CHAPTER III

DISCUSSION
Amides exist in both keto and enol forms as

\[
\begin{align*}
R-\text{CH}_2-\text{C}=\text{N} & \quad \rightleftharpoons \quad R-\text{CH}_2-\text{C}=\text{N}^- \\
\text{(keto) I} & \quad \rightleftharpoons \quad \text{(enol) II}
\end{align*}
\] (ref. 1)

Whatever be the mechanism, it may be seen that enolisation will tend to produce the double bond away from \(X\) (halogen atom, i.e. electron attracting) group. In chloro- and iodo-acetamides the main enolised form should be \(X\text{CH}_2^+\text{C}=\text{N}^-\) ... (II) whereas in \(N\)-bromoacetamide, the enolisation will largely result in \(\text{CH}_2\text{=C}=\text{N}^+\text{Br}\) ... (III). In any case the amide in moderate acid concentration (as used here) should accept proton from the medium (to whatever degree it can) giving \(X\text{CH}_2^+\text{C}=\text{N}^+\text{Br}\) ... (IV). Thus we have a number of species of amide present (amide I, II, III and IV). We assume that amide oxidant complex is most probable with enolised amide II but III represents unreactive species. It justifies our assumption that electron transfer through protonated amide in \(R_i\) is only a minor reaction path due to (a) a very low concentration of \(\text{MOH}^{(n-1)\text{aq}}\) and amide IV as amides are weak bases and (b) also perhaps due to larger
activation energy as it involves the interaction of like charges in the slowest process.

The probability of oxidation of amides preceding the hydrolysis

\[
R-\text{CH}_2-\text{CON} < R_1 \quad \text{H}_2\text{O} \quad \rightarrow \quad R\text{CH}_2\text{COOH} + \text{NH}_3
\]

is not favoured because in DMA and NMA the hydrolysed products, acetic acid and amines, are stable against the oxidants and secondly the hydrolysis of amides takes place at relatively high temperatures\textsuperscript{2,3}.

As the reactions are first order with respect to the concentrations of amides and the oxidants, respectively, the following mechanism would satisfy the rate law.

\[
\text{MO}^{(n-1)+} + \text{H}^+ \quad \text{MO}^{(n-1)+} + \text{H}^+ \quad \text{XCH}_2\text{C} = \text{N} + \text{H}^+ \quad \text{XCH}_2\text{C} = \text{N} + \text{H}^+ \quad \text{OH} \quad \text{OH}
\]

Oxidation of chloro- and iodo-acetamide by Co\textsuperscript{3+} and Ce\textsuperscript{4+}

Route R\textsubscript{1a}

\[
\text{XCH}_2\text{C} = \text{N} + \text{MO}^{(n-1)+} \quad \frac{k_{10}}{k_{10}} \quad \text{XCH}_2\text{COO}^+ + \text{H}^+ + \text{MO}^{(n-1)+} + \text{NH}_3
\]

\(\ldots (R_{10})\)
\[ \text{XCH}_2\text{COO}^\cdot + \text{M}^n+ + \text{H}_2\text{O} \xrightarrow{\text{Fast}} \text{XCH}_2\text{OH} + \text{CO}_2 + \text{M}^{(n-1)+} + \text{H}^+ \]  
.. (ref. 5) (R_{11})

\[ \text{XCH}_2\text{OH} + \text{M}^n+ \xrightarrow{\text{Fast}} \text{XCH}_2\text{O}^\cdot + \text{M}^{(n-1)+} + \text{H}^+ \quad (R_{12}) \]

\[ \text{XCH}_2\text{O}^\cdot \xrightarrow{\text{Fast}} \text{X}^\cdot + \text{CH}_2\text{O} \quad (R_{13}) \]

\[ \text{X}^\cdot + \text{XCH}_2\text{O}^\cdot \xrightarrow{\text{Fast}} \text{X}_2\text{CH}_2 + \frac{1}{2} \text{O}_2 \quad (R_{14}) \]

**Route R_{2a}**

\[ \text{XCH}_2\text{C} = \text{N}^- + \text{M}^n+ + \text{H}_2\text{O} \xrightarrow{K_{20}} \text{XCH}_2 - \text{C} - \text{N}^- \quad (R_{20}) \]

\[ \xrightarrow{K_{21}} \text{XCH}_2 - \text{C} - \text{N}^- + \text{H}^+ \quad (R_{21}) \]

\[ \xrightarrow{K_{22}} \text{XCH}_2\text{COO}^\cdot + \text{M}_{\text{aq}}^{(n-1)+} + \text{NH}_3 \quad (R_{22}) \]

\[ \text{XCH}_2\text{COO}^\cdot + \text{M}_{\text{aq}}^{n+} + \text{H}_2\text{O} \xrightarrow{\text{Fast}} \text{XCH}_2\text{OH} + \text{CO}_2 + \text{M}^{(n-1)+} + \text{H}^+ \]

(ref. 5)(R_{23})

\[ \text{XCH}_2\text{OH} + \text{M}_{\text{aq}}^{n+} \xrightarrow{\text{Fast}} \text{XCH}_2\text{O}^\cdot + \text{H}^+ + \text{M}^{(n-1)+} \quad (R_{24}) \]

\[ \xrightarrow{\text{Fast}} \text{X}^\cdot + \text{CH}_2\text{O} \quad (R_{25}) \]

\[ \xrightarrow{\text{Fast}} \text{X}_2\text{OH}_2 + \frac{1}{2} \text{O}_2 \quad (R_{26}) \]
Oxidation of chloro- and iodo-acetamide by Tl\(^{2+}\)

**Route R\(_{1b}\)**

\[
\begin{align*}
\text{XCH}_2\text{C}=\text{N}^- + \text{TlOH}^{2+} & \overset{k_{10}}{\longrightarrow} \text{XCH}_2\text{COO}^- + \text{H}^+ + \text{Tl}^{2+} + \text{NH}_3 \\
& \quad \text{.. (ref. 5)} \quad (\text{R}_{10}) \\
\text{XCH}_2\text{COO}^- + \text{Tl}^{2+} + \text{H}_2\text{O} & \overset{\text{Fast}}{\longrightarrow} \text{XCH}_2\text{OH} + \text{CO}_2 + \text{Tl}^+ + \text{H}^+ \\
& \quad \text{.. (R}_{11})
\end{align*}
\]

**Route R\(_{2b}\)**

\[
\begin{align*}
\text{XCH}_2\text{C}=\text{N}^- + \text{H}_2\text{O} & \overset{k_{20}}{\longrightarrow} \text{XCH}_2\text{C}^- \text{N}^- \\
& \quad \text{.. (R}_{20}) \\
\text{XCH}_2\text{C}^- \text{N}^- & \overset{k_{21}}{\longrightarrow} \text{XCH}_2\text{C}^- \text{N}^- + \text{H}^+ \\
& \quad \text{.. (R}_{21}) \\
\text{XCH}_2\text{C}^- \text{N}^- & \overset{k_{22}}{\longrightarrow} \text{XCH}_2\text{COO}^- + \text{Tl}^{2+} + \text{NH}_3 \quad \text{.. (ref. 5)} \quad (\text{R}_{22}) \\
\text{XCH}_2\text{COO}^- + \text{H}_2\text{O} + \text{Tl}^{2+} & \overset{\text{Fast}}{\longrightarrow} \text{XCH}_2\text{OH} + \text{CO}_2 + \text{H}^+ + \text{Tl}^+ \quad \text{.. (R}_{23})
\end{align*}
\]

**Oxidation of NMA and DMA by Co\(^{3+}\) and Ce\(^{4+}\)**

**Route R\(_3\)**

\[
\begin{align*}
\text{R} - \text{C} - \text{N}^- & \overset{\text{R}_1}{\longrightarrow} \text{R}^\text{M}^+ \\
& \quad \text{.. (R}_{30}) \\
\text{R} - \text{C} - \text{N}^- & \overset{\text{R}_1}{\longrightarrow} \text{R}^\text{M}^+ \\
& \quad \text{.. (R}_{30})
\end{align*}
\]
\[
R - C - N\leftarrow R_1 \xrightarrow{R_{31}} + H_2O \overset{k_{21}}{\rightarrow} RCOOH + ^*N\leftarrow R_1 + H^+ + M(n-1)^+ \\
\text{(ref. 6)}
\]

\[
^*N\leftarrow R_1 + H_2O \overset{\text{Fast}}{\longrightarrow} HN\leftarrow R_1 + ^*OH \text{ (ref. 7)} \quad (R_{32})
\]

\[
^*OH + ^*OH \overset{\text{Fast}}{\longrightarrow} H_2O + \frac{1}{2} O_2 \text{ (ref. 8)} \quad (R_{33})
\]

**Route R_4**

\[
R - C - N\leftarrow R_1 \xrightarrow{R_{41}} + H^+ \overset{k_{40}}{\rightarrow} R - C - N\leftarrow R_1 + H^+ \text{ (R_{40})}
\]

\[
R - C - N\leftarrow R_1 \xrightarrow{R_{41}} + H_2O \overset{\text{Fast}}{\longrightarrow} R - C - N\leftarrow R_1 + H^+
\]

\[
^*N\leftarrow R_1 + H_2O \overset{\text{Fast}}{\longrightarrow} H - N\leftarrow R_1 + ^*OH \text{ (ref. 7)} \quad (R_{43})
\]

\[
^*OH + ^*OH \overset{\text{Fast}}{\longrightarrow} H_2O + \frac{1}{2} O_2 \text{ (ref. 8)} \quad (R_{44})
\]
Oxidation of N-bromoacetamide by Co$^{3+}$ and Ce$^{4+}$

Route 5$_a$

$$R - C - N^{	ext{Br}} + M^{n+} + 2H_2O \xrightarrow{k_{50}} R - C - N^+ + H^+ + HOBr$$

$$R - C - N^{	ext{OH}} \xrightarrow{\text{OH}} R - C - N^+ + \text{HOBr}$$

$$R - C - N^{	ext{Fast}} \xrightarrow{\text{RCOOH} + \text{NH}_2 + M^{(n-1)+}}$$

$$\text{NH}_2 + H_2O \xrightarrow{\text{Fast}} \text{NH}_3 + \text{OH}$$

$$\text{OH} + \text{OH} \xrightarrow{\text{Fast}} H_2O + \frac{1}{2} O_2$$

$$\text{HOBr} \xrightarrow{\text{Fast}} H^+ + \text{Br}^- + \frac{1}{2} O_2$$

$$2\text{Br}^- + 2M^{n+} \xrightarrow{\text{Fast}} 2M^{(n-1)+} + \text{Br}_2$$

Oxidation of N-bromoacetamide by Tl$^{3+}$

Route 5$_b$

$$R - C - N^{	ext{Br}} + \text{Tl}^{3+} + 2H_2O \xrightarrow{k_{50}} R - C - N^+ + H^+ + HOBr$$

$$R - C - N^{	ext{OH}} \xrightarrow{\text{OH}} R - C - N^+ + \text{HOBr}$$

(R$_{50}$)
\[ R - C - N \xrightarrow{\text{Fast}} \text{RCOOh} + \text{NH}_2 + \text{Tl}^{2+} \quad (R_{51}) \]

\[ \text{NH}_2 + \text{H}_2\text{O} + \text{Tl}^{2+} \xrightarrow{\text{Fast}} \text{NH}_3 + H^+ + \text{Tl}^+ + \frac{1}{2} \text{O}_2 \]

.. (ref. 12) \hspace{1cm} (R_{52})

\[ \text{HOBr} \xrightarrow{\text{Fast}} H^+ + \text{Br}^- + \frac{1}{2} \text{O}_2 \]

.. (ref. 8) \hspace{1cm} (R_{53})

\[ 2\text{Br}^- + \text{Tl}^{3+} \xrightarrow{\text{Fast}} \text{Tl}^+ + \text{Br}_2 \quad \text{(ref. 12)} \hspace{1cm} (R_{54}) \]

From the proposed mechanism following rate law could be derived:

\[
\frac{d[A]}{dt} = k_{10} \left[ \text{MOH}^{(n-1)+} \right] \left[ \text{amide I} \right] + K_{20} K_{21} k_{22} \left[ \text{M}^{n+} \right] \left[ \text{amide} \right] + K_{30} k_{31} \left[ \text{amide} \right] \left[ \text{M}^{n+} \right] + K_{30} k_{40} \left[ H^+ \right] \left[ \text{M}^{n+} \right] \left[ \text{amide} \right] + k_{50} \left[ \text{M}^{n+} \right] \left[ \text{amide} \right] \]
\]

\[
= \frac{k_{10} K_{a} k_{30} \left[ \text{M}^{n+} \right] T \left[ A \right] \left[ H^+ \right]}{[H^+] \left(1+K_{h}\left[H^+\right]\right) \left(1+K_{a}\left[H^+\right]\right)} + \frac{k_{20} K_{21} k_{22} \left[ \text{M}^{n+} \right] T \left[ A \right] \left[ H^+ \right]}{[H^+] \left(1+K_{h}\left[H^+\right]\right) \left(1+K_{a}\left[H^+\right]\right)}
\]

\[
+ \frac{k_{30} k_{31} \left[ A \right] \left[ M^{n+} \right] T}{\left(1+K_{h}\left[H^+\right]\right) \left(1+K_{a}\left[H^+\right]\right)} + \frac{k_{40} K_{40} \left[ H^+ \right] \left[ M^{n+} \right] T \left[ A \right] \left[ H^+ \right]}{\left(1+K_{h}\left[H^+\right]\right) \left(1+K_{a}\left[H^+\right]\right)}
\]

\[
+ \frac{k_{50} \left[ A \right] \left[ M^{n+} \right] T}{\left(1+K_{h}\left[H^+\right]\right) \left(1+K_{a}\left[H^+\right]\right)}
\]
where \( k_1 = k_{10} K_a K_h \); \( k_2 = K_{20} K_{21} k_{22} \); \( k_3 = K_{30} k_{31} \);

\( k_4 = K_{30} k_{40} \) and \( k_5 = k_{50} \); \( M \) is metal (\( \text{Co}^{3+}, \text{Ce}^{4+}, \text{Tl}^{3+} \))

and \( \text{A} \) is amide.

The subscripts \( T \) and \( o \) outside the brackets denote the total and initial concentrations of oxidant and amide, respectively. For all the oxidants \( K_h \) is very small (\( K_h = 0.073 \) at \( 25^\circ C \) for \( \text{Tl}^{3+} \); \( K_h = 0.2 \) m/L at \( 25^\circ C \) for \( \text{Ce}^{4+} \)\(^{15} \) and \( K_h = 0.002 \) at \( 25^\circ C \) for \( \text{Co}^{3+} \)\(^{16} \)) and if \( K_a \) is to assume to be much less than unity (as amides are known to be weak bases) for all amides, the denominator

\[
(1 + K_h/\text{[H}^+]\)(1 + K_a/\text{[H}^+])
\]

is nearly constant and approaches to 1 in moderate acid concentration. Therefore, the rate of reaction may be expressed as follows:

\[
r.r. = n(k_1 + k_2/\text{[H}^+] + k_3 + k_4\text{[H}^+] + k_5)[M^{n+}]_T[A]_o
\]
or \[ \frac{d[M^{n+}]}{dt} = k_{obs} = n(k_1 + k_2/[H^+] + k_3 + k_4[H^+] + k_5) \cdot [A_j]. \]

\[ k = \frac{k_{obs}}{n \cdot [amide]} = (k_1 + k_2/[H^+] + k_3 + k_4[H^+] + k_5) \]

where \( n \) is the number of moles of oxidant required to oxidise one mole of the amide. The rate constants \( k_1, k_2, k_3 \) and \( k_4 \) are obtained from the plots of \( k_{obs} \) against \( 1/[H^+] \) or \( [H^+] \) (fig. 3).

**Oxidation of chloro- and iodo-acetamide**

The route \( R_1 \) and \( R_2 \) represent the oxidation of chloroacetamide and iodoacetamide by all the oxidants. It satisfies the requirements that the reaction is first order with respect to \([oxidant]\) and \([amide]\). It also satisfies stoichiometric as well as gasometric results. Most probably, \( R_3 \) and \( R_4 \) are not operative in the oxidation of chloro- and iodo-acetamides due to the presence of \( X \) at \( CH_2 \), most of the amides to be present in the enolised form

\[ XCH_2 - C = N - \]

\[ OH \]

and due to the absence of \( CH_2 \) at nitrogen, the oxidant-amide interaction at nitrogen is very weak. In \( R_2 \) the amide-oxidant complex in an acid base reaction interacts with water due to the presence of \( X \) at \( CH_2 \) (chloroacetic acid is stronger acid as compared to acetic acid). For the same
reason it can be argued out that $R_5$ is not a probable route in the oxidation of these amides. The general rate law gives the following rate expression for the oxidation of chloroacetamide and iodoacetamide:

$$r = (k_1 + k_2/[H^+]) [M_{n+}]_T [A]_0$$

It satisfies the requirements that the reaction is first order with respect to $[M^{n+}]$ and $[A]$. Furthermore, the plots of $k_{obs}$ against $1/[H^+]$ are linear indicating that the rate vary inversely with $[H^+]$ (fig. 3).

Oxidation of N-methylacetamide (NMA) and N,N-dimethylacetamide (DMA) with $Co^{3+}$ and $Ce^{4+}$

The oxidation of NMA and DMA with Tl(III) was not observed even at $50^\circ$C. At higher temperatures the amides are expected to be hydrolysed and the hydrolysed products are stable against the oxidant. This could be due to lower order potential of Tl(III).

It appears that only $R_3$ and $R_4$ mechanism are involved in the oxidation of NMA and DMA. However, it is evident on the basis of gasometric results that only oxygen is evolved during the oxidation of these amides. Thus further oxidation of acetic acid is ruled out. It explains the difference in the stoichiometry of the oxidation of these
amides as compared to other amides. Due to the presence of CH₃ at nitrogen, it is assumed that most of the amides in keto form, amide(I) is complexed with metal oxidants at nitrogen which is subsequently decomposed either by water or hydrogen ions.

In R₂ mechanism the decomposition of the intermediates

\[
\begin{align*}
\text{XCH}_2 \longrightarrow & \quad \text{C} \quad \text{N} \\
& \quad \text{O-M}(n-1)^+ \\
\end{align*}
\]

is assumed to be rate determining. The electron migration towards carbon is favoured by the presence of X in CH₃ which initiates the decomposition process. In case of NMA and DMA such electron migration is not possible. Therefore, route R₂ becomes insignificant even if the intermediate

\[
\begin{align*}
\text{R} \quad \text{C} \quad \text{N} & \quad \text{R}_1 \\
& \quad \text{O-M}(n-1)^+ \\
\end{align*}
\]

is formed. Furthermore, R₅ is not a probable route for the oxidation of these amides because CH₃ at nitrogen would result in stabilization of the intermediate as given in step R₅₀. The rate of reaction may therefore be expressed as

\[
r.r. = (k_3 + k_4[H^+]) [M^{n+}]_T[A]_0
\]
The rate expression explains our results that the rate of the reaction is first order with respect to $[\text{M}^{n+}]$ and $[\text{amide}]$ and vary proportionally with $[\text{H}^+]$ as is evident from the plots of $k_{\text{obs}}$ against $[\text{H}^+]$ which are linear (fig. 3).

**Oxidation of N-bromoacetamide**

The oxidation of N-bromoacetamide is exclusively proceeding through route $R_5$. In $R_1$ and $R_2$ the enolized amide(II) is taken as a reactive species, however, in this case amide (II) is not possible due to the presence of Br at nitrogen. Furthermore, due to the presence of Br at nitrogen, the complexation at N is not likely. Therefore, $R_1$ and $R_2$ are excluded. $R_3$ and $R_4$ involve complexation at nitrogen which requires the presence of methyl group. Thus $R_3$ and $R_4$ may not be operative in the oxidation of N-bromoacetamide. Finally, the rate of reaction may be given as:

$$r.r. = k_5[M^{n+}]_T[A]_0$$

The rate expression shows that the reaction is first order in both $[\text{oxidant}]$ and $[\text{amide}]$ and the concentration of $\text{H}^+$ does not influence the rate of the reaction.

For the oxidation of chloro- and iodo-acetamides we find that these are two simultaneous routes as given by the mechanism $R_1$ and $R_2$. It is seen that $\Delta H^\circ$ in the case
of R₁ mechanism is significantly larger as compared to \( \Delta H^\text{f} \) for R₂ mechanism for all the oxidants. This is quite expected as the R₁ mechanism involves interaction of similar charges. The activation energy for the second route R₂ has the following order \( \Delta H^\text{f}_{\text{Tl}^{3+}} > \Delta H^\text{f}_{\text{Co}^{3+}} > \Delta H^\text{f}_{\text{Ce}^{4+}} \). The activation energy is largely a measure of repulsive forces in the formation of activated complex. In the interaction of charged ion with neutral molecule with weak dipole - CO -, the greater charge on the oxidant may result in less activation energy. For the similar process in cases of Tl₃⁺ and Co₃⁺ reactions, the steric factor becomes more dominating, resulting in larger \( \Delta H^\text{f} \) for Tl₃⁺ reactions.

When we compare entropy of activation for the reactions, we find that \( \Delta S^\text{f} \) is more negative for route R₂ mechanism. This observation is also not surprising. It is expected that the activated complex in R₁ mechanism will be more positively charged and due to electrostriction effect \( \Delta S^\text{f} \) is relatively more negative. We understand that in an associative type of mechanism, electrostriction effect will be a function of charge and hydrated radii of the oxidant. Thus in case of Ce⁴⁺ or Ce(H₂O)₇OH₃⁺, due to the greater charge on the activated complex \( \Delta S^\text{f} \) is most negative. The difference in \( \Delta S^\text{f} \) for Co³⁺ and Tl₃⁺ reactions is not significant, but as the charges are same, \( \Delta S^\text{f} \) probably depends upon their radii and therefore \( \Delta S^\text{f} \) for Co³⁺.
reactions is marginally more negative as compared to $\Delta S^\neq$ for the oxidation of corresponding amide by $\text{Tl}^{3+}$. Furthermore, it is observed that in the activation parameters for chloro- and iodo-acetamides, $\Delta S^\neq$ is more negative for $R_2$ mechanism as compared to $\Delta S^\neq$ for $R_1$ mechanism. It appears that $\Delta S^\neq$ also depends upon the equilibria preceding the rate determining step. Although entropy of activation for $R_1$ mechanism is expected to be negative. In case of $R_2$ mechanism, it may be more negative due to the requirements of a series of precursors making the process leading to activation less probable. Secondly we suggest that in much complex reactions, activation parameters depend upon the history of precursors leading to activated complex. Assuming that in any given reaction $k_{obs} = kK$, is very small due to the presence of large number of preceding equilibria. This shows that thermodynamics of preceding equilibrium may also have great influence on the activation parameters.

In the oxidation of chloro- and iodo-acetamides, we find that for the same oxidant, the oxidation parameters are observed to be independent of nature of amides. In $R_1$ mechanism the rate determining step involves the interaction like charges. Therefore, it is hardly surprising that nature of amide does not influence activation parameters. In route $R_2$ mechanism the equilibrium preceding the rate determining step involves deprotonation of $\text{-OH}$ group in complex I.
The deprotonation may be greater for chloroacetamide. However, the rate determining step involves dissociation of 0-M\(^{(n-1)}\)\(^+\) bond in complex II. For this process the trend may be in the reverse order. Thus the activation parameters do not depend upon the nature of amides.

While comparing the activation energies for the oxidation of N,N-dimethylacetamide and N-methylacetamide by Co\(^{3+}\)\(_{aq}\) and Ce\(^{4+}\)\(_{aq}\) ions, we find that in the case of DMA, the activation energy for Co\(^{3+}\) oxidation is marginally less than the activation energy for Ce\(^{4+}\) oxidation. We understand that in Ce\(^{4+}\) oxidations the steric factor dominates over all other factors and in the case of Co\(^{3+}\)\(_{aq}\) oxidations, the steric factor is not significant. This is quite evident from the activation energies of DMA and NMA as the activation energy for DMA reactions is greater than the activation energy for NMA reaction with Ce\(^{4+}\)\(_{aq}\) ion. In the oxidations with Co\(^{3+}\)\(_{aq}\) ion, the rate of the reaction depends upon the structure of amide as the order of the activation energies for acetamide\(^{17}\), N-methylacetamide and N,N-dimethylacetamide is \(\Delta H^f_A > \Delta H^f_{NMA} > \Delta H^f_{DMA}\).

From the mechanism we see that route \(R_3\) and \(R_4\) are followed in the oxidation of DMA and NMA. It is evident from the comparison of activation parameters for the both the routes that the mechanisms are identical. First the
amide in keto form, amide(I) is complexed with oxidant at nitrogen which is subsequently decomposed either by water or H⁺.