E_2-Elimination in the Decomposition of *N*-Bromoamino Acid Anions

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The kinetics of oxidation of eight structurally different amino acids by hypobromite ion (BrO^-) in the presence of hydroxide ion has been studied. The reactions proceed through the rapid formation of *N*-bromoamino acid anion which then decomposes in the rate-limiting step. The decomposition of *N*-bromoamino acid anions is found to proceed through an unimolecular and a base-catalyzed reaction. The large negative values of $\Delta S^{\ddagger}$ and the products formed suggest that the hydroxide ion-catalyzed reactions proceed through an E_2 mechanism. *N*-Bromoamino acid anion gives an absorption spectrum with λ_{max} at ≈290 nm.

Nitrogen-containing organic molecules, especially amino acids, can be oxidized to *N*-halo derivatives by a wide variety of halogenating agents. The *N*-haloamino acids themselves are halogenating agents, and hence, their decomposition is of environmental interest. There has been great progress in the past toward the quantitative understanding of the kinetics and thermodynamics of the reactions of *N*-chloroamino acids,[1−7] since chlorine is usually employed in the disinfection of potable water and waste water.[8] Even though the accepted mechanism for the reaction of aqueous bromine with amino acid is analogous to that of *N*-chloroamino acids,[8−11] kinetics have received less attention probably because of the complexity of the reactions.[11] In this paper we have given the details of the kinetics of oxidation of eight structurally different amino acids (AA) by aqueous hypobromite ion.

Results

We have examined the rate of oxidation under the condition $[OH^-]_T \geq [AA]$, and we occassionally refer to the term $[OH^-]_f$ as free hydroxide ion concentration, where $[OH^-]_f = [OH^-]_T - [AA]$. All the kinetics were carried out under pseudo-first-order conditions ($[AA] \gg [BrO^-]$, i.e., at least in the ratio of 10:1) and usually at $[OH^-]_f \approx 6.5 \times 10^{-3}$ M.

Figure 1 is the semilog plot of the concentration of the oxidizing species versus time. The semilog plots show very good correlation between log $[OBr^-]$ and time as evidenced by the high correlation coefficients (usually $r > 0.99$). The pseudo-first-order rate constants, k_{obs}, calculated from the semilog plots are independent of the initial concentrations of the oxidant used and, thus,

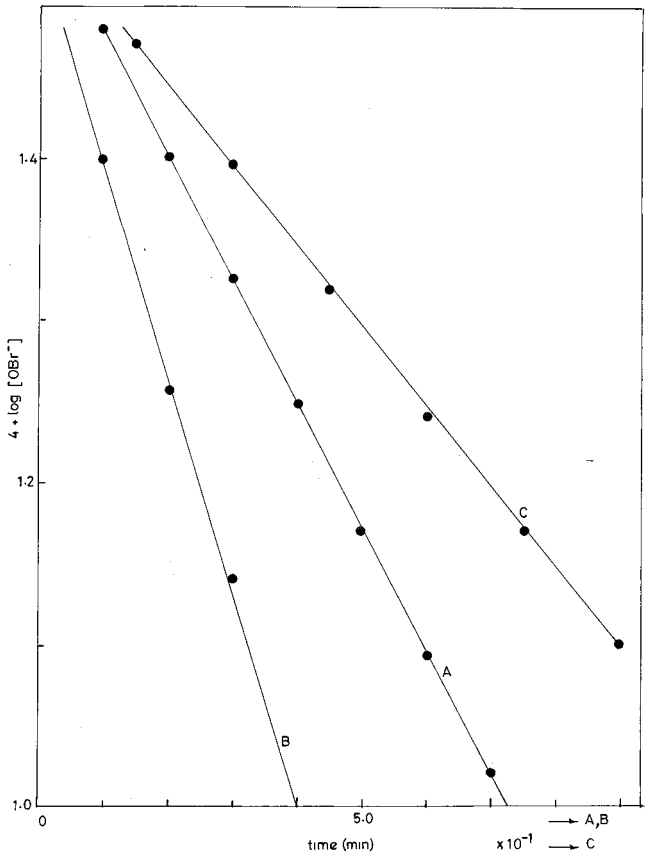

Figure 1. Plot of log $[OBr^-]$ vs. time at 35 °C: (A) [glycine] = 0.05 M; $[OH^-]_f = 8.46 \times 10^{-3}$ M; (B) [alanine] = 0.05 M; $[OH^-]_f = 6.46 \times 10^{-3}$ M; (C) [β-alanine] = 0.05 M; $[OH^-]_f$ = 0.1065 M.

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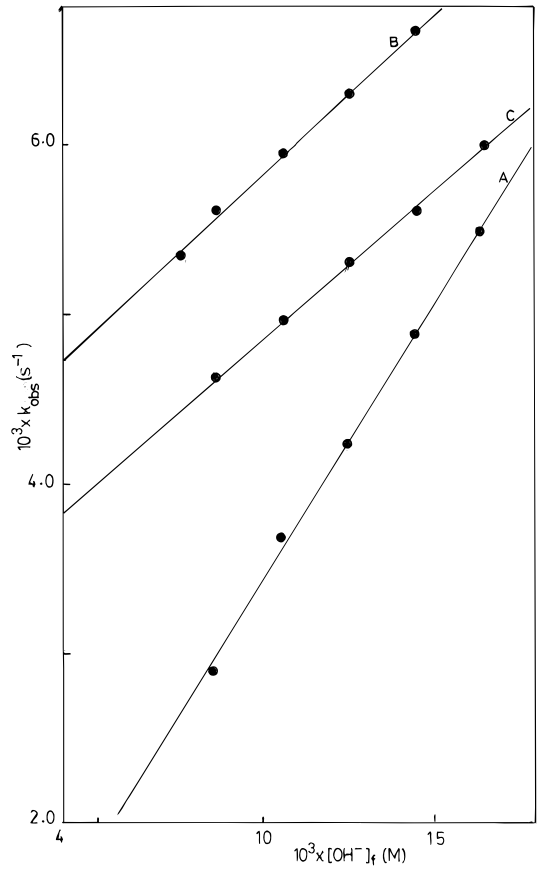

Figure 2. Plot of k_{obs} vs. [OH^-]$_f$ at 35 °C: (A) [glycine] = 0.05 M; [OBr^-] = 3.56 × 10^{-3} M; (B) [alanine] = 0.05 M; [OBr^-] = 3.54 × 10^{-3} M; (C) [*N*-methylglycine] = 0.05 M; [OBr^-] = 3.50 × 10^{-3} M.

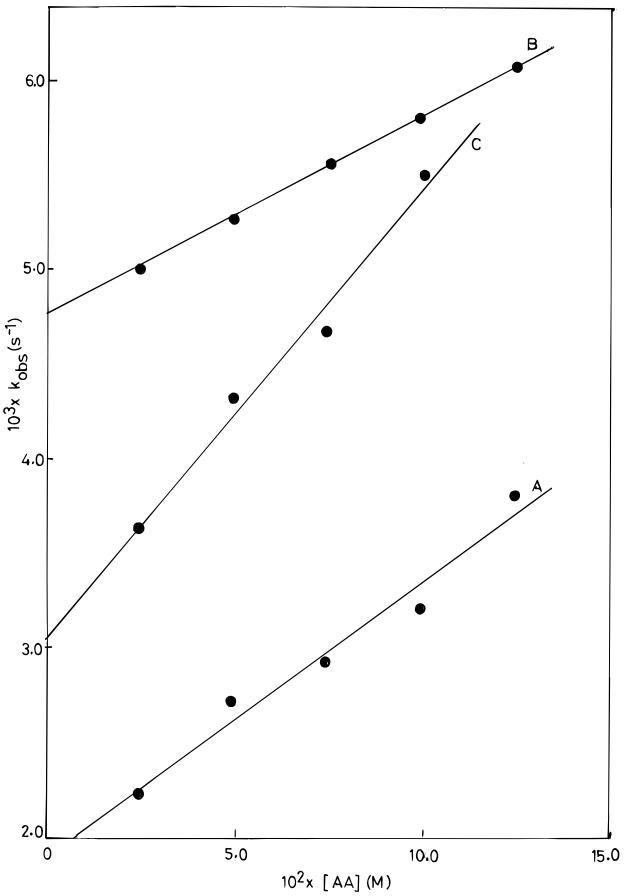

Figure 3. Plot of k_{obs} vs. [amino acid] at 35 °C ([OH^-]$_f$ = 6.44 × 10^{-3} M; [OBr^-] = 3.56 × 10^{-3} M): (A) glycine, (B) alanine, (C) *N*-methylglycine.

confirm that the rate of oxidation is first order in [oxidant]. Moreover, the initial concentration of the oxidant, [OBr^-]$_0$ obtained by the extrapolation of the semilog plot, agrees well to the analytical value within the limits of experimental error (±5%). An interesting observation is that, of all the amino acids studied, the rate of oxidation of α-aminoisobutyric acid alone is immeasurably fast (half-life is less than 1 min) under all conditions used in this study.

The influence of [OH^-]$_f$ on k_{obs} is found to be a simple first order reaction (Figure 2) as $k_{obs} = k_1 + k_2[OH^-]_f$ in all the amino acids studied. The pseudo-first-order rate constant shows a linear dependence on the amino acid concentrations (Figure 3) in glycine, *N*-methylglycine, and alanine only. Perusal of the results shows that the pseudo-first-order rate constant for the decomposition of *N*-bromoamino acid anion satisfies the equation (1). The

$$k_{obs} = k_1 + k_2[OH^-]_f + k_3[AA] \qquad (1)$$

values of k_1, k_2, and k_3 for various amino acids are tabulated in Table 1. Ionic strength (0.1−0.3 M) and bromide ion (0.01−0.075 M) have no effect on k_{obs}. From the effect of temperature on k_{obs}, the enthalpy of activation and entropy of activation for the rate constants k_1, k_2, and k_3 are calculated for glycine, *N*-methylglycine, and alanine and given in Table 2.

The UV−vis absorption spectra of the reaction intermediates were also recorded. The absorption peak[12] of OBr^- was observed at 330 nm with ϵ_{max} 350 dm^3 mol^{-1} cm^{-1}. The peak due to OBr^- completely disappeared, and new absorption peaks appeared immediately on mixing amino acid and OBr^-. The spectra of the intermediate showed two peaks, one at ∼290 nm and the other at ∼225−230 nm (Figure 4). The peak at the shorter wavelength (∼225−230 nm) was highly asymmetric and the absorbance came down sharply on the shorter wavelength side and so the λ_{max} value may involve some error. Analysis of the spectra showed that the lower energy transition appeared at the same wavelength for all amino acids irrespective of the substituents at the amino carbon. A red shift of ∼10 nm was observed for a methyl substitution at the amino nitrogen. This longer wavelength λ_{max} is listed for the intermediate from various amino acids in Table 3. The time history of the absorp-

Table 1. Rate Constants for the Decomposition of *N*-Bromo-α-amino Acid Anion at 35 °C[a]

bromoamine of	10^3k_1 (s^{-1})	10^3k_2 (M^{-1} s^{-1})	10^3k_3 (M^{-1} s^{-1})
glycine $H_2NCH_2COO^-$		324.0	14.7
alanine $NH_2CH(CH_3)COO^-$	4.0	186.2	10.7
valine $NH_2CH(CH(CH_3)_2)COO^-$	2.9	86.7	
phenylalanine $NH_2CH(CH_2C_6H_5)COO^-$	5.9	460.2	
N-methylglycine $CH_3NHCH_2COO^-$	1.9	169.0	24.0
β-alanine $NH_2CH_2CH_2COO^-$		1.7	

[a] Average of the values obtained from different plots are given. *N*-Bromothreonine gives k_{obs} = 6.18 × 10^{-3} at 6.5 × 10^{-3} M of [OH^-]$_f$, and k_1 and k_2 could not be separated due to a very large increase in k_{obs} with [OH^-]$_f$. *N*-Bromo-α-aminoisobutyric acid decomposes rapidly, and we could not measure the *k* values.

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Table 2. Thermodynamic Parameters for the Decomposition of *N*-Bromoglycine, *N*-Bromo-*N*-methylglycine, and *N*-Bromoalanine[a]

N-bromoamino acid anion		$\Delta H^{\ddagger}$ (kcal/mol)	$\Delta S^{\ddagger}$ (cal·deg^{-1}/mol)	$\Delta G^{\ddagger}$ (kcal/mol)
glycine	k_2	15	−13	19
	k_3	15	−17	21
N-methylglycine	k_1	29 (27.5)	+23 (14.6)	22
	k_2	10	−29	19
	k_3	13	−22	20
alanine	k_1	25 (25.6)	+11 (10.7)	22
	k_2	11	−28	19

[a] k_1, k_2, and k_3 represent the process of decomposition as shown in Scheme 1. Values in parentheses correspond to *N*-chloroamino acid (from ref 5). $\Delta G^{\ddagger}$ value at 35 °C.

tion spectrum showed that the absorbance of both peaks are decreasing.

The stoichiometry of the reaction may be represented as

$$1 \text{ amino acid} + OBr^- \rightarrow \text{products} \qquad (2)$$

The oxidative product of amino acid was identified as the corresponding carbonyl compounds, ammonia and carbon dioxide. Glycine and *N*-methylglycine were oxidized to only glyoxalic acid, and the percentage yield was >80%. Alanine gave a mixture of acetaldehyde (70 ± 5%) and pyruvic acid (~25 ± 5%). The yield of acetone in α-amino isobutyric acid was 90%.

Discussion

In the presence of alkali, the amino acids would be in the form of an amino acid anion according to the following reaction.

$$RCH(NH_3^+)COO^- + OH^- \rightarrow RCH(NH_2)COO^- + H_2O \qquad (3)$$

The conversion into amino acid anion may be quantitative since the pK_a values for most of the amino acids are p$K_{a(1)} = 2.1 \pm 0.3$ and p$K_{a(2)} = 9.6 \pm 0.7$. Therefore, it is reasonable that any excess hydroxide ion concentrations over the stoichiometry of the reaction (3) will be available for interaction with intermediates, and we can define this as free hydroxide ion concentration $[OH^-]_f$; that is

$$[OH^-]_f = [OH^-]_T - [AA]$$

Hereafter, by amino acid (AA) we refer only to amino acid anion.

To have insight into the reaction mechanism, it is necessary that the intermediate(s) indicated by the absorbance at ~225 nm and ~290 nm be identified. The generally accepted mechanism for the reaction between amino acids and hypobromite, analogous to the hypochlorite, is the formation of *N*-bromoamino acids,[8−11] as shown below.

$$RCH(COO^-)NH_2 + HOBr \xrightarrow{\text{fast}} RCH(COO^-)NHBr + H_2O \qquad (4)$$

It was observed that the intermediate in β-alanine is quite stable relative to the intermediates in all the other α-amino acids. As a result, we find out the relationship between the absorbance of the longer wavelength peak (at 290 nm), [β-alanine] and $[OBr^-]$. The absorbance

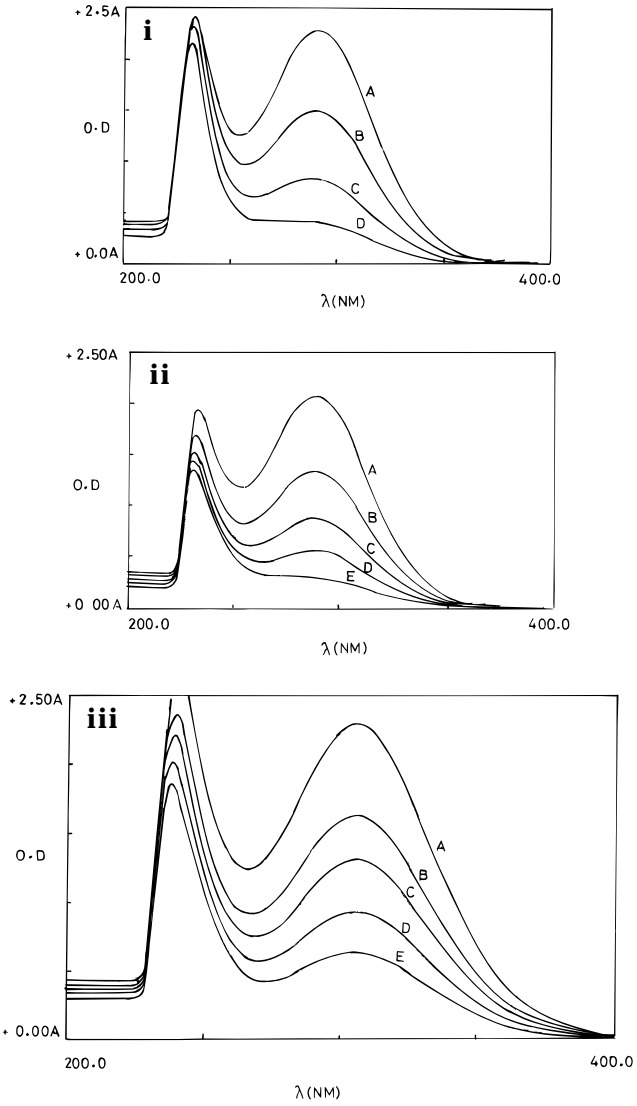

Figure 4. Time history of absorption spectrum of the intermediate ([amino acid] = 0.10 M; $[OH^-]_f = 6.5 \times 10^{-3}$ M; $[OBr^-] = 3.5 \times 10^{-3}$ M): (i) glycine A = 1 min; B = 3 min; C = 6 min; D = 10 min; (ii) alanine A = 1 min; B = 3 min; C = 5 min; D = 7 min; E = 10 min; (iii) *N*-methylglycine A = 1 min; B = 2.5 min; C = 3.5 min; D = 5 min; E = 7 min.

practically does not change with the concentration of amino acid anion, while a Beer's law type of relationship is obtained with $[OBr^-]$. Further, we could not observe any initial increase in the absorbance at ~290 nm; that is, the peak appears instantaneously (i.e., <1 min) in all the amino acids studied. This suggests that the reaction between amino acid anion and hypobromite ion is very fast and can be represented by the following equation.

$$RCH(COO^-)NH_2 + OBr^- \xrightarrow{\text{fast}} RCH(COO^-)NHBr + OH^- \qquad (5)$$

Therefore, the species responsible for the absorption around 290 nm may be *N*-bromoamino acid anion which can be considered the λ_{max} of simple *N*-bromamine (λ_{max} 280 nm)[13] influenced by the alkyl substituent at the nitrogen atom. This is also supported by the fact that the λ_{max} of *N*-bromoamino acid anion is not affected either by the nature of the alkyl substituent at the α-carbon or

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Table 3. Longer Wavelength Absorption Maximum of *N*-Bromoamino Acid Anion at 35 °C

N-bromo-α-amino acid anion[a]	λ_{max} (nm)
N-bromoglycine	290
N-bromoalanine	287
N-bromo-*N*-methylglycine	305
N-bromo-*β*-alanine	290

[a] Spectra were recorded at $[OH^-]_f = 6.5 \times 10^{-3}$ M.

by moving the carboxylate group away from the amino carbon (e.g., *β*-alanine). However, the substitution of a methyl group at the amino nitrogen, which can be considered as the dialkyl-substituted *N*-bromamine, shifts this maximum peak to a longer wavelength.

The oxidative decarboxylation of α-amino acids by other oxidants such as HSO_5^- in alkaline medium also produces an intermediate/product which gives a highly asymmetric peak around 220 nm.[14] Therefore, in comparison with other oxidants, the intermediate species responsible for the λ_{max} at ~230 nm can be assigned to the imine.

On the basis of the experimental results, we can propose the following reaction scheme for the oxidation of amino acids by hypobromite ion as follows in Scheme 1.

Scheme 1

$$RCH(COO^-)NH_2 + OBr^- \xrightarrow{fast} RCH(COO^-)NHBr + OH^- \quad (5)$$

$$RCH(COO^-)NHBr \xrightarrow{k_1} RCH{=}NH + Br^- + CO_2 \quad (6)$$

$$RCH(COO^-)NHBr + OH^- \xrightarrow{k_2} RC(COO^-){=}NH + H_2O + Br^- \quad (7)$$

$$RCH(COO^-)NHBr + RCH(NH_2)COO^- \xrightarrow{k_3} RC(COO^-){=}NH + RCH(NH_2)COO^- + H^+ + Br^- \quad (8)$$

The imines will hydrolyze to give the corresponding carbonyl compounds. The observed pseudo-first-order rate constant for the disappearance of $[OBr^-]$ from the reactions 5−8 is given as

$$k_{obs} = k_1 + k_2[OH^-] + k_3[AA] \quad (9)$$

The values of k_1, k_2, and k_3 calculated from various plots such as k_{obs} vs $[OH^-]$ and k_{obs} vs [AA] are agreeable within the limits of experimental error, and the average values are given in Table 1.

The unimolecular decomposition of *N*-chloro-α-amino acids in alkaline medium has been studied extensively, and several mechanisms have been proposed.[1−6] The accepted mechanism is the one in which the chlorine and carboxylate groups are in antiperiplanar configuration and the *N*-chloro compound decomposes via a slow concerted fragmentation, i.e., an E_2-like mechanism. This mechanism explains the observed changes in the rates with change of substituents. The relative rates of decomposition of *N*-bromoamino acids along with their chlorine analogues are given in Table 4. Analysis of the results shows that the relative rate for unimolecular process (k_1) is almost identical in *N*-bromovaline and *N*-chlorovaline. This suggests that the mechanism for the decomposition of *N*-bromo amino acids through the process represented by k_1 is unimolecular as its chlorine analogue. This is also supported by the large positive entropy value observed for k_1 in *N*-methylglycine and alanine (Table 2).

Table 4. Relative Rate of Decomposition of *N*-Bromoamino Acid Anion at 35 °C

	relative rate		
N-bromo-α-amino acid anion	k_{obs}[a]	k_2	k_1
N-bromoglycine	1.00 (1.00)	1.00	
N-bromoalanine	1.95 (64.0)	0.58	1.00
N-bromovaline	1.30	0.27	0.73 (0.75)[b]
N-bromophenylalanine	3.68	1.42	1.49
N-bromo-*N*-methylglycine	1.60 (12.0)	0.52	0.49 (0.31)[b] (0.19)[c]
N-bromo-*β*-alanine	~0.02	~0	
N-bromothreonine	2.28 (50.0)		
N-bromo-α-aminoisobutyric acid	very high (3100.0)		

[a] $[OH^-]_f = 6.5 \times 10^{-3}$ M. Values given in the parantheses correspond to *N*-chloroamino acid anion from ref 5. The relative rate for k_1 is determined with respect to *N*-bromoalanine since k_1 could not be determined for *N*-bromoglycine. [b] Value calculated from ref 6. [c] Value calculated from ref 5.

Table 5. Fragmentation[a] of *N*-Bromoamino Acids

	% fragmentation through		
bromoamine of	unimolecular (k_1)	OH^- catalyzed (k_2)	AA catalyzed (k_3)
glycine		74	26
alanine	70	21	9
valine	84	16	
phenylalanine	66	34	
N-methylglycine	59	34	7

[a] Values are calculated from the *k* values at [AA] = 0.05 M, $[OH^-]_f = 6.5 \times 10^{-3}$ M, and $[OBr^-] = 3.5 \times 10^{-3}$ M at 35 °C.

The percentage of fragmentations through unimolecular hydroxide ion and amino acid anion catalyzed processes are calculated for various *N*-bromoamino acids from the rate constant values, and they are given in Table 5. Comparison of the values in Table 5 with product yields (e.g., alanine) supports the calculated fragmentation percentage. Analysis of the results in Table 5 indicates that the major fraction of the alkyl side chain α-amino acids decompose through the unimolecular process (k_1). To explain this, we can first consider a reaction scheme in which the breaking up of the $C-COO^-$ bond preceeds the carbon nitrogen bond formation resulting in a carbanion intermediate. This mechanism is very similar to the one proposed by Awad et al.[6] for the unimolecular decomposition of *N*-chloroamino acid anion. If carbanion intermediate is formed in the rate-limiting step, we should expect that *N*-bromoglycine would decompose faster than *N*-bromoalanine since the former compound forms a more stable carbanion intermediate. On the other hand, in the disappearance of carbanion, the more stable the anion the slower the reaction would be, which is consistent with the observation that *N*-bromoalanine decomposes faster than *N*-bromoglycine. This will also explain the fact that the oxidation of α-aminoisobutyric acid is very fast since it forms a more unstable (more substituted) carbanion. Though the mechanism of disappearance of the carbanion intermediate explains the observed variation of the unimolecular decomposition k_1, it does not rationalize the thermodynamic parameters which are independent of the nitrogen−

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halogen bond (Table 2). The mechanism that would be more consistent with the observed results may be the concerted E_2-like mechanism in which decarboxylation and debromination occur in a single step via an imine-like transition state as suggested by Hand and Margerum in *N*-chloroamino acids.[5] In the activated state carbon−nitrogen bond formation and C−COO^- bond fission may occur to a large extent while the change in the nitrogen−halogen bond would be relatively small. Since the −I effects of Cl and Br are almost equal (as measured from the σ^* values),[15] one cannot expect much energy difference between the activated states of *N*-chloro- and *N*-bromoamino acids. Since the bonded halogen atom would be solvated appreciably,[5] the change in the degree of solvation of halogen, as it gains (partial) negative charge, is negligible. Thus, the contribution for $\Delta S^{\ddagger}$ from the N−Cl and N−Br bonds is almost identical. This will explain why the $\Delta S^{\ddagger}$ values for *N*-chloro- and *N*-bromoalanine are identical.

The influence of substituents on the stability of substituted imines may be same as that of the stability of olefins.[16] Thus, the transition state with highly substituted imines may be more stable and more reactive. Each methyl substitution at the amino carbon increases the unimolecular decomposition of *N*-chloroamino acids[5] by a factor of ~60. The similar trend may hold true for *N*-bromoamino acid also. This will explain why *N*-bromoglycine disintegrates very slowly while the *N*-bromo-α-amino isobutyric acid decomposes rapidly.

For unimolecular decomposition, the halogen element effect (k_1^{Br}/k_1^{Cl}) is calculated for alanine and *N*-methylglycine and the values are 3.6 and 7.6,[17] respectively. Thus, the halogen atom effect is more pronounced in N-substituted amino acid. Comparison of the results for glycine and *N*-methylglycine in Table 5 indicates that the methyl substitution at the amino nitrogen enhances the fragmentation through the unimolecular process. These two observations indicate that the mechanism of unimolecular fragmentation of *N*-bromo-*N*-methylglycine may be different from other *N*-bromoamino acids. Some authors[7,18] have suggested the formation of nitrenium ion as an alternative for the E_2-like unimolecular mechanism in *N*-chloroamino acids. Therefore, *N*-bromo-*N*-methylglycine may disintegrate through the formation of a nitrenium ion intermediate which would be stabilized by the electron-donating methyl group. Moreover, a nitrenium ion would be expected to yield substitution and/or elimination products. This will explain why the major reaction product in sarcosine is glyoxalic acid rather than formaldehyde.

N-Bromoglycine and to a smaller extent (~30−40%) other *N*-bromoamino acids disintegrate through the hydroxide ion- and α-amino acid anion-catalyzed mechanism. We can suggest a E_2 mechanism for the base-catalyzed reaction in which the α-hydrogen and bromine atom would be in an antiperiplanar configuration, thereby eliminating hydrogen bromide (Figure 5). The resultant intermediate α-imino acid may rapidly hydrolize to give α-carbonyl carboxylate. The large negative entropies of activation observed for k_2 and k_3 are also consistent with the reactions involving E_2 elimination of hydrogen halide from *N*-chloro compounds.[19]

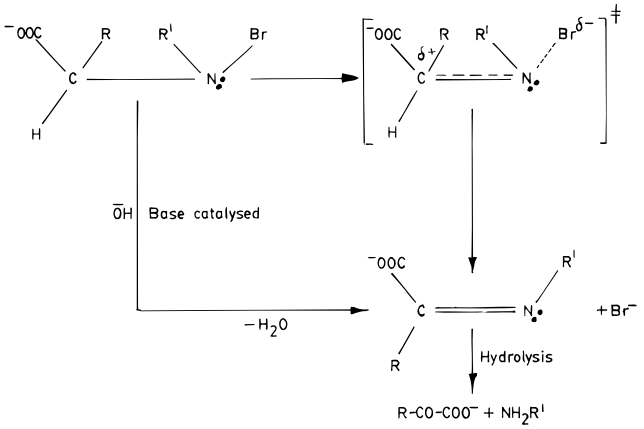

Figure 5. Mechanistic scheme.

The factors that influence the carbon−heteroatom multiple bond formation through β-elimination are (i) lower stability of the heteroatom−leaving group bond and (ii) increased basicity of β-hydrogen.[20] Thus, the observed variation in the base-catalyzed reaction contants (k_2 and k_3) with the structure of amino acid should come from the relative basicity of the hydrogen atom at the α-carbon.

Earlier reports on the oxidation of α-amino acids suggest that the hydrogen atom at the α-carbon is slightly acidic and can interact with hydroxide ion.[1,14] This interaction is influenced by the substituent R at the α-carbon, and the observed order[14] is H > CH_3 > $(CH_3)_2$-CH. Perusal of the k_2 values in Table 1 shows that the observed values are also in the above order. Thus, the inductive effect (+I) of alkyl substituent R is an important factor in the base-catalyzed elimination. A simple linear free energy relationship (LFER) analysis[21] of k_2 with Taft's constant σ^* shows a reasonably good correlation ($r = 0.967$) even with limited amino acid anions such as glycine, alanine, and valine. The observed relationship is $\log k_2 = -0.86 + 0.79\sigma^*$. Phenylalanine shows a positive vertical deviation (to this correlation line), and this could be assigned to the α effect.[22] Similar deviation is exhibited by phenylalanine in the reaction with *N*-bromosuccinimide also.[23] Even though great reliance cannot be placed on the absolute value of the reaction constant ρ^*, the positive value indicates the presence of the carbanion character at the α-carbon in the transition state; i.e., the transition state has appreciable scission of the C−H bond. We would expect that an electron-donating/releasing substituent at the α-position (relative to the halogen) may slightly increase the base-catalyzed reaction constant k_2 or at least should remain the same as that of the unsubstituted one.[24] Comparison of the k_2 values of *N*-bromo-*N*-methylglycine and *N*-bromoglycine shows that the methyl substitution at the nitrogen atom actually decreases the rate. This means that the electron-donating/releasing substituent at the nitrogen, i.e., α-position, probably destabilizes the incipient negative charge or double bond.[25] This is in accordance with the proposed

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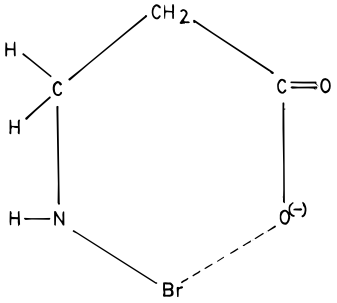

Figure 6.

activated state in which the C−H bond fission and C−N bond formation occur to a large extent.

The amino acid anion can be expected to act as a base since the pK_a and pK_b of classical amino acid $RCH(NH_2)$-COOH is ≈9.8.[26] The glycine anion-catalyzed reaction is also reported in the oxidation by *N*-bromosuccinimide in alkaline medium.[23] Therefore, the k_3 values tabulated (Table 1) for glycine, *N*-methylglycine, and alanine represent the amino acid anion-catalyzed elimination reactions.

The functional group $-CH_2COO^-$ with a σ^* value of −0.06 is a poor electron donor compared to $-COO^-$ ($\sigma^* = -1.06$).[15] Perusal of the structure of amino acids in Table 1 suggests that β-alanine should be more reactive than glycine toward E_2 elimination, contrary to what is observed in this study. The unusual stability of *N*-bromo-β-alanine suggests that some other force is also operating additionally. The more probable reason may be that the conformation with bromine and carboxylate on the same side of the carbon−nitrogen bond may reduce the reactivity of the bromine by the interaction with carboxylate oxygen as in (Figure 6). If it is so, one would expect that *N*-bromo-γ-aminobutyric acid anion, $BrNHCH_2CH_2CH_2COO^-$, should also be stable toward the base-catalyzed elimination of HBr. This is found to be true from the rate constant value for k_2 which is of the same order as that of β-alanine.[27] This observation also supports the fact that the Br and H atoms are in an antiperiplanar configuration, which is favorable for E_2 elimination.

Finally, we have to explain the important difference in the decomposition of *N*-chloroamino acid anions and *N*-bromoamino acid anions. The *N*-bromoamino acid anions undergo a base-catalyzed hydrogen halide elimination resulting in carbon−nitrogen double bond formation. The −I effect of chlorine ($\sigma^* = 2.96$) is slightly greater than bromine ($\sigma^* = 2.84$).[15] Therefore, we can only expect the acidity of the hydrogen atom at the α-carbon in *N*-bromoamino acid to be approximately equal to (should be slightly less than) that of *N*-chloroamino acid. The actual bond energies of $RCH(COO^-)$-HNCl and $RCH(COO^-)$HNBr or of the related compounds H_2NCl and H_2NBr are not known. However, the calculated bond energies of NCl and NBr in diatomic[28] and polyatomic molecules[29] suggest that the nitrogen−bromine bond is less stable by 14.0 kcal/mol than the nitrogen−chlorine bond. Therefore, the lower stability of heteroatom−leaving group bond (i.e., >N−Br) is mainly responsible for the observed difference between *N*-bromoamino acid and *N*-chloroamino acids toward the base-catalyzed elimination.

Experimental Section

All the chemicals used were of highest purity and used as received unless stated otherwise. α-Aminoisobutyric acid (Aib) was from Sigma (USA), and all other amino acids were from Loba chemie (India). The ionic strength was adjusted to 0.15 M with sodium perchlorate produced from the neutralization of Na_2CO_3 with $HClO_4$.

Aqueous solutions of hypobromite ion were prepared by dissolving bromine in an aqueous solution of sodium hydroxide. The formation of hypobromite ion is rapid as shown in eq 10.

$$Br_2 + 2OH^- \rightarrow BrO^- + Br^- + H_2O \qquad (10)$$

Since the rate of disproportionation of BrO^- to BrO_3^- is at least at higher pH (∼13.0),[30] an excess of OH^- over Br_2 (usually $2[OH^-] - [Br_2] \approx 0.035$ M) was kept in the stock solution. Hypobromite solutions were prepared fresh daily just before starting the experiments. The OBr^- concentration was estimated by iodometry, while its purity was ascertained by spectrometry at 330 nm.[13]

The kinetics of decomposition were followed by measuring the concentration of active bromine by iodometry. Hypobromite solution was rapidly injected into the reaction mixture with an excess (usually ∼10-fold) of amino acid anion. The $[OBr^-]$ remaining at different times was measured by arresting the reaction through the addition of acidified KI solution (10% w/v) into the reaction mixture. Rate constants were determined from the slope of the least-squares regression of log $[OBr^-]_t$ vs time. For the calculation of $[OH^-]_f$ in the kinetic expression, the concentration of OH^- ion produced as in eq 5 was also taken into account.

UV−vis absorption spectra were recorded (200−360 nm) on a Schimatzu UV-160 spectrophotometer using 1 cm matched cells. Corrections for the absorbance of amino acid, if any, were made.

Glyoxalic acid was detected by the reaction with phenylhydrazine and H_2O_2.[31] The presence of pyruvic acid as a minor oxidation product was established by the color reaction with β-naphthylamine.[32] The concentration of carbonyls were determined spectrophotometrically by their (2,4-dinitrophenyl)hydrazones as given by Wells.[33] Estimation of glyoxalic acid was optimized by generating a calibration curve from a stock solution. Acetaldehyde and pyruvic acid were estimated from the (standardized) ϵ values at 425 and 550 nm.

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(26) Reference 15, Section 5, pp 17−41.
(27) The rate constant for the base-catalyzed disintegration in *N*-bromo-γ-aminobutyric acid is calculated as 3.4×10^{-3} M^{-1} s^{-1} at 35 °C from the oxidation by Br_2 in aqueous alkaline medium.
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