0.003 mm)], which in turn was obtained from 3-oxycyclopentylacetic acid,[41] made from norcamphor.[42] Ammonolysis of 4.0 g (0.0187 mol) of the ketal in 60 ml of concentrated ammonium hydroxide gave 3.22 g (85%) of a pale yellow solid. Vpc analysis on column II at 165° indicated small amounts of starting material and other impurities. Ir spectrum of **3-(2-carboxamidomethyl)cyclopentanone ethylene ketal** (**20**) ($CHCl_3$): H_2N at 3535 (sh), 3500 (broad), 3420 (sh), 3360 (broad); C=O at 1675 cm^{-1} (vs). *Anal.* Calcd for $C_9H_{15}NO_3$: C, 58.50; H, 8.16; N, 7.55. Found: C, 58.19; H, 7.90; N, 7.56. A solution of 1.35 g (0.0073 mol) of **20** in 60 ml of tetrahydrofuran was added dropwise to a stirred solution of an excess of $LiAlH_4$ in 75 ml of THF. After 24 hr at reflux and decomposition with aqueous NaOH, THF extraction, and removal of solvent, 1.3 g (93%) of a yellow oil was obtained. It was purified on column II at 130°: ir ($CHCl_3$) NH at 3390 (w), 3320 (w), 1580 (m), 1330 (s), 1110 (s), and 1025 cm^{-1} (m); nmr spectrum ($CDCl_3$) ketal CH_2 δ 3.85

(38) R. L. Shriner, R. C. Fuson, and D. Y. Curtin, "The Systematic Identification of Organic Compounds," Wiley, New York, N. Y., 1965, p 226.

(39) R. Griot, *Helv. Chim. Acta*, **42**, 67 (1959).

(40) H. Stetter, I. K. Hansen, and M. Rizk, *Chem. Ber.*, **94**, 2702 (1961).

(41) E. Demole and M. Stoll, *Helv. Chim. Acta*, **45**, 692 (1962).

(42) R. K. Hill and A. G. Edwards, *Tetrahedron*, **21**, 1501 (1965).

(s, 4 H), NCH_2 δ 2.69 (t, 2 H), ring CH at 2, 4, 6, and 1 δ 1.1–2.3 (m, 9 H), NH_2 δ 1.2 (s, 2 H). The hydrochloride of **3-(2-aminoethyl)cyclopentanone ethylene ketal** (**21**), **21** HCl, had mp 130–132° (from methanol–ether). A solution of 0.4 g (0.00193 mol) of **21** HCl in 6 ml of 20% aqueous HCl was heated to 100° for 24 hr and the solvent was removed to give 0.4 g of impure **13** HCl. Because of its instability (presumably caused by attack of the amino group on the carbonyl group), the **13** HCl was acetylated.[38] Extraction with $CHCl_3$ gave 0.17 g of an oil, purified on column II at 165°, which was found to have identical spectra with those of the **14** from hydrolysis of **10**. Ir spectrum ($CHCl_3$): NH at 3460 (sharp), 3360 (broad), CH at 2970 (s), 2930 (s), 2870 (m), C=O at 1712 (vs) and 1670 cm^{-1} (vs). Nmr spectrum ($CDCl_3$): NH at δ 5.8 (s, 1 H), NCH_2 δ 3.3 (q, 2 H), other CH at δ 1.5 (9.3 H), CH_3 δ 1.92 (3 H). Spin decoupling of the quartet at δ 3.3 gave a doublet when irradiating between δ 1.8 and 2.0 and a triplet when irradiating at δ 5.8, revealing coupling with both the adjacent CH_2 (side chain) and the NH. Mass spectrum: p 169 (83), p + 1 is 11.5% of p (calcd 10.4); the base peak 73 (100) corresponds to loss of C_6H_9O; others 72 (86) (loss of C_6H_9O), 87 (86) (loss of C_5H_6O), 110 (83) (loss of C_2H_5NO). The amount of material was insufficient for combustion analysis, but the high-resolution mass spectrum[43] showed a parent peak of 169.1647 (calcd for $C_9H_{15}NO_2$: 169.1643).

4-Acetamidomethylcyclohexanone (**16**) was prepared from ethyl *p*-hydroxybenzoate by reducing it with Raney nickel[44,45] to ethyl 4-hydroxycyclohexylcarboxylate, bp 90–92° (0.45 mm) [lit.[46] 118–126° (3 mm)]. Ir spectrum (CCl_4): C=O at 1730, HO at 3620 (sh) and 3500 cm^{-1} (broad). The hydroxy compound was oxidized to the ketone and converted to the ethylene ketal by Stetter's[40] methods. **Ethyl 4-oxocyclohexylcarboxylate ethylene ketal** was obtained in 74% yield from the ketone, bp 93–94° (0.5 mm), $n^{21}D$ 1.4639. Ir spectrum: C=O at 1730 cm^{-1} (vs). Nmr spectrum (CCl_4) ethyl CH_2 δ 4.05 (q), ketal CH_2 3.84 (s, overlapping the q of the ethyl CH_2, together 6 H), ring CHs δ 1.4–2.4 (m), ethyl CH_3 δ 1.22 (t, overlapping ring CHs, together 12 H). *Anal.* Calcd for $C_{11}H_{18}O_4$: C, 61.56; H, 8.46. Found: C, 61.38; H, 8.39.

4-Carboxamidocyclohexanone Ethylene Ketal (**22**).—Ethyl 4-oxocyclohexylcarboxylate ethylene ketal (8.75 g, 0.04 mol) was added to a solution of 3.5 g of KOH in 16 ml of diethylene glycol and 4 ml of water, and ethanol was distilled for 0.5 hr. The solution was diluted with water, washed with ether, and acidified with HCl. Ether extraction gave 6.2 g (82%) of the acid, a yellow oil. To a solution of 4.7 g (0.025 mol) of this and 2 g of pyridine in 50 ml of ether was added 3 g of thionyl chloride. Evaporation *in vacuo* after 1 hr left crude acid chloride, which was added dropwise to concentrated aqueous ammonia to form 4.67 g of **22**, mp 170–172° (from methanol). Ir spectrum ($CHCl_3$): NH at 3540 (sh), 3500 (broad), 3420 (sh), 3350 (broad), C=O at 1675 (s), NH_2 at 1590 cm^{-1} (m). Nmr spectrum ($CDCl_3$): NH_2 δ 5.85 (s, 1.7 H), ketal CH_2 δ 3.92 (s, 4 H), ring CH_2 δ 1.4–2.4 (m, 9.5 H). *Anal.* Calcd for $C_9H_{15}NO_3$: N, 7.55. Found: N, 7.69.

4-Aminomethylcyclohexanone ethylene ketal (**23**) was prepared from the carboxamide **22** as described for **21**: ir NH at 3385 cm^{-1}; nmr ketal CH_2 δ 3.9 (s, 4 H), NCH_2 δ 2.55 (d, 2 H), ring CH's and NH_2 δ 1.1–2.0 (11 H). The hydrochloride had mp 186° dec from ether–methanol. **23** was hydrolyzed as described for **21**: ir of **15** HCl (Nujol) C=O at 1706 cm^{-1}; nmr (D_2O) NCH_2 δ 3.1 (2 H), ring CH's δ 1.2–2.6 (m, 9 H). Acetylation of **15** as described for **14** gave **4-acetamidomethylcyclohexanone** (**16**), purified on column II at 165°: ir ($CHCl_3$) NH 3460 (sh), 3360 (broad), C=O at 1710 and 1670 cm^{-1} (s); nmr ($CDCl_3$) NH δ 5.8 (s, 0.8 H), NCH_2 δ 3.22 (t, 2 H), ring CH's δ 1.2–2.5 (m), acetyl CH_3 (s, overlapped by ring CH's, together 12 H). Spin decoupling of the triplet at δ 3.22 gave a doublet on irradiation at δ 2.0 and a doublet on irradiation at δ 5.8 (NH). Mass spectrum: p 169 (23), p + 1 is 11.4% of p (calcd 10.4%); base peak 73 (100) (loss of C_6H_9O); others 110 (20), 60 (10), 72 (11), 113 (4). High-resolution mass spectrometry[43] gave p 169.1637 (calcd for $C_9H_{15}NO_2$, p 169.1643). The **16** thus prepared had ir and nmr spectra and vpc retention times identical with those of the **16** made by hydrolysis and acetylation from **11**

Reaction of *N*-Chloro-1-aminonorbornane with Silver Nitrate.—To a solution of 0.352 g (0.00317 mol) of 1-aminonorbornane (**8**) in 50 ml of ether containing 0.05 g of sodium bicarbonate was added with stirring at 10° in the dark an ether solution of 0.316 g (0.00327 mol) of *tert*-butyl hypochlorite. After stirring in the dark for 2 hr, the salts were removed by filtration. The solution of *N*-chloro-1-aminonorbornane was diluted with 40 ml of methanol, and 0.68 g (0.004 mol) of silver nitrate was added. After stirring for 2 hr, silver chloride was filtered off. The filtrate was concentrated *in vacuo* to 5 ml, made basic with 2 *N* sodium hydroxide, saturated with sodium chloride, and continuously extracted with ether for 36 hr. The ether extract yielded 0.239 g of a yellow solid. Vpc analysis at 100° on column I or 145° on column II showed that nine components were present, four of which comprised about 80% of the products. Neither **10** or **11**, nor **8** or **12** were present. The first large peak had a parent peak in the mass spectrum of 111, and seems to be an isomer of 1-aminonorbornane, $C_7H_{13}N$; its p + 1 was 8.8% of p (calcd 8.15%). Its ir spectrum, however, was different from those of **8** or **12**. The second major peak, parent mass 145, seems to contain chlorine, since in its mass spectrum p/(p + 2) is about 3. The third peak has a p of 218, the fourth of 153. The fourth showed NH absorption at 3460 (s) and 3350 (broad), C=O at 1690 cm^{-1}. Since none of the peaks corresponded, in vpc retention times or spectra, to any of the compounds encountered above, the reactions of the *N*-chloro-1-aminonorbornane were not studied further.

Registry No.—**1**, 28673-83-8; **8**, 21245-51-2; **10**, 30482-11-2; **10** HCl, 30482-12-3; **11**, 30545-58-5; **11** HCl, 30482-13-4; **12**, 279-79-8; **12** HCl, 16994-01-7; **13** HCl, 30482-16-7; **14**, 30482-17-8; **16**, 30482-19-9; **17**, 30482-19-0; **17** HCl, 30482-20-3; **18**, 30482-21-4; **18** HCl, 30482-22-5; **20**, 30482-23-6; **21** HCl, 30545-59-6; **22**, 30482-24-7; **23**, 30482-26-8; ethyl 4-oxocyclohexylcarboxylate ethylene ketal, 7489-97-0.

Acknowledgment.—We are greatly indebted to the National Science Foundation for support of this work.

(43) We are indebted to Phillips Petroleum Co. for determining this spectrum.

(44) M. F. Clarke and L. N. Owen, *J. Chem. Soc.*, 2108 (1950).

(45) We are indebted to Dr. F. Ziegler for assistance with the reduction.

(46) M. Kilpatrick and J. G. Morse, *J. Amer. Chem. Soc.*, **75**, 1846 (1953).