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A Hydrolysis of Ester Catalyzed by Pentaammine-imidazolatoruthenium(III) complexes

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Introduction

It is well known that the imidazole group is included in the Zn-carbonic anhydrase [1]. Various mechanisms have been proposed for the reaction of tne anhydrase [2–5]. In order to investigate the reaction mechanism of the Zn-carbonic anhydrase, a hydrolysis of *p*-nitro-phenylacetate (PNPA) has been carried out as a model reaction by using pentaamine-imidazolatocoblat(III), $Co(Im)(NH_3)_5^{2+}$ (herewith, imidazole and imidazolato anion are abbreviated as ImH and Im^-, respectively.). On the other hand, some investigations have been reported about an asymmetrical hydrolysis of ester by an imidazole group coordinated to a transition metal ion with a view to obtain an enzyme-like catalyst [6–8]. However, reaction rate of hydrolysis is usually decreased by an addition of metal ion, whereas the enantio-selectivity is increased by the addition [7, 8]. A good catalyst must not only give high enantio-selectivity but also high reaction rate. In this work, the hydrolysis of PNPA is carried out by using pentaammine-imidazolatoruthenium(III), $[Ru(Im)(NH_3)_5]^{2+}$.

This work has two purposes, because unobscure imidazole complex of transition metal ion has never been applied to hydrolysis of ester except for $Co(Im)(NH_3)_5^{2+}$, as far as the authors are aware: first, to investigate whether the results obtained from the PNPA hydrolysis by $Co(Im)(NH_3)_5^{2+}$ are valid for any metal complex of imidazole, or not; second, to look for the desirable metal ion which coordinates the imidazole group to give high activity for the hydrolysis of ester.

Experimental

Pentaammineimidazolaruthenium(III), $[Ru(Im)(NH_3)_5](BF_4)_2$, and pentaammineaquaruthenium(III), $[Ru(NH_3)_5(H_2O)](PTS)_3$ (PTS = *p*-toluenesulfonate), were synthesized according to a method of Taube *et al.* [9, 10], with slight modification. Their purity was ascertained by elemental analysis. The latter complex was converted to pentaammine-hydroxoruthenium(III), $Ru(OH)(NH_3)_5^{2+}$ in high pH range and was used to catalyze PNPA hydrolysis for comparison with the hydrolysis by $Ru(Im)(NH_3)_5^{2+}$- The hydrolysis of PNPA (5.0×10^{-4} mol dm^{-3}) was performed by using these complexes (*ca.* 2.5×10^{-3} mol·dm^{-3} and *ca.* 2.5×10^{-2} mol·dm^{-3} for the Ru(III)-imidazole complex, *ca.* 2.5×10^{-3} mol·dm^{-3} for the Ru(III)-hydroxo complex), where the trizma buffer was used to give pH = 8 ~ 10 and the ionic strength was made 0.10 by addition of sodium *p*-toluenesulfonate. The reaction rate was measured by observing an increase in absorbance at 400 nm due to released *p*-nitrophenolato anion with stopped flow apparatus (Union Giken RA-401).

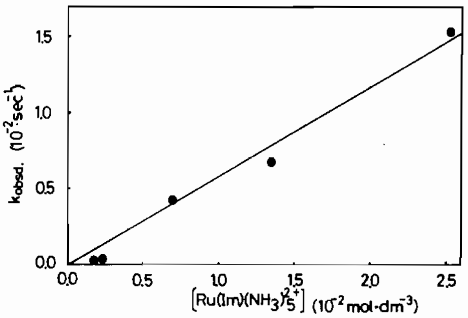

Fig. 1. Relation between the k_{obsd} for PNPA hydrolysis and the concentration of $Ru(Im)(NH_3)_5^{2+}$.

Results and Discussion

Because pKa of $Ru(ImH)(NH_3)_5^{3+}$ is 8.9 [9], the reaction system includes $Ru(Im)(NH_3)_5^{2+}$ and $Ru(ImH)(NH_3)_5^{3+}$ under the examined pH range (8 ~ 10). It is also conceivable that ruthenium(III) hydroxo complex is formed by hydrolysis of $Ru(Im)(NH_3)_5^{2+}$ and/or $Ru(ImH)(NH_3)_5^{3+}$, because the ruthenium(III) pentaammine complex is well known to be easily converted to the ruthenium(III) hydroxo complex in the high pH range. Following two experiments were carried out in this work. In the first one, the hydrolysis of PNPA was examined under various pH values. The reaction is described by a pseudo-first order rate law. The observed rate constant, k_{obsd}, was given as a function of a concentration of $Ru(Im)(NH_3)_5^{2+}$ estimated under assumptions that the reaction system includes $Ru(Im)(NH_3)_5^{2+}$ and $Ru(ImH)(NH_3)_5^{3+}$ and that the ruthenium(III) hydroxo complex is absent. As is shown in Fig. 1, the k_{obsd} is linearly dependent on the concentration of Ru-

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TABLE I. Rate Constants of PNPA Hydrolysis by Various Catalysts.

Catalyst	k_a[a] (sec^{-1} mol^{-1} dm^3)	k_{tot}[b] (sec^{-1} mol^{-1} dm^3)	pKa	
OH^-	9.5	3.0×10^{-7}	15.5	Ref. 11
Imidazole	5.8×10^{-1}	5.0×10^{-1}	7.2	Ref. 11
$Co(Im)(NH_3)_5^{2+}$	1.52×10^{-3}	8.5×10^{-2}	10.02	Ref. 3
$Ru(Im)(NH_3)_5^{2+}$	6.5×10	7.3	8.9[c]	This work

[a] $k_a = k_{obsd}$/(concentration of active species). [b] $k_{tot} = k_{obsd}$ at pH = 8)/(concentration of total catalyst). [c] See Ref. 9.

(Im)$(NH_3)_5^{2+}$. In the second one, the PNPA hydrolysis was carried out by using Ru(OH)$(NH_3)_5^{2+}$. But the reaction rate is very slow relative to the ruthenium(III) imidazole catalytic system*, where the reaction obeys the pseudo-first order rate law. These results suggest that the active species is Ru(Im)$(NH_3)_5^{2+}$ and that the ruthenium(III) hydroxo complex is scarcely formed in the examined pH range.

The rate constant per active species, k_a, is evaluated to be 65 $sec^{-1} \cdot mol^{-1} \cdot dm^3$ from the slope of the line given in Fig. 1, and it is listed in Table I, together with rate constants of the other catalysts. The k_a value of Ru(Im)$(NH_3)_5^{2+}$ is remarkably larger than those of the free imidazole [11] and the similar cobalt(III)-imidazolato complex, Co(Im)$(NH_3)_5^{2+}$ [3]. We are interested in the activity at pH 7 ~ 8 where the enzyme shows the greatest catalytic activity. The rate constant per total metal complex, k_{tot}, is evaluated at pH = 8.0 from the k_a and pKa values. As is listed in Table I, it is noted that the k_{tot} of cobalt(III) imidazole catalytic system is remarkably less than that of the free imidazole catalytic system. This result suggests the catalytic ability of imidazole is decreased by coordination to a metal ion in the near neutral pH range. Since the zinc(II) ion is included in the active center of the zinc-carbonic anhydrase, the nucleophilic zinc-imidazolate mechanism, where the imidazolato anion coordinated to the zinc(II) ion is considered to play an essential role of the catalysis, seems doubtful. However, the k_{tot} value of ruthenium(III) imidazole catalytic system is remarremarkably larger than those of the free imidazole and the cobalt(III) imidazole catalytic systems, as is shown in Table I, suggesting that the catalytic ability of the imidazole is increased by coordination to the ruthenium(III) ion. Thus, the nucleophilic zinc-imidazole mechanism is not always neglected, even though the imidazole coordinates to the cobalt(III) to decrease its catalytic ability at pH 7 ~ 8.

It should be noted that the ruthenium(III) imidazole catalytic system is the first example to give higher rate constant of PNPA hydrolysis than the free imidazole at pH = 8. It is expected to obtain a good catalyst having enatio-selectivity and high activity, when some optical active ligands are introduced to the ruthenium(III) imidazole complex.

In summary, two important conclusions are obtained. One, the much effective catalyst for the ester hydrolysis is expected to be obtained by using the ruthenium(III) ion, because Ru(Im)$(NH_3)_5^{2+}$ gives remarkably high catalytic ability. Another, although the nucleophilic zinc-imidazole mechanism for carbonic anhydrase seems questionable from the PNPA hydrolysis using cobalt(III) imidazole complex, the present result of PNPa hydrolysis using ruthenium(III) imidazole complex partially eliminates the problem. Of course, a clear conclusion is not achieved here and further study is necessary in order to elucidate the active site and reaction mechanism of zinc-carbonic anhydrase.

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*k = 0.04 ± 0.01 sec^{-1} mol^{-1} dm^3 for the PNPA hydrolysis by Ru(OH)$(NH_3)_5^{3+}$.

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