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Location of Catalytic Head Group of 2-Hydroxymethylimidazole•Cu^{2+} Complex on the Micellar Surface of Anionic SDS in the Hydrolysis of *p*-Nitrophenyl Picolinate

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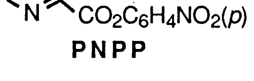
Five cationic surfactants, each having a 2-hydroxymethylimidazole moiety which is connected to ammonium nitrogen with a spacer group of $(CH_2)_m$ and co-micelled with a non-functional surfactant, have been examined for their catalytic activities for the hydrolysis of *p*-nitrophenyl picolinate. They were highly active in the presence of Cu^{2+} and the activity increased with increasing methylene number in the order m = 3<4<6.

We have reported several functional surfactants which serve as the apoenzyme models of hydrolytic metalloenzymes.[1-3] Previously, we suggested that such functional surfactants may be classified into two classes, i.e. (a) a charged group occupies the terminal of the surfactant chain with a functional group inside, and (b) a functional group occupies the terminal with a charged group inside, and that the catalytic activities of the metal ion complexes of the latter surfactants are more susceptible to the change of microenvironment surrounding the catalytic group than those of the former surfactants.[2] We wish to report herein a remarkable effect of chain length of the spacer connecting the terminal catalytic group to the charged group of a functional surfactant which belongs to the above (b) surfactant.

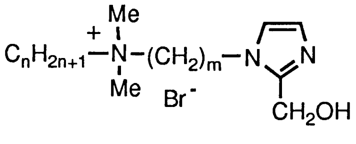
Five cationic surfactant-ligands (**1**-**5**), each having a metal ion-chelating 2-hydroxymethylimidazole functional group, have been prepared and their catalytic activities for the hydrolysis of *p*-nitrophenyl picolinate (**PNPP**) in the presence of Cu^{2+} have been examined under the co-micellar conditions of either of three non-functional surfactants, i.e. a cationic **HTAB**, an anionic **SDS**, and a non-ionic **Triton X-100**. The ligands **1**-**3** have methylene spacers of different length between the imidazole ring and the charged ammonium nitrogen. The ligands **1**, **4**, and **5** have long alkyl chains of different length.



PNPP

$CH_3(CH_2)_{15}N^+Me_3Br^-$

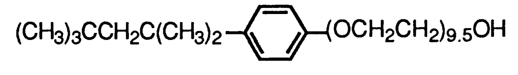
HTAB



1 : n=12, m=3
2 : n=12, m=4
3 : n=12, m=6
4 : n=14, m=3
5 : n=16, m=3

$CH_3(CH_2)_{11}OSO_3^-Na^+$

SDS



Triton X-100

The kinetics were conducted in buffered mixed micelles of a surfactant ligand and a non-functional surfactant, dissolving **PNPP** and Cu^{2+}. The molar ratio of the former ligand and the latter surfactant was 1:100, so that the micellar environment must be governed largely by the latter non-functional surfactant. The pseudo-first-order rate constants (k_{obsd}) were determined as usual by monitoring the release of *p*-nitrophenolate from **PNPP** at 400 nm by using a stopped-flow spectrophotometer. The results are shown in Figs. 1-4.

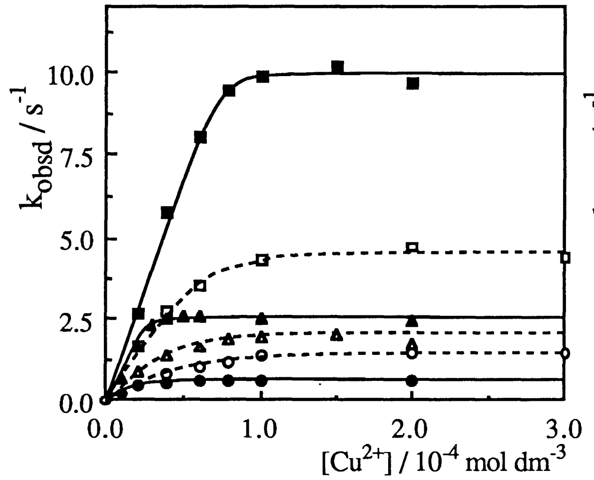


Fig. 1. Plots of pseudo-first-oder rate constants vs. Cu^{2+} concentration for the transacylation of **PNPP** in miceller conditions, [Ligand]=1.0×10^{-4} mol dm^{-3}, [Surfactant]=1×10^{-2} mol dm^{-3}, [PNPP]=2.0×10^{-5} mol dm^{-3};
○ : **1**-HTAB, △ : **2**-HTAB, □: **3**-HTAB (--- line);
● : **1**-SDS, ▲ : **2**-SDS, ■ : **3**-SDS (— line).

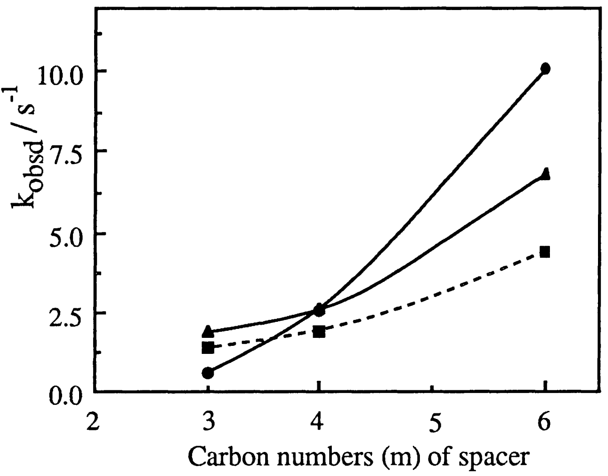
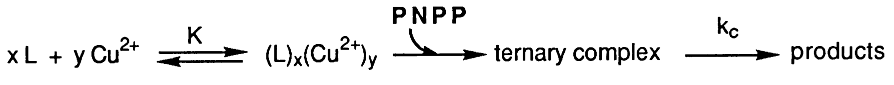


Fig. 2. Effects of the carbon numbers of the spacers in Ligands **1**-**3** vs. pseudo-first-order rate constants at the saturated levels in Fig. 1; ● : in SDS, ▲ : in Triton X-100, ■ : in HTAB.

As shown in Fig. 1, the rates of **1**-**3** increased with increasing concentration of Cu^{2+} up to a saturation level for each combination of ligand and surfactant (**HTAB** or **SDS**). Although not shown, the rate constants of **4** and **5** were almost the same as those of **1**. Thus the rates were almost indifferent to the change of chain-length of alkyl groups (n).[4] On the other hand, Figs. 1 and 2 indicate that the k_{obsd} values at the saturation levels were highly dependent on the carbon number (m) of spacer groups of **1**-**3**. Such dependency was in the order of **SDS** > **Triton X-100** > **HTAB** micelles. For example, in **SDS** micelles, the rate increased more than 20 fold by increasing the carbon number from m=3 (**1**) to 6 (**3**), and the rate constant of the latter **3** was 7.7×10^5 fold larger than that of spontaneous rate (1.3×10^{-5} s^{-1}).

In Fig. 3 is shown the kinetic version of Job plots which were carried out in **SDS** micelles in order to obtain the information about the stoichiometry in forming an active complex $(L)_x(Cu^{2+})_y$ illustrated in Scheme 1. The plot of **3** appears to indicate that the most active complex is a 1:1 complex showing a rate maximum at $\gamma = 0.5$

(x=y=1). However, the plots of **1** and **2** are rather unusual giving a rate plateau for a wide range of γ values. Although it is difficult to give any rational explanation at present, such a plateau plot may suggest that co-existing complexes of different composition have similar activities.



$$x\,L + y\,Cu^{2+} \underset{}{\overset{K}{\rightleftharpoons}} (L)_x(Cu^{2+})_y \xrightarrow{\text{PNPP}} \text{ternary complex} \xrightarrow{k_c} \text{products}$$

Scheme 1.

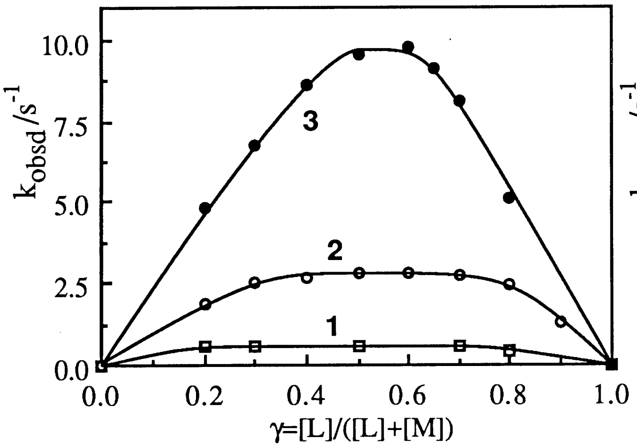


Fig. 3. Job plots of pseudo-first-order rate constants for the transacylation of **PNPP** in SDS micelles, [Ligand]+[Cu^{2+}]=2.0x10^{-4} mol dm^{-3}, [SDS]=1x10^{-2} mol dm^{-3}, and [**PNPP**]=2.0x10^{-5} mol dm^{-3}; □ : **1**, ○: **2**, and ● : **3**.

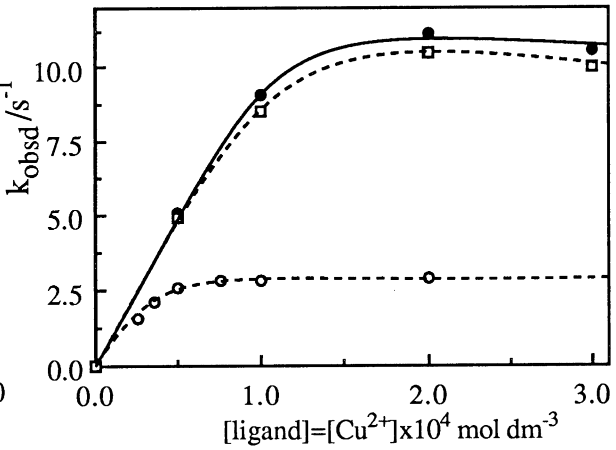


Fig.4. Plots of rate constants vs. concentrations of ligand and Cu^{2+} ion for the transacylation of **PNPP** in SDS micelles; [ligand]=[Cu^{2+}], [SDS]=1x10^{-2} mol dm^{-3}; ○: **2**, ● : **3** at [**PNPP**]=1.0x10^{-5} mol dm^{-3}, □ : 3 at [**PNPP**]=2.0x10^{-5} mol dm^{-3}.

Figure 4 shows the rate profiles of **2** and **3** obtained as the functions of their concentrations. The profiles are very similar to the correspoding profiles of **2** and **3** in Fig. 1, suggesting that the formation of ternary complex (in Scheme 1) completes at low concentrations of three components, i.e. **PNPP**, a ligand, and Cu^{2+}.

The charged head groups in a normal non-functional micelle are located in the Stern layer which covers the micellar surface with a few angstroms in thickness.5) The length of the spacer units of **1**-**3** in a extended form is calculated to be 3.8-7.5 Å based on 1.25 Å per one carbon. In SDS micelles, a cationic ammonium nitrogen of

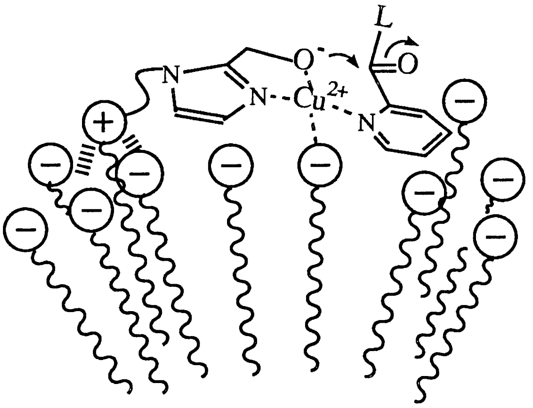


Fig. 5. A schematic illustration how a cationic imidazole ligand **3** is bound and activated on the micellar surface of **SDS**.

1-3 is likely held firmly on the anionic Stern layer by electrostatic interaction as well as cooperative hydrophobic interaction between alkyl chains, and thus a catalytic group of 2-hydroxymethyl-imidazole•Cu^{2+} of these ligands is also bound on or close to the Stern layer as illustrated schematically in Fig. 5. It is conceivable that a spacer of an appropriate length like in **3** gives flexibility to the ligand to form a more favored complex for catalysis. Such a flexibility may be lost in the case of **1** resulting to a low activity, even lower than those in HTAB.

Much remains to be clarified. Nevertheless, the above mentioned findings on the effects of spacer unit are valuable for the design of catalytic functional micelles.

References

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2) K. Ogino, T. Yoshida, K. Nishi, T. Fujita, and W. Tagaki, *Chem. Lett.*, **1991**, 341.
3) For other examples, see: R. Fornasier, D. Milani, P. Scrimin, and U. Tonellato, *J. Chem. Soc., Perkin Trans. 2*, **1986**, 233; V. Faivre, A. Brembillia, D. Roizard, and P. Lochon, *Tetrahedron Lett.*, **26**, 192 (1986) ; R. Fornaiser, P. Scrimin, P. Tecilla, and U. Tonellato, *J. Am. Chem. Soc.*, **111**, 224 (1989).
4) The system becomes a non-micellar reaction with a low catalytic activity when the alkyl chain-length becomes much shorter, i.e. n=1-4.
5) J. H. Fendler and E. J. Fendler, "Catalysis in Micellar and Macromolecular Systems," Academic Press, New York, (1975); F. M. Menger and D. W. Doll, *J. Am. Chem. Soc.*, **106**, 1109 (1984).

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