RELATIVE RATES OF ABSTRACTION OF CHLORINE BY PHENYL RADICALS FROM N-CHLORAMIDES

by

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I. Introduction and Literature Survey

It was the purpose of this study to determine the relative rates of chlorine abstraction from various N-chloro-N-substituted amides and to probe the facility with which amido radicals might undergo decomposition via a unimolecular β-elimination reaction. The formation and subsequent reactions of acylamino or amido radicals have been the subject of several studies including photolytic investigations on the N-nitrosamides, RCON(NO)R',[1-4] and the N-halamides, RCONXR'.[5-9] In most of these studies the R and R' groups were simple alkyl or aryl groups and the major subsequent reaction of the amido radical was one of hydrogen abstraction with formation of the parent amide. There was also some α-hydrogen elimination resulting in an alkylidenimide[2] which was isolated in the trimer form (eq. 1). In the studies where

(1) $$CH_3(CH_2)_4-\overset{O}{\overset{\|}{C}}-\underset{NO}{N}-CH_3 \xrightarrow{h\nu} CH_3(CH_2)_4-\overset{O}{\overset{\|}{C}}-\dot{N}-CH_3 \longrightarrow \left[CH_3(CH_2)_4-\overset{O}{\overset{\|}{C}}-N=CH_2\right]_3$$

R and/or R' were alkyl chains of four or more carbons, photolytic rearrangements occurred yielding isomeric 4-nitrosamides[2] with the nitroso group on the alkyl portion of the amide (eq. 2). Similar

(2) $$CH_3-\overset{O}{\overset{\|}{C}}-\underset{NO}{N}-(CH_2)_3CH_2CH_2CH_3 \xrightarrow[C_6H_6]{h\nu} CH_3-\overset{O}{\overset{\|}{C}}-\dot{N}-(CH_2)_3CH_2CH_2CH_3 \longrightarrow$$

$$\left[CH_3-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-(CH_2)_3-\underset{NO}{CH}-CH_2CH_3\right]_2 \xleftarrow{NO} CH_3-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-(CH_2)_3\dot{C}HCH_2CH_3$$

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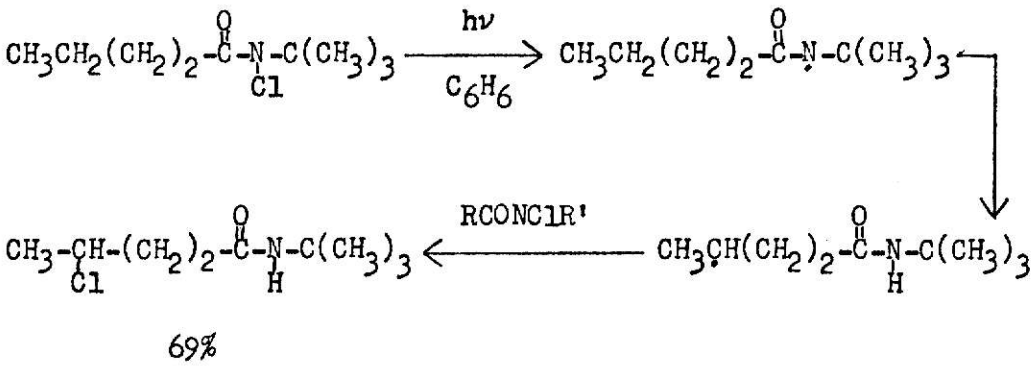
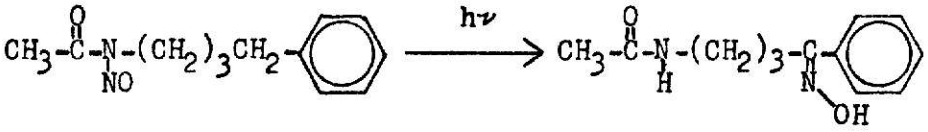
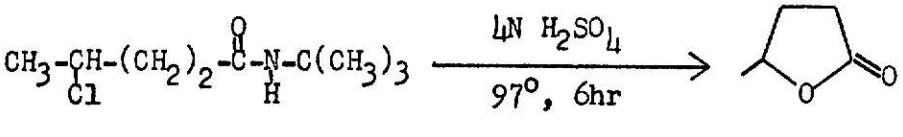
rearrangements occurred in the N-halamides[9] with the halogen ultimately residing on the C-4 in the acyl portion of the amide (eq. 3). In other

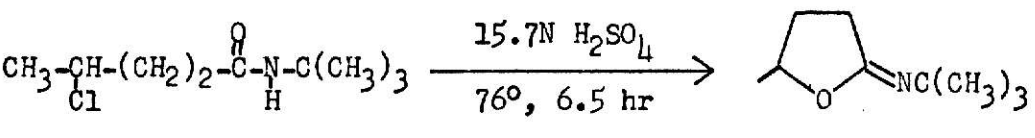
(3) 

instances an oximino amide[2] was formed and where cyclization was more favored lactone,[9] iminolactone,[9] or oxazoline[9] resulted. The oximino amide resulted (eq. 4) from photolysis of a nitrosamide in petroleum

(4) 

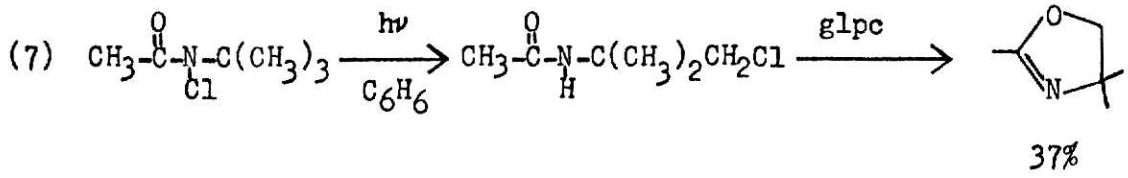
ether by a mechanism similar to that shown in equation 2. The lactone and iminolactone were formed (eqs. 5 & 6) by acid treatment

(5) 

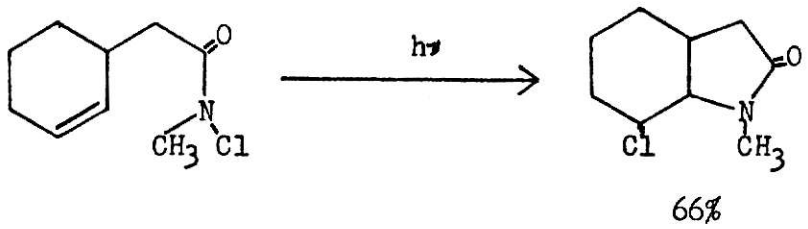
(6) 

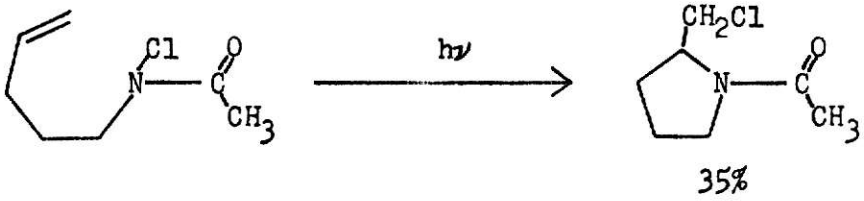
of the rearranged product in eq. 3. The oxazoline was formed (eq.7) during the glpc analysis of reaction products from the photolysis of

N-chloro-N-tert-butylacetamide. Kuehne and Horne[7] have shown that

(7) 

photolytic cyclization of olefinic N-chloramides results in the formation of chlorine substituted lactams and N-heterocyclic amides (eqs. 8 & 9).

(8) 

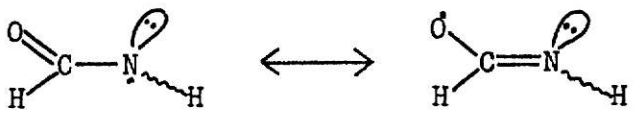
(9) 

Since these stereospecific intramolecular hydrogen abstraction reactions have been shown to give fairly good yields, more emphasis has been placed on the study of their usefulness in organic syntheses rather than on the investigation of the amido radicals involved. The amido radical, its formation, structure, and reactivity, is of considerable importance not only in the above synthetic reactions but also because of the consequences of its possible formation in biological systems.

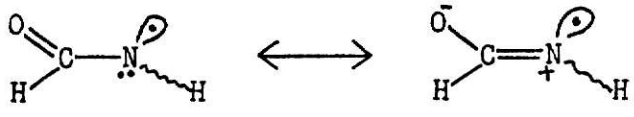
The amide bond is a very common and essential chemical bond in living systems since it is responsible for linking the amino acids into protein molecules. The amide functional group could potential-

ly be transformed into an amido radical by a free radical attack from the normal pool of free radicals present in the living system, or by some type of high frequency radiation such as ultraviolet, x-rays, or gamma rays. The subsequent reaction of this amido radical could cause denaturation of the protein and thus could lead to serious consequences depending on the type of protein involved.

Whereas the electronic features of free radicals formed from most common organic functional groups have been rather well-characterized, there has been much controversy as to the electronic structure of the ground state of the amido radical. On the basis of semiempirical INDO calculations, Koenig, et al.,[10] presented three possible structures for the amido radical. In the π radical (10) the unpaired electron is



(10)



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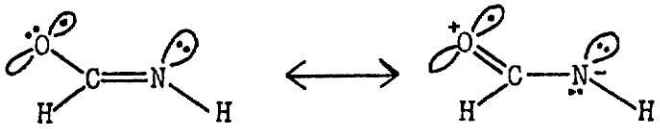
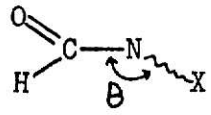


(12)

capable of entering into conjugation with the π bond of the carbonyl group while in the $\sum_N$ radical (11) it is the lone pair that enters into the conjugation with the carbonyl bond. The $\sum_O$ radical (12) results from the unpaired electron residing on the oxygen atom with the

oxygen donating a lone pair of electrons to the OCN conjugated system.

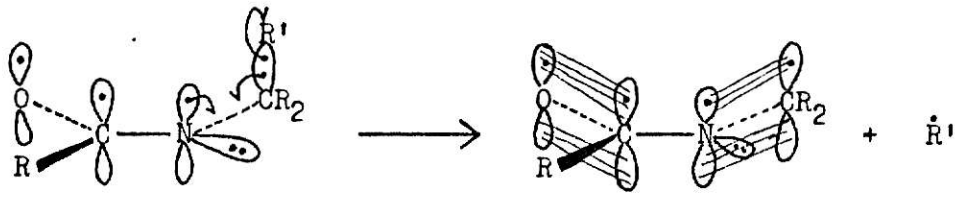
Koenig, et al.,[10] were concerned with the C-N-X angle, θ, and the dependence of the structure of the amido radical on θ. The INDO cal-

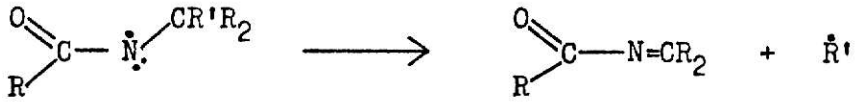


culations performed for the formamido, N-hydroxy formamido and N-methyl formamido radicals showed the π radical to be the more favored structure with $\theta \sim 114\text{-}120^{\circ}$. In the case where $X=CH_3$ the π radical was still favored but by a lower energy value. From this they predicted the possibility of steric effects causing the angle to increase and tending toward the more favorable Σ_N at $\theta = 180^{\circ}$.

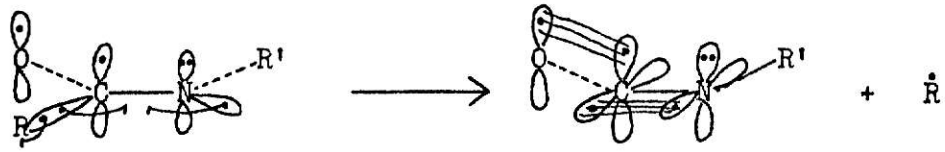
In 1972, Danen and Gellert[11] published evidence which suggested that the amido radical exists in the π electronic state. This was the result of an esr study of N-chloro-N-methyl-t-butylamide and N-chloro-N-t-butylacetamide. Although their results suggested a π electronic ground state it was also evident that there was little delocalization of the unpaired electron into the carbonyl π system. A related C^{13}-CIDNP study[12] in 1975 on the N-methylbenzamido radical supported the π electronic ground state. Danen and Neugebaur[13] have compiled a review on various amino free radicals including discussions of reactivities, reaction types, and structure.

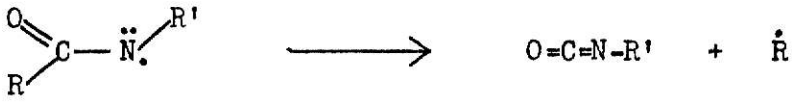
The electronic structure of the amido radical is important in determining its subsequent reactions, particularly β-scission reactions. If the π radical is favored β-scission would more likely occur in the N-alkyl group forming an alkylidenimide (eqs. 13 & 14).

(13) 

(14) 

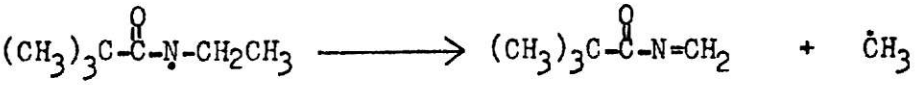
β-Scission of the acyl portion with formation of an isocyanate would be the more favored reaction of the Σ_N radical (eqs. 15 & 16). In

(15) 

(16) 

view of either type of β-scission occurring in a peptide linkage it could result in the less of a substituent group or the complete scission of the peptide chain.

Evidence of alkyl β-scission has previously been detected by both Gellert[14] and West[15] in this laboratory in their esr studies of amido radicals. Gellert obtained esr evidence of β-scission occurring in the N-ethylpivalamido radical by the presence of the methyl radical (eq. 17). West obtained evidence of a similar β-scission

(17) 

using ethyl-N-methoxycarbamate which formed carboethoxymethyl nitroxide presumably via methyl elimination and then recombination (eq. 18).

(18) $C_2H_5O-\overset{O}{\overset{\|}{C}}-\dot{N}-O-CH_3 \longrightarrow C_2H_5O-\overset{O}{\overset{\|}{C}}-N=O + \dot{C}H_3 \longrightarrow C_2H_5O-\overset{O}{\overset{\|}{C}}-\overset{\cdot\cdot}{N}-CH_3$

As noted above it was the purpose of this study to determine the relative rates of chlorine abstraction from N-chloro-N-substituted amides and, secondly, to probe briefly into the facility by which amido radicals undergo decomposition via β-elimination. The chlorine was abstracted by phenyl radicals formed from the decomposition of phenylazotriphenylmethane (PAT) at 60°C. An extensive search of the literature did not reveal any type of study dealing with the relative rates of formation of substituted amido radicals.

The halogen abstraction method of forming a radical is an extremely valuable method to use when a specific radical site is desired.[16] Although hydrogen abstraction by free radicals has been studied extensively, most compounds have two or more abstractable hydrogens and hence, the site of radical formation may be indefinite if formed by hydrogen abstraction. Using the hydrogen abstraction method on the N-monosubstituted amides, the more facile abstraction would be that of the hydrogen from the α-carbon of the N-alkyl group or the acyl group rather than from the nitrogen. Such results were obtained by Hayon, et al.,[17] in their studies of hydrogen abstraction from amides using the hydroxyl radical in an aqueous system. Their results showed that in certain amides the rate of hydrogen abstraction from either α-carbon (19 or 20) was an order of magnitude greater than from the

$R-\dot{C}H-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-CH_3$ (19)

$R-CH_2-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-\dot{C}H_2$ (20)

$R-CH_2-\overset{O}{\overset{\|}{C}}-N-CH_3$ (21)

nitrogen (21). Therefore the need existed to use the halogen abstraction method on the N-chloro-N-substituted amides to be certain that the amido radical was being formed. Since N-chloramides are not difficult to prepare, this is a convenient method of generating the amido radical by an abstraction technique.

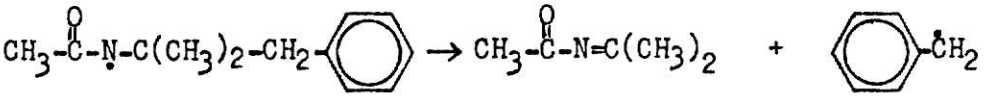
As mentioned previously a search of the literature revealed that most amido radical reaction studies have been concerned with hydrogen abstraction either intramolecularly or intermolecularly from the amide or the solvent. In this study the solvent used primarily was benzene which is a poor hydrogen atom donor[3] and the N-chloramides chosen for study were such that intramolecular hydrogen abstraction was unlikely. Therefore major consideration was given to β-scission and to intermolecular hydrogen abstraction from the amide.

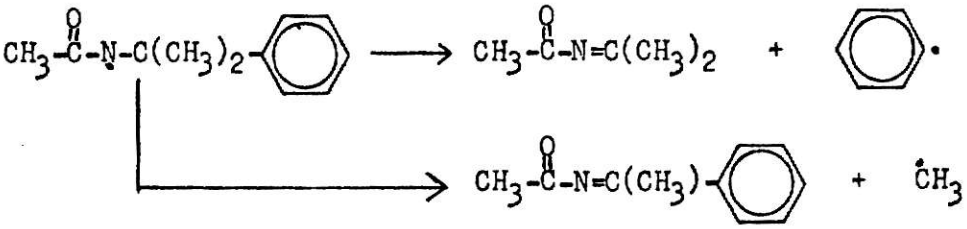
It has been shown in studies of peroxide decomposition[18] that where β-scission is more highly favored the rate is greatly increased. This is shown by the following reaction rate comparisons (eqs. 22-24).

	Peroxide	Relative Rate
(22)	$\underline{t}\text{-BuO-O-}\overset{\overset{O}{\|}}{C}\text{-CH}_3 \longrightarrow \underline{t}\text{-BuO}\cdot + \cdot\text{O-}\overset{\overset{O}{\|}}{C}\text{-CH}_3$	1
(23)	$\underline{t}\text{-BuO-O-}\overset{\overset{O}{\|}}{C}\text{-CH}_2\text{Ph} \longrightarrow \underline{t}\text{-BuO}\cdot + CO_2 + \cdot\text{CH}_2\text{Ph}$	1,340
(24)	$\underline{t}\text{-BuO-O-}\overset{\overset{O}{\|}}{C}\text{-CH(Ph)}_2 \longrightarrow \underline{t}\text{-BuO}\cdot + CO_2 + \cdot\text{CH(Ph)}_2$	22,000

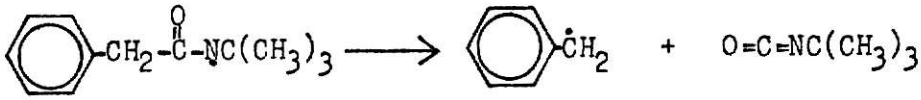
Since β-scission is possible in the N-chloramides then it is logical to assume that where the R and R' groups would easily lend themselves to a concerted β-scission the rate of chlorine abstraction should

increase. For example in N-chloro-N-(1,1-dimethyl-2-phenethyl)acetamide where β-scission would result in a relatively stable benzyl radical (eq. 25) this rate would be faster than in N-chloro-N-α,α-dimethylbenzylacetamide where β-scission would result in a destabilized phenyl radical or methyl radical (eq. 26). In the other

(25) 

(26) 

type of β-scission, that more similar to the perester decomposition, the rate would be faster for the N-chloro-N-t-butylphenylacetamide resulting in a stabilized radical (eq. 27) than for N-chloro-N-t-butylbenzamide resulting in a destabilized radical (eq. 28). The

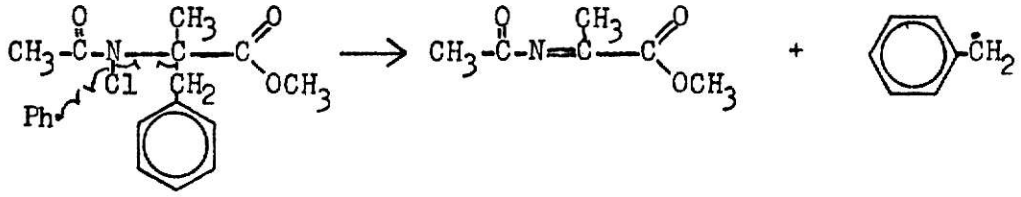
(27) 

(28) 

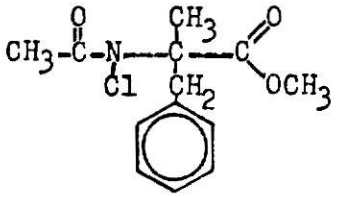
stabilized radical[19] has a positive stabilization energy and allows for delocalization of the unpaired electron while the destabilized radical has a negative stabilization energy and does not allow for delocalization of the unpaired electron. The stabilization energies of these two types of radicals are defined in reference to that for the ethyl radical which is zero. Since the stabilization energy of the stabilized radical is positive, β-scission resulting in a sta-

bilized radical would be more likely to occur than where it would result in a destabilized radical.

By combining the driving forces of a concerted β-scission and of the formation of a conjugated -enedione system the rate of chlorine abstraction could conceivably be greatly increased. The rate of chlorine abstraction from N-chloro-N-(1-methyl-1-benzyl methylacetate) acetamide (eq. 29) could be much greater than in the case of where

(29) 

only a benzyl radical is eliminated. This particular N-chloramide (30) has a structure similar to a dipeptide. It contains in part the common



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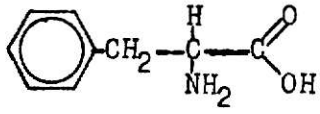


(31)

amino acid phenylalanine (31). Although it would be necessary to methylate the α-carbon and esterify the carboxyl group of this amino acid in the N-chloramide to prevent undesirable side reactions in the present studies, the benzyl moiety would still be free for β-elimination. Rates of chlorine abstraction from these types of N-chloramides could give some indication as to types and rates of amido radical reactions possible in proteins.

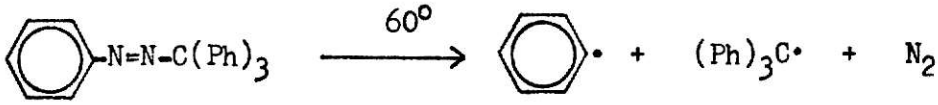
II. Kinetic Studies

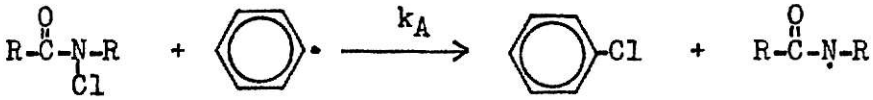
A. Results

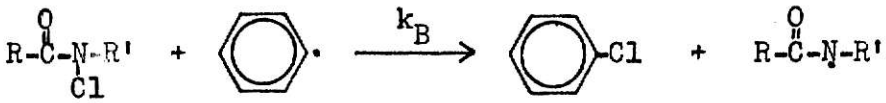
The N-chloro-N-substituted amides were prepared by a reaction of the parent amide with tert-butylhypochlorite in carbon tetrachloride solvent[9] (eq. 32). Several amides proved difficult to chlorinate in which case tert-butylhypochlorite was used also as the solvent with a few drops of bromine added as a catalyst.

(32) $$R\text{-}\overset{O}{\overset{\|}{C}}\text{-}\underset{H}{N}\text{-}R' \xrightarrow[\text{or } t\text{-BuOCl, } Br_2 \text{ (trace)}]{t\text{-BuOCl, } CCl_4} R\text{-}\overset{O}{\overset{\|}{C}}\text{-}\underset{Cl}{N}\text{-}R'$$

Phenyl radicals were generated by the thermal decomposition of phenylazotriphenylmethane (PAT) at 60°C in benzene solvent (eq.33) with the presence of two N-chloramides, A (eq. 34) and B (eq. 35).

(33) 

(34) 

(35) 

With both N-chloramides available for attack by the phenyl radical a measure of the initial and final concentrations of both N-chloramides would indicate the relative rate of chlorine abstraction. It was not necessary to determine the exact initial and final concentrations since the ratio of initial to final concentration could be used to calculate

the relative rate constants. This ratio was determined by integration of appropriate peaks in the nmr spectra. An internal standard was used in the recording of each nmr spectrum to eliminate error introduced by the nmr spectrometer. The ratios of the area of one peak of amide A to the internal standard S before (A_o) and after (A_t) the reaction were calculated. The log of the two ratios calculated for amide A was divided by the log of the two ratios calculated for amide B (eq. 36) to determine k_A/k_B, the relative rate ratio.

$$\frac{\log \dfrac{(A_o/S)}{(A_t/S)}}{\log \dfrac{(B_o/S)}{(B_t/S)}} = k_A/k_B \tag{36}$$

This equation was proposed by Bunnett[20] for use where there is direct competition between two reactants for the attack of a third reactant. If it is first order in F and first order in both A and B then it is a second order reaction and equation (37) may be used if the

$$F + A \longrightarrow X$$

$$F + B \longrightarrow X$$

$$\frac{-d[A]}{-d[B]} = \frac{k_A[A]}{k_B[B]} \xrightarrow{\text{integration}} (37) \quad \frac{\log [A]_o/[A]_t}{\log [B]_o/[B]_t} = k_A/k_B$$

concentrations of both A and B change appreciably in the reaction. This same equation was successfully used by Walsh and Kuivila[21] in determining competitive rates of halogen abstraction from aryl and alkyl halides using the tri-n-butyl tin radical.

Though the use of this nmr technique in determining the ratios of initial and final concentrations was a relatively easy method to use there were certain disadvantages involved, namely peak overlap and inability to get good resolution on some of the spectra. For some N-chloramides the relative rates could not be calculated due to nearly identical chemical shifts occurring in the two N-chloramides thus causing a complete peak overlap.

There were at least four runs and usually six runs performed in determining each rate ratio value. The standard deviation was calculated according to equation (38)[22] for each set of runs and varied from 0.045 to 0.46 with the average value being ca. 0.19. To

$$S = \sqrt{\frac{\sum(X_n - \bar{X})^2}{(n - 1)}} \qquad (38)$$

n = number of runs
X_n = rate ratio for run number n
$\bar{X}$ = average rate ratio

determine whether a rate ratio value for a certain run, X_n, should be retained equation (39)[22] was used. If the t_i was greater than the

$$t_i = \frac{|X_n - \bar{X}|}{R} \qquad (39)$$

X_n = rate ratio value in question
$\bar{X}$ = average rate ratio
R = range of rate ratio values

theoretical value of t_i for a given n value then the X_n value must be discarded. Applying this method to the obtained data it was found that none of the X_n values had to be eliminated. Therefore, it seems that the method used in obtaining the rate ratios was reliable although the results exhibited somewhat less precision than ideally desired.

The first series of N-chloramides studied was that of the rate of chlorine abstraction from N-chloro-N-tert-butylacetamide compared to that of N-chloro-N-methylacetamide, N-chloro-N-1,1-dimethyl-2-phenethylacetamide and N-chloro-N-α,α-dimethylbenzylacetamide (Table I).

Table I

Relative Rate of Chlorine Abstraction from Representative N-Chloramides

Amide: RCONClR'		Relative Rate
R	R'	
CH_3	$C(CH_3)_3$	1.00
CH_3	CH_3	0.641
CH_3	$C(CH_3)_2CH_2Ph$	1.22
CH_3	$C(CH_3)_2Ph$	1.28

The results showed that even though β-scission is favorable where R' = $C(CH_3)_2CH_2Ph$ the relative rate of chlorine abstraction was similar to the amide R' = $C(CH_3)_2Ph$ for which a concerted elimination was unlikely. These preliminary data suggested a steric influence on the rates of chlorine abstraction.

Since the preliminary data did seem to follow the trend of increased rate with increased bulkiness of R', such a series of N-chloro-N-substituted amides was synthesized and subjected to chlorine abstraction. The results are tabulated in Table II. Rates relative to both N-chloro-N-methylacetamide and to N-chloro-N-tert-butylacetamide were calculated. Throughout the remainder of this paper reference will be made only to the rates relative to N-chloro-N-methylacetamide. This amide was preferred because of considerable overlap of

Table II

Relative Rates of Chlorine Abstraction by the Phenyl Radical from N-Chloramides at 60°C

No. n	R	Amide: RCONClR' R'	k_1/k_n [a]	S [b]	R [c]	k_7/k_n [d]	S [e]	C [f]
1.	CH_3	CH_3			1.00	1.56	0.33	
2.	CH_3	CH_2CH_3	2.48	0.46	0.40			
3.	CH_3	$CH_2CH_2CH_3$	1.59	0.17	0.63			
4.	CH_3	CH_2CH_2Ph	1.17	0.19	0.86	1.62	0.21	0.722
5.	CH_3	$CH(CH_3)_2$	1.15	0.18	0.87			
6.	CH_3	$CH_2C(CH_3)_3$	0.944	0.23	1.05	1.36	0.18	0.694
7.	CH_3	$C(CH_3)_3$	0.641	0.33	1.56			
8.	CH_3	$C(CH_3)_2CH_2Ph$	0.524[g]		1.91	0.817	0.04	
9.	CH_3	$C(CH_3)_2Ph$	0.498[g]		2.01	0.777	0.11	
10.	CH_3	$C(CH_3)(COOCH_3)CH_2Ph$	0.341	0.045	2.93			
11.	$PhCH_2$	$C(CH_3)_3$	0.462	0.15	2.16	0.752	0.27	0.614
12.	Ph	$C(CH_3)_3$	0.265	0.057	3.77			
		Amine						
13.	N-chloro-2,2,6,6-tetramethylpiperidine		1.31	0.23	0.76			

Table II continued,

a The experimentally determined rate ratio of N-chloro-N-methylacetamide to the n N-chloramide.

b The calculated standard deviation of the experimentally determined rate ratio in a.

c The rates of chlorine abstraction relative to N-chloro-N-methylacetamide.

d The experimentally determined rate ratio of N-chloro-N-tert-butylacetamide to the n N-chloramide.

e The calculated standard deviation of the experimentally determined rate ratio in d.

f The cross-check value calculated from equation 40.

g These two rate ratios are calculated values from the experimentally determined k_7/k_8 and k_7/k_9 values by the use of the cross-check value. They were not determined directly due to lack of sufficient amount of the N-chloramides 8 and 9.

peaks of different amides with N-chloro-N-tert-butylacetamide on the nmr spectra. However this latter amide was used where possible to serve as a cross-check on the relative rates. The cross-check value was calculated according to equation (40). There was a need for this

$$\frac{k_1/k_n}{k_7/k_n} = k_1/k_7 \qquad (40)$$

control to eliminate the possibility of any secondary reaction affecting the relative rate value. If the calculated cross-check value was similar to the experimental value, 0.641, then it could be assumed that there were no secondary reactions affecting the rate of abstraction.

It is possible in these reactions that HCl could be formed. This could cause a significant change in the rate of chlorine abstraction

by its ability to convert the N-chloramide to the parent amide (eqs. 41-44). In order to check the presence of HCl and any effect it might

(41) $$R\text{-}\overset{\overset{O}{\|}}{C}\text{-}\underset{\underset{Cl}{|}}{N}\text{-}CH_3 \longrightarrow R\text{-}\overset{\overset{O}{\|}}{C}\text{-}N{=}CH_2 + HCl$$

(42) $$R\text{-}\overset{\overset{O}{\|}}{C}\text{-}\underset{\underset{Cl}{|}}{N}\text{-}R' + HCl \longrightarrow R\text{-}\overset{\overset{O}{\|}}{C}\text{-}\underset{\underset{H}{|}}{N}\text{-}R' + Cl_2$$

(43) $$R\cdot + Cl_2 \longrightarrow RCl + Cl\cdot$$

(44) $$Cl\cdot + RH \longrightarrow R\cdot + HCl$$

have on the reaction rate sodium carbonate was added in excess to three of the reaction ampoules. The rate ratio values obtained for k_1/k_7 were 0.595, 0.694 and 0.567 and were well within the range of the k_1/k_7 values previously obtained.

To check the fact that the relative rate was not dependent on the concentration of the N-chloramides A and B the ratio of $[A]_o/[B]_o$ was varied from ca.0.5 to 2.0. The relative rate values obtained were independent within experimental error of the concentration ratio.

To determine whether there was a rate dependence on both steric and inductive effects a multiple regression analysis was run on part of the experimental data as illustrated in Table III. Correlations obtained by varying the input data are shown in Table IV.

Infrared spectra were recorded on the Perkin-Elmer Model 180 Spectrophotometer for an accurate determination of the C=O stretching frequency in a few representative N-chloramides for the purpose of estimating relative amounts of C-N double bond character. The results of these spectra are listed in Table V.

Table III

Data Used in Multiple Regression Analysis

Amide: RCONClR' R	R'	k_1/k_7	E_s [a]	σ^* [a]
CH_3	CH_3	1.00	0.00	0.000
CH_3	CH_2CH_3	2.48	-0.07	-0.100
CH_3	$CH_2CH_2CH_3$	1.59	-0.36	-0.115
CH_3	CH_2CH_2Ph	1.17	-0.38	+0.080
CH_3	$CH_2C(CH_3)_3$	0.944	-1.74	-0.165
CH_3	$CH(CH_3)_2$	1.15	-0.47	-0.190
CH_3	$C(CH_3)_3$	0.641	-1.54	-0.300

a These values were taken from reference (24).

Table IV

Correlations Obtained from the Multiple Regression Analysis by Varying Input Data

1. Including N-chloro-N-methylacetamide:

   (a) E_s and σ^*

   $$\log k_1/k_n = -0.18\,\sigma^* + 0.20\,E_s + 0.18 \qquad r = 0.672$$

   (b) σ^* only

   $$\log k_1/k_n = 0.54\,\sigma^* + 0.13 \qquad r = 0.360$$

   (c) E_s only

   $$\log k_1/k_n = 0.18\,E_s + 0.19 \qquad r = 0.665$$

2. Excluding N-chloro-N-methylacetamide:

   (a) E_s and σ^*

   $$\log k_1/k_n = -0.0013\,\sigma^* + 0.23\,E_s + 0.26 \qquad r = 0.820$$

Table IV continued,

(b) σ^* only

$$\log k_1/k_n = 0.76\sigma^* + 0.18 \qquad r = 0.478$$

(c) E_s only

$$\log k_1/k_n = 0.23\ E_s + 0.26 \qquad r = 0.820$$

Table V

The C=O Stretching Frequency of N-Chloramides

Amide: R	RCONClR' R'	Frequency (cm^{-1})
CH_3	CH_3	1680
CH_3	$C(CH_3)_3$	1680
$PhCH_2$	$C(CH_3)_3$	1672
Ph	$C(CH_3)_3$	1675

After completion of the relative rate determinations and a brief study of reaction products the question arose as to whether an equilibrium was being established during the chlorine abstraction reaction between an N-chloramide and the parent amide of the other competing N-chloramide (eq. 45). To determine whether this reaction was occurring

(45) $$R-\overset{O}{\overset{\|}{C}}-\underset{Cl}{N}-R + R-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-R' \underset{\leftarrow}{\overset{K_{eq}}{\rightarrow}} R-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-R + R-\overset{O}{\overset{\|}{C}}-\underset{Cl}{N}-R'$$

representative N-chloramides and parent amides were reacted as indicated in Table VI. The reaction ampoules were prepared in the same

Table VI

Equilibrium Constant Values for the Chlorination of an N-Alkylacetamide by an N-Chloro-N-alkylacetamide

Ampoule	Amide	K_{eq}
1	N-methylacetamide N-chloro-N-ethylacetamide	1
2	N-ethylacetamide N-chloro-N-methylacetamide	1
3	N-phenethylacetamide N-chloro-N-methylacetamide	1
4	N-methylacetamide N-chloro-N-t-butylacetamide	10.6[a]
5	N-t-butylacetamide N-chloro-N-methylacetamide	.006[a]

a These should be reciprocal values. Perhaps the equilibrium was not yet established.

manner and subjected to the same conditions as those used in the relative rate studies with the exception of no PAT being present. The K_{eq} values (eq. 45) for the reactions listed in Table VI were obtained from measurements of the peak heights on the nmr spectra.

The results in Table VI show that an equilibrium reaction (eq. 45) does occur. To determine whether this equilibrium had a significant affect on the relative rate ratios obtained in the competitive rate studies using the phenyl radical, hypothetical k_A/k_B ratios were calculated for different initial concentration ratios, $[A]_o/[B]_o$, assuming $K_{eq} = 10$. If the calculated k_A/k_B ratios varied according to the $[A]_o/[B]_o$ ratios, then it could be concluded that the equilibrium (eq. 45) did not significantly affect the observed relative rate of chlorine abstraction by the phenyl radical since it had been shown previously that this value was insensitive to the ratio