reaction mixture was treated with ice and water and the product was extracted with benzene. The benzene solution was dired over anhydrous sodium sulfate and the solvent was removed on a rotary evaporator. The crude product was distilled through a Vigreux column and the fraction which boiled at 90° (1.8 Torr) was collected. The yield was 6.0 g (84%). The nmr spectrum displayed signals at δ 1.39 (s, 9 H, *tert*-butyl), 3.68, 3.74, and 3.78 (s, 6 H, ester methyls), 4.04 (d, 2 H, allylic methylene), $\sim$5.2 (m, 2 H, vinylidene), and $\sim$6.0 (m, 1 H, methine). The two singlets at δ 3.78 and 3.74 were found to coalesce at 40–35°. The mass spectrum gave a parent peak at mass 244.1418 (calcd for $C_{11}H_{20}N_2O_4$, 244.1423).

Preparation of *tert*-Butylazo-3-propene (8). A slow stream of nitrogen was bubbled through 60 ml of ethylene glycol for 20 min in a mechanically stirred flask with mild heating. Potassium hydroxide (6.07 g, 107 mmol) and dimethyl *N*-allyl-*N'*-*tert*-butylbicarbamate (1.7 g, 23.6 mmol) were added. The mechanical stirrer was replaced with a Liebig condenser. The hydrazine, along with the methanol formed, was distilled under a stream of nitrogen at the bath temperature of 150–160°. Concentrated hydrochloric acid was added to the distillate to give, upon further evaporation, 1.7 g of 1-allyl-2-*tert*-butylhydrazine hydrochloride, mp 165–175°. The nmr spectrum in D_2O displayed signals at δ 1.37 (s, 9 H, *tert*-butyl), 3.64 (d, 2 H, allylic methylene), 4.74 (s, 4 H, NH), $\sim$5.5 (m, 2 H, vinylidene), and $\sim$5.8 (m, 1 H, methine). The yield was 36%.

Potassium hydroxide (3 g, 60 mmol) was added to a solution of the hydrochloride of the hydrazine (1.7 g, 8.45 mmol) in 20 ml of water. The hydrazine was extracted with ether and the ether solution dried over anhydrous sodium carbonate. The dried solution of the hydrazine (8.45 mmol) in ether (50 ml) was stirred at room temperature with a slurry of red mercuric oxide (10 g, 46 mmol) and anhydrous sodium sulfate (20 g). After 6 hr the solution was filtered and concentrated to 2 ml by distillation through a Vigreux column, and the azo compound **8** was separated by gc using a 2-ft column of 20% dimethylsulfolane on Chromosorb P at room temperature. The yield was 0.8 g (75%). The nmr spectrum displayed signals at δ 1.19 (s, 9 H, *tert*-butyl), 4.34 (d, 2 H, allylic methylene), $\sim$5.2 (m, 2 H, vinylidene), and $\sim$6.2 (m, 1 H, methine). The uv spectrum has a λ_{max} at 355 nm (ϵ $\sim$25 as a gas). The mass spectrum gave a parent peak at mass 126.1159 (calcd for $C_7H_{14}N_2$, 126.1157).

Control Experiments. (a) Mass Spectrometric Analysis of Nitrogen and Isotope Nitric Oxide (^{15}NO). The mass spectrometric analyses of pure nitrogen, and of nitrogen produced from **6** and **8**, were found consistent with the natural abundance of nitrogen ($^{14}N^{15}N/^{14}N^{14}N = 7.4 \times 10^{-3}$ and $^{15}N^{15}N/^{14}N^{14}N$ = nil).[26] Scrambling between ^{15}NO and N_2 under the reaction conditions could not be detected (<0.1%).

(b) Reaction of 1-Butene with Nitric Oxide. The reaction of 1-butene with NO was carried out in order to test the inertness of the olefinic bond under the thermolysis conditions. The olefinic bond was found to be stable to NO at 130° which is the highest temperature used for the study of the inhibited thermolysis of azo compounds. A sample left at 145° for 10 hr did show a loss in butene and 4% of the nitric oxide was converted to nitrogen.

(c) Nmr Analysis of the Recovered Methylazo-3-propene-*3,3-d*$_2$ (14). Mixtures of **14** and ^{15}NO (29.1–31.4 μmol of **14**, ^{15}NO/**14** = 0.161) were thermolyzed at 126.00° for 30–130 min. The unreacted **14** was collected and analyzed by 100-MHz nmr. The signal at δ 4.46 for allylic protons was completely absent indicating that no scrambling was observed under these conditions.

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Rearrangement of *N*,*N*-Dichlorotri-*n*-butylcarbinamine by Aluminum Chloride[1]

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Abstract: Treatment of *N*,*N*-dichlorotri-*n*-butylcarbinamine with aluminum chloride in methylene chloride, followed by acid hydrolysis, produced di-*n*-butyl ketone and *n*-butylamine in yields of 95 and 92%, respectively. Careful control of variables during rearrangement and work-up was necessary for best results. Optimum yields were realized at −30° followed by steam distillation during hydrolysis. The mechanistic interpretation involves abstraction of chloride ion by aluminum chloride and migration of an alkyl group from carbon to electron-deficient nitrogen. Hydrolysis of the rearranged product presumably generates a carbinolamine which decomposes to the ketone and amine. Supporting evidence is discussed, including literature analogy. This comprises the first example of a 1,2 shift to positive nitrogen derived from a simple, open-chain *N*-haloalkylamine.

Many articles and reviews have dealt with rearrangements involving migration of an alkyl group from carbon to an electron-deficient atom. Carbon to carbon migrations which are well established include the Wagner–Meerwein and pinacolic types.[4] Alkyl shift from carbon to oxygen is also known,[5] as exemplified by the Baeyer–Villiger oxidation. Carbon to nitrogen rearrangement[6] has been observed with various substrates, such as azides, hydroxylamines, and haloamines. Rearrangements involving *N*-haloamines[7] include the Hofmann–Löffler reaction,[8] conversion of *N*,*N*-dichloro-*sec*-alkylamines to α-amino ketones,[9] and intermediacy of nitrenium ions.

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(1) Paper XVII. Chemistry of *N*-Haloamines. Preliminary communication: T. A. Kling, M. B. Nazareno, and P. Kovacic, *J. Amer. Chem. Soc.*, **94**, 2157 (1972).

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Gassman and coworkers[10] have proposed, through studies of *N*-chloroalkylamine rearrangements in the presence of silver salt, the existence of the nitrenium ion as a discrete intermediate. The *N*-chloroamines rearranged[10,11] by alkyl migration in those cases containing a strained ring system whose carbon analog is known to undergo carbonium ion rearrangement quite readily. Similar rearrangements have been found to occur with *N*,*N*-dichloro-2-aminonorbornane[12] and *N*-halo derivatives of 1-aminoadamantane[13-15] in the presence of aluminum chloride. Other transformations of electron-deficient nitrogen are reported[10,16,17] which resemble those of the carbon counterparts. Presumably the only noncyclic case contained in the literature is the Stieglitz rearrangement[7] of trityl *N*-halo- and *N*,*N*-dihaloamines. In summary, prior rearrangements in aliphatic systems have involved mono-, bi-, or tricyclic ring structures characterized by some degree of strain, usually quite appreciable. Apparently, the only open-chain examples comprise migration of an aromatic nucleus.

The objective of the present work was to effect carbon to nitrogen migration in an *N*-haloamine containing simple, open-chain alkyl groups. The system selected for investigation was *N*,*N*-dichlorotri-*n*-butylcarbinamine–aluminum chloride.

Results and Discussion

Preparation of Starting Materials. Tri-*n*-butylcarbinamine (**1**) was prepared by two methods. The first approach was based on literature procedures:[18,19] reaction of *n*-butyl bromide with acetonitrile to form tri-*n*-butylacetonitrile and subsequent conversion to the amide followed by Hofmann degradation. The overall yield was 16% based on *n*-butyl bromide. Improvement was realized from application of the Ritter reaction[20] to tri-*n*-butylcarbinol. The alcohol precursor was obtained[21] from *n*-butylmagnesium bromide and diethyl carbonate. Based on *n*-butyl bromide, the yield of amine was 53%.

The *N*,*N*-dichloroamine **2** was prepared by treatment of the amine with calcium hypochlorite.[22] In the initial part of our work, yields of 74–78% were observed. However, alteration of conditions brought an increase to 90–98%. A solution of crude *N*,*N*-dichloro compound was used directly in the reaction with aluminum chloride. It is important to recognize that the calculated yields of products from the rearrangement vary depending upon the nature of the impurity in the starting material, which could conceivably be either unchanged amine or *N*-monochloroamine. Since we consider it very likely that the impurity is the latter, yields are calculated on this basis. Support is provided by the observation[23,24] that chlorination of primary amines can be made to proceed stepwise, as well as the finding[24] that the rate constants for the two steps differ by a factor of 10^3 with the initial one being the faster.

Rearrangement. Rearrangement of *N*,*N*-dichlorotri-*n*-butylcarbinamine (**2**) by aluminum chloride, followed by acid hydrolysis, yielded a mixture consisting of di-*n*-butyl ketone, *n*-butylamine, recovered parent amine **1**, and intractable material (Table I). The indicated reaction variables were investigated: time, temperature, solvent, amount of solvent, catalyst, amount of catalyst, and hydrolytic procedure. Generally, an aluminum chloride–*N*,*N*-dichloroamine ratio of 2:1 was used.

Table I. Rearrangement of *N*,*N*-Dichlorotri-*n*-butylcarbinamine by Aluminum Chloride

Procedure	Temp, °C	Di-*n*-butyl ketone, % yield[a]	*n*-Butylamine, % yield[a]	Crude RNH_2,[b] % recovery[c]	Residue, %[d]
A[e,f]	0	47	8	29	33
B[e]	0	71	26	26	17
C[e]	0	59	55	21	23
C[g]	−30	88	77	4	5
C[g,h]	−30	95	89	4	2
C[g-i]	−30	95	92	3	3
C[g,j]	−20	57	90	7	7
C[g,h,k]	−30	19	30	60	5
C[g,h,l]	−30	<1	<1	66	28
D[e]	0	71	13	17	16
D[e]	−30	71	24	19	9
D[e]	−50	86	14	16	8
D[e,m]	0			96	

[a] Based on $RNCl_2$. [b] R = $(n\text{-}C_4H_9)_3C$. [c] Based on starting amine. [d] Per cent of crude product. [e] *N*,*N*-Dichloroamine prepared by procedure I. [f] Double scale. [g] *N*,*N*-Dichloroamine prepared by procedure II. [h] 180 ml of CH_2Cl_2. [i] 45 min. [j] CCl_4 solvent. [k] 12.5 mmol of $AlCl_3$. [l] $SnCl_4$ catalyst. [m] Aluminum chloride omitted.

Initially, a standard procedure was followed which was taken from prior rearrangement studies[13] in related systems (general procedure A). The reaction was carried out at 0°, followed by exposure of the product in organic solvent to hydrochloric acid for 3 hr at 0–25°. Di-*n*-butyl ketone and *n*-butylamine were isolated in yields of 47 and 8%, respectively. However, analysis revealed that a substantial amount (70% of theory) of positive chlorine was still present in the product after the hydrolytic step. It had been noted in previous investigations[23,25] that higher molecular weight *N*-haloamines are hydrolyzed relatively slowly according to this procedure. Therefore, general procedure B was applied in which complete destruction of positive chlorine was effected by prolonged contact with acid after solvent removal. As a result yields were increased to 71 (ketone) and 26% (amine).

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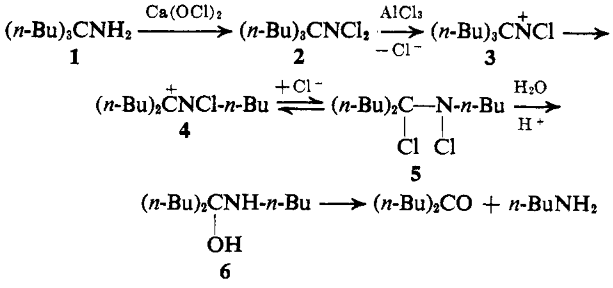
Studies were also made with another general procedure (D) entailing a greatly reduced amount of solvent and the hydrolysis work-up described in B. For reaction at 0°, yields were 71% for the ketone and 13% for the amine, indicating an adverse effect from the use of less solvent. Lowering the temperature 30° exerted a favorable influence on the quantity of *n*-butylamine (24%), with the amount of ketone unchanged. At −50°, the amine yield regressed to 14%. Further alteration in the work-up procedure was made in general procedure C. Here hydrolysis was effected during steam distillation of the acid mixture after removal of solvent. At 0°, di-*n*-butyl ketone was isolated in 59% yield and *n*-butylamine in 55% yield. Again, lowering the temperature to −30° proved beneficial, increasing the yields to 88 and 77%, respectively.

Several other variables were investigated with the best system developed. Tripling the volume of solvent appeared to enhance yields somewhat. Decreasing reaction time by half did not affect the yields. However, an experiment with an aluminum chloride–*N*,*N*-dichloroamine ratio of 0.5:1 gave greatly reduced yields of 19 and 30% for di-*n*-butyl ketone and *n*-butylamine, respectively. Recovery of 60% of tri-*n*-butylcarbinamine was further indication that a 2:1 ratio is needed for essentially complete reaction. Use of a weaker Lewis acid, tin(IV) chloride, resulted in less than 1% rearrangement with recovery of the majority of the parent amine. In two experiments with carbon tetrachloride as solvent the yield of di-*n*-butyl ketone decreased while the amount of *n*-butylamine remained unchanged. However, in other runs yields appreciably higher and lower were observed indicating difficulty in obtaining reproducible results. No difference was noted when the ordinary atmosphere was displaced by nitrogen.

A number of generalizations may be made based on the overall data. The yield of *n*-butylamine changed drastically with variation in rearrangement and work-up conditions, from 8 to 92%. Although the yield of ketone also varied (19–95%), it was somewhat less sensitive to changes. Best results for both products were obtained with general procedure C at −30°. Recovered parent amine **1** was present in all cases, to the extent of 3–66% for C and D and 26–29% for A and B. For a given procedure, the amount of **1** isolated is essentially unaffected by alteration in temperature or work-up conditions. In general, minor quantities of intractable material were also produced. There was a good correlation between increase in reaction temperature and enhancement in the amount of this by-product. The nature of the work-up also appears to have a bearing on the deleterious side reaction. There was no evidence of rearrangement of the *n*-butyl group during migration.

On the basis of present evidence and prior analogy, we propose the indicated mechanistic pathway to rationalize formation of di-*n*-butyl ketone and *n*-butylamine (eq 1).



$$\underset{\mathbf{1}}{(n\text{-Bu})_3\text{CNH}_2} \xrightarrow{\text{Ca(OCl)}_2} \underset{\mathbf{2}}{(n\text{-Bu})_3\text{CNCl}_2} \xrightarrow[-\text{Cl}^-]{\text{AlCl}_3} \underset{\mathbf{3}}{(n\text{-Bu})_3\text{C}\overset{+}{\text{N}}\text{Cl}} \longrightarrow$$

$$\underset{\mathbf{4}}{(n\text{-Bu})_2\overset{+}{\text{C}}\text{NCl-}n\text{-Bu}} \xrightleftharpoons{+\text{Cl}^-} \underset{\mathbf{5}}{(n\text{-Bu})_2\underset{\text{Cl}}{\text{C}}\text{—}\underset{\text{Cl}}{\text{N}}\text{-}n\text{-Bu}} \xrightarrow[\text{H}^+]{\text{H}_2\text{O}}$$

$$\underset{\mathbf{6}}{(n\text{-Bu})_2\underset{\text{OH}}{\text{C}}\text{NH-}n\text{-Bu}} \longrightarrow (n\text{-Bu})_2\text{CO} + n\text{-BuNH}_2 \quad (1)$$

The individual steps will be considered in greater detail. In relation to the initial ionization process, a control experiment revealed that reaction did not proceed in the absence of catalyst. This type of role for aluminum chloride in generation of a nitrenium ion was previously advanced for the rearrangement of 1-*N*,*N*-dichloroaminoadamantane[13] and 2-*N*,*N*-dichloroaminonorbornane.[12] Ample evidence points to analogous involvement of silver salts in related systems.[10] The presence of chlorine on the nitrogen of **3** would comprise a favorable driving force for ionization, similar to the assistance[26] provided in formation of carbonium ions of type $^+$CCl. The second step entails migration of an alkyl group from carbon to electron-deficient nitrogen. As mentioned in the introduction, this type of 1,2 shift is well established in related cyclic substrates. Considering the overall transformation of **2** to **4**, two possibilities exist: a synchronous process or a two-stage pathway in which the nitrenium ion **3** is generated as an intermediate. The available evidence does not permit a choice between the alternatives. Gassman[10] has compiled substantial support for formation of the nitrenium ion as a discrete intermediate from his studies. Conversion of **3** to **4** would occur readily since a carbonium ion is inherently more stable than a nitrenium ion, and the charge on **4** is delocalized by two alkyl groups and the unshared electrons on nitrogen. At the end of reaction rearranged product could conceivably exist either as **4** or **5**. The N–Cl bond in the product apparently does not undergo ionization because of greater lability associated with the C–Cl bond in **5** and presence of the positive charge in **4**. Conversion of N–Cl to N–H by acid hydrolysis is well established.[7] Carbinolamines, *e.g.*, **6**, are unstable entities,[27] decomposing readily to amines and carbonyl compounds. The same functionalities are formed as end products in the rearrangement[13] of 1-*N*,*N*-dichloroaminoadamantane.

A similar mechanistic scheme apparently pertains in the acid-catalyzed rearrangement of azides.[6] Migration is believed to occur with the form derived from protonation on the substituted nitrogen (eq 2). Hydrolysis of the end product yields a primary amine and a carbonyl compound, the same types of materials as in the present study. Sherk, Houpt, and Browne investigated[28] the behavior of ethyl azide on contact with fuming sulfuric acid. They obtained ammonia (86% yield) and methylamine (14% yield), in addition to acetaldehyde and formaldehyde (in roughly the same ratio as for the amines). The methylamine and formaldehyde are nicely accounted for according to eq 2. Ammonia and acetaldehyde might arise from either

$$\text{RCH}_2\text{N}_3 \xrightleftharpoons{\text{H}^+} [\text{RCH}_2\text{NHN}{=}\text{N}]^+ \longrightarrow \text{RCH}_2\overset{+}{\text{N}}\text{H}\cdots\text{N}_2 \xrightarrow{-\text{N}_2}$$

$$\text{CH}_2{=}\overset{+}{\text{N}}\text{HR} \xrightarrow[\text{H}^+]{\text{H}_2\text{O}} \text{CH}_2\text{O} + \text{RNH}_2 + \text{H}^+ \quad (2)$$

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(26) A. Streitwieser, Jr., "Solvolytic Displacement Reactions," McGraw-Hill, New York, N. Y., 1962, p 102.

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hydrogen migration[28] or elimination of an α proton[29] (eq 3). Benzyl azide gave similar results, as demonstrated by the formation of benzaldehyde and aniline.[30]

$$\mathrm{CH_3CH_2\overset{+}{N}H\cdots N_2 \xrightarrow{-N_2} CH_3CH{=}NH + H^+} \qquad (3)$$

In related studies by Boyer and coworkers, *n*-propylamine and ammonia were observed from the acidic decomposition of *n*-butyl azide.[31] With higher homologs, *e.g.*, *n*-hexyl azide and *n*-dodecyl azide, there was essentially no alkyl migration; instead, there was nearly quantitative conversion to the corresponding aldimine. On the other hand, Pritzkow and Mahler claimed[32] that *n*-heptyl azide in perchloric acid–acetic acid gave a 42% yield of basic product containing both ammonia and hexylamine. In the case of 2-azidoheptane, *n*-amyl rearranged about twice as easily as methyl. With the 3 isomer, *n*-butyl migrated about 50% more readily than ethyl. These reactions proceeded about 70–90% through proton loss and about 10–30% *via* 1,2 shift of an alkyl residue. In rate studies, they observed second-order kinetics during the first 25% of reaction. Acid-catalyzed rearrangements were also investigated[33] with alkyl azides derived from alcohols and hydrazoic acid. Complex mixtures of amines were obtained suggesting that rearrangement of the carbonium ion from the alcohol occurred before interaction with azide ion. Here, also, hexylamine was observed as a product from 1-heptanol. In the case of alicyclic azides, similar processes were observed:[29,31] ring expansion (alkyl migration), forming cyclic imines (Schiff bases), or imine formation by loss of hydrogen without rearrangement. Attention has been given to the question of concerted *vs.* two-step process in azide rearrangements.[6]

Recovered parent amine **1** most likely arises for the most part from the *N*-monochloro impurity in **2** (*vide supra*). It was found that the amount of recovered amine was reduced from 19 to 4% when purity of the *N*,*N*-dichloro substrate was increased from 78 to 98%. In addition, the *N*-monochloro compound probably does not undergo rearrangement to any appreciable extent.[14] Hydrogen abstraction[10] by the triplet form of the nitrenium ion is judged to be no more than a minor contributor to the recovered amine.

An interesting sidelight was noted in one of the experiments performed with general procedure A. After exposure to aqueous acid for 3 hr at 0–25°, the product still contained large amounts (*ca.* 70% of theory) of positive chlorine. The material was allowed to stand in solution over the weekend. Subsequent work-up demonstrated the presence of α-chloro-di-*n*-butyl ketone in the steam distillate, in addition to di-*n*-butyl ketone. The α-chloro compound may arise from chlorination, by unhydrolyzed positive chlorine, of some di-*n*-butyl ketone formed from partial hydrolysis. The literature records[34] this type of interaction between ketones and positive halogen in the N–Cl function. The nmr spectrum of this product exhibits splitting of the α methylene into an unusual multiplet. An analogous situation exists for α-chlorodiethyl ketone, which was ascribed to the presence of an asymmetric center.[35,36]

There was no evidence for ionization[37] of the type, $(n\text{-Bu})_3\mathrm{C^+(Cl_2NAlCl_3)^-}$. In addition to the olefin, $n\text{-PrCH{=}C}(n\text{-Bu})_2$, which could arise from the cation, one might expect ammonia as the other product. Neither substance was detected. If the olefin were formed, it would likely polymerize, as evidenced by a control experiment in which authentic olefin was converted to higher molecular weight material on treatment with aluminum chloride.

Experimental Section

Materials. In general, high purity commercial chemicals were used directly. Diethyl carbonate was purified according to a published procedure [21]

Analytical Procedures. Infrared spectra were obtained on a Beckman IR-8 or Perkin-Elmer 137 or 337 spectrophotometer with neat samples or dilute solutions in carbon tetrachloride or chloroform. The 1601.8- and 1028.3-cm^{-1} bands of polystyrene were used for calibration. The Varian T-60 was used to obtain nmr data which are reported in parts per million relative to tetramethylsilane as internal standard. Gas chromatography was carried out with Varian Aerograph instruments (Hy-Fi 1700, 1800, and 1200) by means of the columns listed in Table II.

Table II. Glpc Columns

Column	Dimensions ft, in.	Packing
1	10, 0.25	15% Carbowax 20M on Chromosorb W (45–60 mesh)
2	8, 0.25	SF-96 and Bentone 34 on A–W Chromosorb W (30–60 mesh)
3	10, 0.25	15% UCON-50HB2000 and 5% NaOH on Chromosorb W (30–60 mesh)
4	6, 0.25	10% tetraethylenepentamine on Porapak Q (60–80 mesh)

Quantitative glpc was accomplished by comparison of peak areas of known solutions of authentic materials with those of solutions of crude products. Positive chlorine content in solutions of *N*-chloro compounds was determined by standard iodometric titration.[22] Melting points and boiling points are uncorrected. Elemental analyses were performed by Micro-Tech Laboratories, Skokie, Ill. The titrimetric method for basic products involved a modified Kjeldahl procedure.[38] After the volatile amines were distilled into hydrochloric acid, water was removed by evaporation under reduced pressure. The hydrochloride, dried at 110°, was weighed, made basic, and then distilled into a dilute boric acid solution. Titration was carried out potentiometrically with standardized hydrochloric acid.

Tri-*n*-butylacetonitrile. A literature procedure[18] afforded a 42% yield of product, bp 78–80° (0.5 mm) [lit.[18] bp 126–128° (4.6 mm)].

Tri-*n*-butylacetamide.[18] A published procedure yielded 60% of desired material, bp 148–150° (1 mm) [lit.[18] bp 160–162° (3.5 mm)]. The distillate slowly changed to a waxy solid, mp 56–58° (lit.[18] mp 57–59°).

Tri-*n*-butylcarbinamine (Hofmann Degradation). A previous method[19] was employed except that the isocyanate was not isolated. The amine was obtained in 65% yield: bp 78–80° (0.5 mm) [lit.[19] bp 78–80° (0.5 mm)]; ir (neat) 3300 (NH), 1610 (NH), and 810 cm^{-1} (NH); nmr (CCl$_4$) δ 1.3 (m, 18, CH$_2$), 1.0 (m, 9, CH$_3$), and 0.7 (m, 2, NH, exchangeable with D$_2$O).

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(37) C. M. Sharts, *J. Org. Chem.*, **33**, 1008 (1968).

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Tri-*n*-butylcarbinol. Use of a prior procedure[21] provided 75% of the alcohol: bp 89–91° (0.5 mm) [lit.[21] bp 129–131° (20 mm)]; ir (neat) 3420 (OH), 1145, 990 (CO), 905, 787, and 728 cm^{-1}; nmr ($CDCl_3$) δ 1.3 (m, 18, CH_2), 1.2 (s, 1, OH, exchangeable with D_2O), and 0.9 (m, 9, CH_3).

Tri-*n*-butylcarbinamine (Ritter Reaction). A published procedure[20] was followed with tri-*n*-butylcarbinol to yield 71% of basic product, bp 71–74° (0.2 mm) [lit.[19] bp 78–80° (0.5 mm)].

5-*n*-Butyl-4-nonene. A literature method[39] yielded 60% of alkene: bp 98–101° (15 mm) [lit.[39] bp 100–102° (17 mm)]; ir (neat) 880 (C=CH) and 720 cm^{-1}; nmr ($CDCl_3$) δ 5.1 (t, 1, C=CH), 2.0 (m, 6, $C{=}CCH_2$), 1.3 (m, 10, CH_2), and 0.9 (m, 9, CH_3).

α-Chloro-di-*n*-butyl Ketone. A solution of chlorine in acetic acid (170 ml, 0.45 mol) was added to a mixture of di-*n*-butyl ketone (10 g, 0.07 mol) in 50 ml of glacial acetic acid at 20° followed by stirring for 2 hr at the same temperature. After the addition of methylene chloride (100 ml), 50% sodium hydroxide solution (190 ml) was added. The layers were separated, and the aqueous phase was washed twice with methylene chloride. The combined organic layer was washed with water, dried with sodium sulfate, and evaporated. The residue was distilled, yielding 8 g (70%) of α-chloro-di-*n*-butyl ketone:[40] bp 92–94° (12 mm); 95% pure, column 3; ir (neat) 1715 (C=O), 1260, 1045, 885, and 755 cm^{-1} (CCl); nmr ($CDCl_3$) δ 4.2 (t, 1, COCHCl), 2.5 (m, 2, CH_2CO), 1.4 (m, 8, CH_2), and 0.9 (m, 6, CH_3).

***N,N*-Dichlorotri-*n*-butylcarbinamine. Procedure I.** A solution of 10 g (0.05 mol) of tri-*n*-butylcarbinamine in 100 ml of methylene chloride was added at 0° to 13.3 g of HTH (70% calcium hypochlorite, 0.13 mol of positive chlorine) in 150 ml of water.[22] The mixture was stirred for 10 hr at 0°, and then 70 ml of 1.2 *M* hydrochloric acid was added. The layers were separated, the aqueous portion was washed with methylene chloride, and the combined phase was dried with sodium sulfate. Yields of 74–78% of the *N,N*-dichloroamine were obtained, as indicated by titration for positive chlorine.

Procedure II. To a suspension of 5 g (25 mmol) of tri-*n*-butylcarbinamine and 6.65 g of HTH (70% calcium hypochlorite, 65 mmol of positive chlorine) in 50 ml of methylene chloride was added 30 ml of 1.2 *M* hydrochloric acid at 0°. After 1 hr of stirring, 35 ml of 1.2 *M* hydrochloric acid was added, and the layers were separated. The aqueous portion was washed with methylene chloride, and the combined organic phase was dried with sodium sulfate. Yields of 90–98% of the *N,N*-dichloroamine were obtained, as indicated by titration for positive chlorine. Crude product: ir (neat) 960, 895, and 710 cm^{-1} (NCl); nmr (CCl_4) δ 1.5 (m, 18, CH_2) and 1.0 (m, 9, CH_3).

***N,N*-Dichlorotri-*n*-butylcarbinamine and Aluminum Chloride. General Procedure A.** A solution of the *N,N*-dichloroamine (*ca.* 0.05 mol) in 125 ml of dry methylene chloride was slowly added with vigorous stirring to a slurry of aluminum chloride (13.4 g, 0.1 mol) in 250 ml of dry methylene chloride at 0°. After the mixture was stirred for 2 hr at 0°, 250 ml of ice-cold 18% hydrochloric acid was added at −10–0°. The mixture was stirred for 3 hr while the temperature rose to room temperature. The acidic layer was separated and extracted twice with methylene chloride. The combined organic extract was washed with water, dried with sodium sulfate, and evaporated to afford a viscous oil. Steam distillation of the oil gave 2.7 g (47%) of di-*n*-butyl ketone (97% pure). The nonvolatile residue was worked up as described in general procedure C to yield 2.9 g (29%) of tri-*n*-butylcarbinamine and 3 g of a black residue.

Anal. Found: C, 58.01; H, 8.69; N, 3.23; Cl, 22.31.

The acidic aqueous layer yielded 0.6 g of a black, gum-like substance, estimated to contain 65% of *n*-butylamine hydrochloride (about 7% yield) as indicated by nmr analysis and the modified Kjeldahl procedure.

General Procedure B. General procedure A was followed except that after reaction the methylene chloride was removed at reduced pressure at 20° and then the mixture was stirred for 8 hr with hydrochloric acid.

General Procedure C. Anhydrous aluminum chloride (6.7 g, 0.05 mol) was added quickly to a solution of *N,N*-dichlorotri-*n*-butylcarbinamine (*ca.* 0.025 mol) in 60 ml of dry methylene chloride which had been precooled to −50°. The temperature quickly rose to −30°, and stirring was maintained at that temperature for 1.5 hr. The temperature was lowered to −50°, and 50 ml of concentrated hydrochloric acid was added. The methylene chloride was removed *in vacuo* at about 20°. The reaction mixture was then steam distilled for 1 hr, and the distillate was extracted with methylene chloride. The solution was dried over sodium sulfate and freed of solvent by evaporation to afford 3.4 g (88%) of di-*n*-butyl ketone (89% pure according to glpc analysis, column 1). The steam distillation residue was extracted with methylene chloride, and the layers were separated. The organic extract was washed with water, dried with sodium sulfate, and evaporated to afford a light-brown viscous oil. The oil was made basic with 50% sodium hydroxide and extracted with methylene chloride. Following evaporation of solvent from the organic extract, the residue was distilled with a Minilab apparatus to yield 0.2 g (4%) of tri-*n*-butylcarbinamine, bp 72–74° (0.2 mm) [lit.[19] bp 78–80° (0.5 mm)]. Distillation residue consisted of a black solid, 0.2 g

Evaporation of the acidic aqueous layer from the steam distillation residue gave salts which were then dissolved in a minimum amount of water and added to 50% sodium hydroxide (60 ml). The mixture was steam distilled into hydrochloric acid. After evaporation, 2.0 g (77%) of *n*-butylamine hydrochloride, mp 193–194.5° (lit.[41] mp 195°), remained. This was shown to be about 99% pure according to quantitative nmr and the modified Kjeldahl procedure.

General Procedure D. General procedure A was followed except that after reaction the methylene chloride was removed at reduced pressure at 20° and then the mixture was stirred for 8 hr with hydrochloric acid. Unless otherwise indicated, yields of rearranged products are based on the assumption that the starting material is a mixture of *N,N*-dichloroamine and some *N*-monochloroamine.

Control Experiments for the Work-up Procedure. 1. Di-*n*-butyl Ketone and Tri-*n*-butylcarbinamine Hydrochloride. A mixture of 0.58 g of tri-*n*-butylcarbinamine hydrochloride and 0.23 g of di-*n*-butyl ketone was subjected to steam distillation. Both compounds were recovered quantitatively.

2. Recovery of *n*-Butylamine Hydrochloride. A mixture of 5.5 g (0.05 mol) of *n*-butylamine hydrochloride and 24.1 g of hydrated aluminum chloride (0.1 mol), dissolved in the minimum amount of water, was added to 60 ml of 50% sodium hydroxide. The mixture was steam distilled into hydrochloric acid. After evaporation, 5.4 g of *n*-butylamine hydrochloride remained.

Product Identification. Di-*n*-butyl Ketone. Comparison with authentic material showed identical ir and nmr spectra. Peak enhancement in glpc was noted after addition of authentic material to a sample of crude reaction product (column 1).

***n*-Butylamine.** The indicated techniques were used: glpc, nmr, and titration (see Analytical Procedures). The salt from general procedure C, −30° run (1.5 hr), melted at 193–194.5° (lit.[41] mp 195°). Mixture melting point with authentic material showed no depression. The nmr spectrum of the hydrochloride was identical with that of authentic material. The free amine, formed by treatment of the hydrochloride with concentrated sodium hydroxide, was extracted with ether. Peak enhancement in glpc was noted after addition of authentic material to the ether extract (columns 3 and 4). Glpc analysis revealed that no more than 1% of *sec*- and *tert*-butylamines was present.

Stability of Rearranged Product in Solution. In two runs involving general procedure A, the organic layer after hydrolysis was analyzed for positive chlorine content. The amounts were 68 and 70% based on structure **5** as the end form of the rearranged product. The positive halogen was not present as molecular chlorine since the same percentage value was obtained after the volume of the solution was reduced by half through evaporation. In another experiment, the organic layer was stored for 2 days after exposure to aqueous acid. Glpc (column 1) revealed two major peaks, representing di-*n*-butyl ketone and the α-chloro derivative, 60/40 (peak areas). With longer storage time, an increase in the proportion of α-chloro compound was noted.

5-*n*-Butyl-4-nonene and Aluminum Chloride. A solution of 5-*n*-butyl-4-nonene (1 g, 0.005 mol) in 15 ml of dry methylene chloride was added slowly to anhydrous aluminum chloride (0.7 g, 0.005 mol) in 15 ml of dry methylene chloride. The mixture was stirred for 2 hr at 0° and then 25 ml of 18% hydrochloric acid was added slowly at 0°. After the mixture was stirred for 3 hr,

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the layers were separated. On evaporation, the organic phase afforded 1 g of a brown liquid which by glpc analysis showed no unchanged starting material.

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Reactions of General Bases and Nucleophiles with Bis(*p*-nitrophenyl) Methylphosphonate

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Abstract: Primary, secondary, and tertiary amines react with bis(*p*-nitrophenyl) methylphosphonate (b-*p*-NPMP) (I) *via* general base catalysis of water attack (eq 1). The rate law is first-order in substrate and in amine. One mole of b-*p*-NPMP yields quantitatively 1 mol of *p*-nitrophenyl methylphosphonate (VI) and 1 mol of *p*-nitrophenol (*p*-NP) or its anion depending on pH. The rates of formation of VI and *p*-NP are identical. Solvent deuterium isotope effects, $k_2(H_2O)/k_2(D_2O)$, are greater than 2 for amine reactions. Different classes of amines follow a Brønsted relation with a slope of 0.38. *s*-Collidine falls below the Brønsted line but is as reactive as pyridine. Fluoride ion and several oxyanions react with I by a nucleophilic mechanism. At high fluoride ion concentration, 2 mol of *p*-NP is released in a first-order process. At lower fluoride concentrations less than 2 mol of *p*-NP is produced. II, a product of initial fluoride ion attack, can react with a second mole of fluoride *or* other bases in solution. *p*-Methoxyphenolate anion reacts with I in two kinetically separable reactions, releasing 2 mol of *p*-NP. Benzohydroxamate anion releases 2 mol of *p*-NP in a first-order process. Phosphate and hydroxide anions produce 1 mol of *p*-NP and VI probably in nucleophilic processes. $k_2(H_2O)/k_2(D_2O)$ for the reactions of fluoride and phosphate ions with b-*p*-NPMP $\cong$ 1.00–1.15. Steric crowding in the transition state can be invoked to explain the reactions of amines with I *via* a general base mechanism and the reactions of fluoride anion and oxyanions with I *via* a nucleophilic mechanism.

The question of the relative importance of general base and nucleophilic catalysis in displacement reactions at the tetrahedral organophosphorus center is most intriguing. Reactions of neutral esters have been shown to proceed by both pathways.[1-5] The factors which determined whether a nucleophilic or general base mechanism obtains have only just begun to be assembled.[1-5] Of particular interest are the reactions of amino groups in enzyme-catalyzed reactions.[6] We will demonstrate that the reactions of nitrogen bases with bis(*p*-nitrophenyl) methylphosphonate (I) occur by general base catalysis of water attack, while fluoride ion and oxyanions react *via* a nucleophilic mechanism.

Experimental Section

Bis(*p*-nitrophenyl) methylphosphonate (b-*p*-NPMP) and *p*-nitrophenyl methylphosphonate (*p*-NPMP) were synthesized as previously reported:[7] b-*p*-NPMP, mp 127–129°; nmr (CDCl$_3$) δ 1.98 (d, 3), 7.82 (q, 8); *p*-NPMP, mp 112–113°; nmr (CDCl$_3$) δ 1.63 (d, 3), 7.71 (q, 4), 12.18 (s, 1).

Commercial piperidine hydrochloride was recrystallized from absolute ethanol, *n*-butylamine hydrochloride from ethanol–hexane, and imidazole from benzene. *s*-Collidine hydrochloride was prepared by bubbling hydrogen chloride gas through *s*-collidine dissolved in hexane. The hydrochloride was filtered and recrystallized from 1-butanol. Pyridine was distilled from potassium hydroxide under reduced pressure (2 mm) and aziridine (Dow Chemical Co.) was distilled from potassium hydroxide at atmospheric pressure. Hydrazine dihydrochloride and ammonia (0.1 *M* standardized) were Fisher Certified Reagents and used without further purification. Benzohydroxamic acid (Aldrich Chemical Co.) was recrystallized from ethyl acetate[8] and *p*-methoxyphenol from 1-butanol. Deuterium oxide, 99.8% purity, was obtained from Bio-Rad Laboratories. Acetonitrile was Mallinckrodt Nanograde. All other materials were of reagent grade and used without further purification.

Phosphate and carbonate buffers were prepared according to the procedures in the Biochemists Handbook.[9] For amines, partially neutralized solutions (usually 0.5 or 0.1 neutralized) of the nitrogen bases were used as buffers. Standardized hydrogen chloride and sodium hydroxide solutions were used to neutralize amines as the free base or as the hydrochloride, respectively. Potassium chloride was employed to maintain ionic strength at 0.5 *M*. Approximately 10^{-4} *M* EDTA was added to all solutions. pH measurements were made on a Radiometer Model 26 pH meter. Desired pH values were easily maintained since low substrate concentrations were used.

Spectra. Nmr spectra were recorded on a Varian T-60 instrument. Ultraviolet spectra were obtained on a Cary 14 spectrophotometer. A pK_a value of 7.15 for *p*-nitrophenol was employed;[10] spectra of *p*-nitrophenol[11] and *p*-nitrophenolate anion[7] yielded absorbance maxima at 317 nm (ε 9500) and 400 (18,200), respectively. *p*-Nitrophenyl methylphosphonate had a maximum

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