Decarboxylation of 6-Nitrobenzisoxazole-3-carboxylate Anion Catalyzed by Systematically Quaternized Poly(4-vinylpyridines). "Average Side-Chain Length" as a Useful Index for Relative Hydrophobicity of the Polymer Domain[1]

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In an attempt to find a relation between the structure of water–soluble polymers and their catalytic efficiencies, decarboxylation (30 °C, aqueous medium) of the title carboxylate ion (1) was used as a kinetic probe. The polymers employed were poly(vinylpyridines) quaternized by octyl (C_8; 3–15 mol %), dodecyl (C_{12}, 22–33 mol %), octadecyl (C_{18}, 3–15 mol %), and docosyl (C_{22}, 3–10 mol %) groups. The majority of the remaining pyridine unit was quaternized by an ethyl group. The augmentation of the decarboxylation rate was associated with formation of the hydrophobic domain by side-chain aggregation as inferred from viscosity reduction and shifts of λ_{max} of methyl orange. A new parameter "average side-chain length ($\bar{L}$)" was introduced as an index of the relative contribution of pendant alkyl groups to the polymer hydrophobicity. The optimal balance of water solubility and hydrophobicity was achieved by the octyl-substituted polymer: $\bar{L} = 5.0$. The logarithmic rate constant linearly correlated with this parameter. The transition from polyelectrolyte (extended polymer chain) to polymer micelle (shrunken polymer chain) was shown to occur at $n\bar{L} \simeq 40$. Poly(vinylpyridines) of different molecular weight were prepared and quaternized by dodecyl (ca. 30 mol %) and ethyl groups. The catalytic efficiency of these polysoaps agreed within the experimental error. The decarboxylation data were compared with the acyl-transfer data between a long-chain hydroxamate and *p*-nitrophenyl acetate. The local hydrophobicity was influential for the latter reaction, in contrast with the dominant influence of the overall hydrophobicity ($\bar{L}$) in the decarboxylation.

Charged polysoaps (polymer micelles) which are prepared, for example, by quaternization of polymeric amines by long alkyl chains combine within a molecule structural characteristics of the conventional micelles and polyelectrolytes, and the hydrophobicity is readily adjustable by changing the content and length of the alkyl group. Therefore, the polysoap may be one of the most convenient systems to study the role of electrostatic and hydrophobic interactions in aqueous systems.

The catalytic behavior of polysoaps has been reported by several groups.[3–8] To the best of our knowledge, however, there is no precedent for the systematic investigation concerning the influence of both the content and length of the pendant alkyl group on the catalytic efficiency. We thus prepared poly(4-vinylpyridine) polysoaps by systematic quaternization by ethyl (C_2), octyl (C_8), dodecyl (C_{12}), octadecyl (C_{18}), and docosyl (C_{22}) groups and dissected the possible relation between the polymer structure and the catalytic efficiency. The decarboxylation of 6-nitrobenzisoxazole-3-carboxylate anion (eq 1) is uni-

(1)

1   **2**
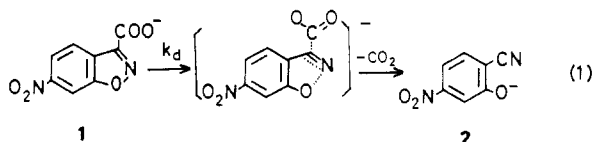
molecular, free from acid and base catalyses, and particularly sensitive to the medium effect. Because of these advantages, the reaction has been used as a kinetic probe

under a variety of reaction conditions. The reaction medium employed in the past includes homogeneous solution (organic and aqueous),[9–12] aqueous micelles,[13–15] cyclodextrins,[16] polymer micelles,[7,17] polymeric crown ethers,[18–20] and bilayer membranes.[21]

A previous study of the polysoap catalysis of the decarboxylation from these laboratories was limited to dodecyl-substituted polysoaps.[7] It is expected that a general structure-reactivity relation may be found by using systematically prepared polysoaps.

The cleavage of *p*-nitrophenyl acetate was also studied using a hydrophobic nucleophile (eq 2). A comparison of the polysoap catalysis in these different reactions would provide important information on the nature of the polysoap catalysis.

Experimental Section

Materials. The preparation and/or purification of **1**, DBHA, and PNPA were reported previously.[7,22] The unfractionated

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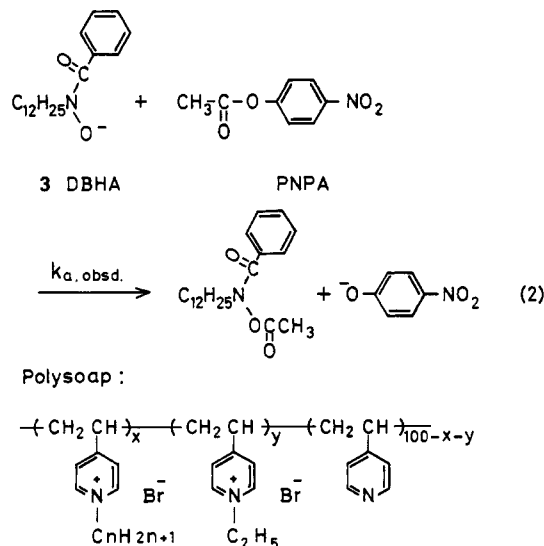(17) Suh, J.; Scarpa, I. S.; Klotz, I. M. *J. Am. Chem. Soc.* 1976, *98*, 7060–7064.
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3 DBHA   **PNPA**

$$\xrightarrow{k_{a,\text{obsd.}}} \quad \text{(2)}$$

Polysoap :

Table I. Composition of Polymers

| | | compn | | | |
polymer	abbreviation	alkyl chain length, n	x, mol %	y (ethyl), mol %	$\bar{L}$
1	4VP-C$_8$(8)	8	8	67	2.0
2	4VP-C$_8$(23)	8	23	71	3.3
3	4VP-C$_8$(34)	8	34	58	3.9
4	4VP-C$_8$(43)	8	43	45	4.3
5	4VP-C$_8$(54)	8	54	36	5.0
6	4VP-C$_{12}$(22)	12	22	42	3.5
7	4VP-C$_{12}$(33)	12	33	48	4.9
8	4VP-C$_{18}$(3)	18	3	81	2.2
9	4VP-C$_{18}$(6)	18	6	64	2.4
10	4VP-C$_{18}$(8)	18	8	77	3.0
11	4VP-C$_{18}$(15)	18	15	58	3.9
12	4VP-C$_{22}$(3)	22	3	89	2.4
13	4VP-C$_{22}$(10)	22	10	68	3.6
14	4VP-C$_2$(84)	2	$x + y = 84$		1.7

Table II. 4VP-C$_{12}$ Polysoaps

| | polymerization conditions | | | | content of |
polymer	method[b]	temp, °C	time, h	mol wt of starting polymer[a]	dodecyl group, mol %
15	solution[c] (EtOH)	70	24	4.4×10^3	41
16	solution (MeOH)	50–70	19	2.1×10^4	29
17	solution (MeOH)	70	20	7.1×10^4	30
18	suspension (H$_2$O)	60–90	3	2.2×10^5	28
19	suspension (H$_2$O)	65	3	4.3×10^5	37
20[d]	solution (MeOH)	70	17	6.8×10^4	30

[a] Estimated from $[\eta]_{30\ °C}$ (EtOH) = (2.5 × $10^{-4})M_w{}^{0.68}$.[22]   [b] The solvent is indicated in parentheses. [c] Dodecylmercaptane was used as a chain-transfer agent. [d] Unfractionated polymer.

polysoaps were prepared from a single lot of poly(4-vinylpyridine) and a series of alkyl bromides. The details of the preparative method have been described.[6,7] The extent of quaternization of the polymers is summarized in Table I with their abbreviations. In order to obtain polymers with different molecular weights, we polymerized 4-vinylpyridine under several sets of conditions. The polymers were then fractionated by methanol and toluene.[23] The middle fraction was recovered, its molecular weight was measured, and it was subjected to quaternization by dodecyl and ethyl bromides. Completion of the quaternization was confirmed by disappearance of IR peaks at 1420 and 1600 cm^{-1}. Table II summarizes these results.

Measurements. The spectroscopic and rate measurements were carried out at 30 ± 0.1 °C and pH 9.1 ± 0.1 with 0.02 M borate buffer in 2.9% (v/v) aqueous ethanol with an ionic strength of 0.01 (KCl), unless otherwise stated. The kinetic method has been described in the preceding papers.[6,7] Viscosities of aqueous polymers were measured at 30 °C by using a modified Ubbelohde viscometer. Linear plots of η_{sp}/c vs. c were observed for all the polymers at an ionic strength of 0.01.

Results

Characterization of Polysoaps. For estimation of the relative hydrophobicity of the polysoap, the absorption maximum (λ_{max}) of methyl orange was measured in the presence of 1.0×10^{-3} M polysoaps. The polysoap concentration is given by the total monomeric unit. According to Klotz et al.[24,25] and others,[26] methyl orange has λ_{max} at 465 nm in aqueous solution, whereas apolar environments cause significant shifts of λ_{max} to shorter wavelengths. Thus, the absorption spectrum of methyl orange is quite useful as a qualitative measure of the hydrophobic environment. The results summarized in Figure 1 reveal that all the polysoaps (except for 4VP-C$_2$(84) produce appreciable hypsochromic shifts and that the magnitude of the shift increases with the increase in the alkyl group content. It is also noted that, when the shift is compared at the same alkyl group content, the polysoaps with longer alkyl chains such as octadecyl or docosyl elicit greater hypsochromic shifts. In particular, the largest hypsochromic shift observed for 4VP-C$_{22}$(10) (λ_{max} 409 nm) far exceeds that observed in the presence of native bovine serum al-
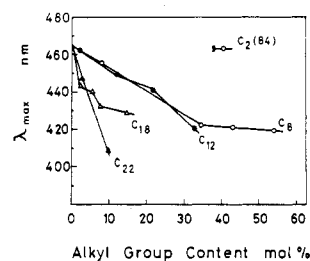

Figure 1. Shifts of the absorption maximum of methyl orange plotted against the content of long-chain alkyl groups: 30 °C, 3% (v/v) ethanol, μ = 0.01 with KCl, pH 8.9 with 0.01 M borate buffer, [methyl orange] = 2.60×10^{-5} M, [polymer (monomeric unit)] = 1.0×10^{-3} M.

bumin (430–440 nm), a hydrophobic carrier protein.[26] The λ_{max} shift was insensitive to the difference in molecular weight of the starting polymer.

The intrinsic viscosity was determined under the same conditions as those of the kinetic study. Since the same starting polymer was used for quaternization, the variation in the viscosity should closely reflect the conformation change of the polysoap. The intrinsic viscosity is markedly dependent on the content and length of the alkyl group. Table III provides several interesting features for the relation between the polymer structure and the viscosity: (1) the intrinsic viscosity is reduced at lower extents of quaternization for polymers with longer alkyl chains; (2) the

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Table III. Viscosity and Kinetic Data

polysoap	$[\eta],^a$ dL g^{-1}	$10^4 k_d{}''$, s^{-1}	K, M^{-1}	r^b
4VP-C$_8$(8)	0.33	1.4	2600	0.971
4VP-C$_8$(23)		1.8	3600	0.989
4VP-C$_8$(34)	0.37	5.7	600	0.988
4VP-C$_8$(43)		9.0	2100	0.987
4VP-C$_8$(54)	0.04	11.0	4100	0.992
4VP-C$_{12}$(22)^c		4.6	3270	0.979
4VP-C$_{12}$(33)^c		10.1	2370	0.997
4VP-C$_{18}$(3)	0.40	2.0	1400	0.975
4VP-C$_{18}$(6)		3.9	1200	0.981
4VP-C$_{18}$(8)	0.19	5.2	1800	0.977
4VP-C$_{18}$(15)	0.24	6.6	1700	0.998
4VP-C$_{22}$(3)		3.2	2000	0.999
4VP-C$_{22}$(10)	0.14	4.9	700	0.994
4VP-C$_2$(84)		0.36×10^{-4} ^{d} (k_d)		
none		0.07×10^{-4} $(k_d{}')$		

^{a} 30 °C, $\mu = 0.01$ with KCl. ^{b} Correlation coefficient for the treatment by eq 2. ^{c} Cited from ref 5.
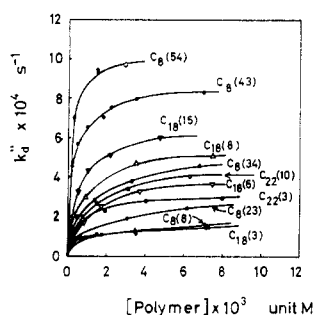^{d} [Polysoap] $= 3.0 \times 10^{-3}$ M.

Figure 2. Decarboxylation rate plotted as a function of the concentration of the 4-VP polysoaps: [1] $= 1.23 \times 10^{-4}$ M, pH 9.0 with 0.02 M borate buffer, $\mu = 0.01$ with KCl.

smallest $[\eta]$ value was observed for the 4VP-C$_8$(54) polymer, not for polymers with longer alkyl chains such as 4VP-C$_{18}$ and 4VP-C$_{22}$; (3) data for the 4VP-C$_{18}$ series suggest that there is an optimal alkyl content for the viscosity reduction.

It is known that the viscosity of the 4VP polymer quaternized by dodecyl and ethyl groups changes drastically at the 10–13 mol % dodecyl content.[27] Similar changes occur for 4VP-C$_8$ and 4VP-C$_{18}$ polymers as indicated by the data of Table III, but the transition composition varies with the alkyl chain length: 40–50 mol % for 4VP-C$_8$ and ca. 5 mol % for 4VP-C$_{18}$. The polymer with longer alkyl chains undergoes the transition at lower contents of the alkyl group.

Polysoap Catalysis of the Decarboxylation. The decarboxylation of 1 is extremely slow in an aqueous solution: k_d (first-order rate constant) $= 7 \times 10^{-6}$ s^{-1} at 30 °C. The 4VP-C$_2$(84) polymer which hardly affects the absorption maximum of methyl orange accelerated the decarboxylation only 5-fold. The intrinsic viscosity of the quaternized polymer is large when the polymer shows the polyelectrolyte behavior in the absence of pendant, long alkyl chains (see Table III). The negligible rate enhancement by 4VP-C$_2$(84) suggests that the macroscopic viscosity increase, if any, of the reaction medium by added polymers does not influence the decarboxylation rate. In fact, the decarboxylation rate was enhanced more efficiently by other polysoaps which give reduced viscosities. The rate increased at very low concentrations and finally reached plateaus (Figure 2). As described previously,[7] the
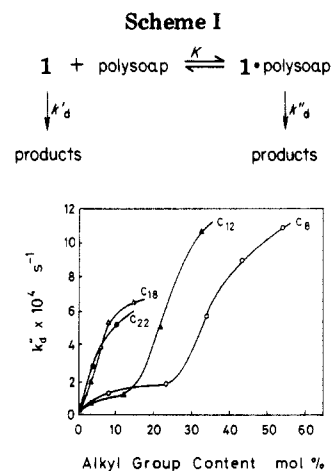
Scheme I

$$1 + \text{polysoap} \underset{}{\overset{K}{\rightleftharpoons}} 1 \cdot \text{polysoap}$$

Figure 3. $k_d{}''$ vs. higher alkyl group content of the polysoap. The reaction conditions are the same as in Figure 2.

rate–polymer concentration profile is rationalized in terms of the partitioning of substrate between the bulk phase and the polysoap phase and progressive binding to the polysoap phase with increasing polysoap concentrations. This situation is expressed by Scheme I, where K is the equilibrium constant for the association of substrate with polysoap ($=[1(\text{adsorbed})]/[1][\text{polymer}]$), $k_d{}'$ is the decarboxylation rate constant without polymer, and $k_d{}''$ is that for the polysoap-bound species. Since $k_d{}'$ is obtained separately in the absence of the polysoap (7×10^{-6} s^{-1}), two kinetic parameters, K and $k_d{}''$, can be determined by the least-squares computation of the experimental data by eq 3,[28,29] where $q = (k_d{}''/k_d{}') - 1$. The results of the calculation

$$\frac{k_d{}'}{k_d - k_d{}'} = \frac{1}{qK[\text{polysoap}]} + \frac{1}{q} \tag{3}$$

are summarized in Table III together with the correlation coefficient (r).

It is seen from Table III that the change in the decarboxylation rate for the polysoap-bound substrate ($k_d{}''$) corresponds approximately to the reduction of the intrinsic viscosity. For example, the rate change in the presence of the 4VP-C$_8$ polymer is pronounced at around 30–40 mol % of the octyl group content where the viscosity reduction is observed. Clearly, the rate enhancement is associated with the formation of the compact, hydrophobic domain. The rate enhancement occurs at lower alkyl contents for polymers with longer alkyl chains.

Figure 3 shows the $k_d{}''$ value plotted against the alkyl group content. As already reported for the 4VP-C$_{12}$ polysoap,[7] $k_d{}''$ increases with the alkyl group content. The largest rate was attained by the 4VP-C$_8$ polymer. In the case of the other polysoaps with longer alkyl chains, $k_d{}''$ is enhanced efficiently at lower alkyl contents. These polymers become insoluble upon further increases in the alkyl content and cannot be used as a catalyst.

The binding constant K is in the range of 1000–3000 M^{-1} in most cases. This value cannot be correlated well with the polymer structure (the content and the length of alkyl substituents) or with the intrinsic viscosity. The K value is experimentally less reliable because it is determined by the saturation curvature (Figure 2). Therefore, the exceptionally low K values for 4VP-C$_8$(34) and 4VP-C$_{22}$(10) could be artifacts.

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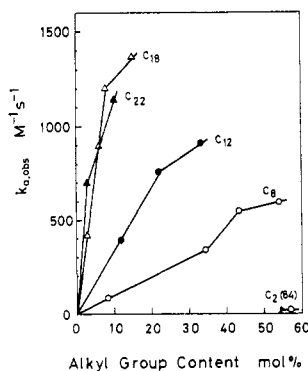(29) Menger, F. M.; Portnoy, C. E. *J. Am. Chem. Soc.* **1967**, *89*, 4698–4702.

Figure 4. Apparent second-order rate constant of acylation ($k_{a,obsd}$) plotted against the content of long-chain alkyl groups: 30 °C, 3% (v/v) ethanol, $\mu = 0.01$ with KCl, pH 8.9 with 0.02 M borate, [polymer] = 5.00×10^{-4} unit M, [PNPA] = 3.94×10^{-6} M, [DBHA] = 3.93×10^{-5} M.

Polysoap Catalysis of Acyl Transfer. Figure 4 shows the rate constant of acylation, $k_{a,obsd}$, plotted against the alkyl group content. The $k_{a,obsd}$ value increases with increasing alkyl content, and steeper slopes are seen for polysoaps with longer alkyl chains. In contrast with the results of Figure 3, the 4VP-C_8 polysoap is less effective than 4VP-C_{22} and 4VP-C_{18} polymers.

Discussion

Polymer Structure and Catalytic Efficiency. The catalytic efficiency for bimolecular reactions in micellar systems mainly stems from two factors: the concentration effect and the environmental effect. In most cases it is not easy to discuss these two factors separately. In the case of the unimolecular reaction, one need not take the former effect into account, so that the catalytic efficiency observed can be solely ascribed to the environmental effect. Furthermore, the kinetic analysis of decarboxylation described in the Results section enables us to know the rate constant for the polymer-bound substrate, i.e., k_d''. Therefore, the decarboxylation reaction is conveniently used for the study of the microenvironmental effect of polysoaps.

Kemp and co-workers[9-11] have examined the solvent effect on the decarboxylation rate. According to their investigation, the rate is influenced mainly by two factors: hydrogen bonding of the carboxylate ion with protic solvents (inhibition) and the stabilization of the transition state in dipolar aprotic solvents (acceleration). The results obtained in micellar and polymeric systems may be accounted for by this proposition. For example, the rate acceleration observed in the cationic micelle[13-15] was attributed to dehydration of the carboxylate ion by the hydrophobic environment (i.e., destabilization of the initial state) and to the stabilization of the delocalized transition state by the micellar positive charge.

The relation observed between the intrinsic viscosity and the k_d'' value (Table III) implies that the compact polymer conformation is advantageous for forming the catalytically efficient, hydrophobic domain. Strauss and co-workers[27,30,31] previously found for the 4VP-C_{12} polymer that drastic changes in some physical properties (viscosity decrease, solubilization of hydrocarbons) occurred at 10–13 mol % of the dodecyl group content. These changes were attributed to a transition from polyelectrolyte to polymer micelle. The present study substantiates the occurrence
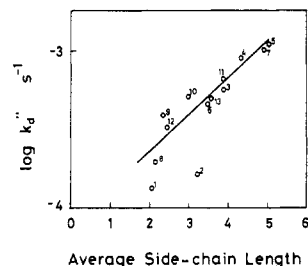

Average Side-chain Length

Figure 5. Correlation between log k_d'' and the average side-chain length L. The numbers correspond to those of Table I. The plots for 4VP-C_8(8) (1) and 4VP-C_8(23) (2) are omitted from the least-squares computation.

of similar transitions for the 4VP-C_8 polymer and probably for the 4VP-C_{18} polymer. The content of the alkyl group where the transition occurs is dependent upon the chain length.

In the case of acyl transfer (eq 2), $k_{a,obsd}$ increases gradually with increasing alkyl group content, and transitional changes are not found. Hydrophobic nucleophiles such as N-dodecylbenzohydroxamate ion **3** would additionally strengthen the local hydrophobicity by forming ion pairs with the ammonium group in the polymer.[6] As a result, the polysoap even with low alkyl group content can form highly hydrophobic catalytic sites, and the above-mentioned transition may not be found.

It is interesting in this respect to compare Figures 1, 3, and 4. These figures show the relative effectiveness of polysoaps in forming the hydrophobic domain. When a probe (methyl orange) or a reagent (DBHA) is sufficiently hydrophobic, polymers with higher alkyl chains (C_{18} and C_{22}) are more effective than the others. In contrast, if a substrate is not strongly hydrophobic, polymers with larger contents of the alkyl chain (4VP-C_8) give reaction sites of greater hydrophobicity (Figure 3). The contribution of the coulombic interaction was assumed to be the same for the three substrates. These problems will be discussed later in connection with the overall hydrophobicity of polysoaps.

Some years ago, Kirsh et al.[32] reported that the viscosity of partly benzylated poly(vinylpyridines) showed a sharp minimum at a fixed content of benzyl group. The sharp reduction was observed only for fractionated polymers and was dependent on both the benzyl content and the molecular weight. If this is the case, a polysoap having a peculiar catalytic environment may be obtained at a proper combination of the alkyl content and molecular weight. As shown in Table II, poly(4-vinylpyridine) polysoaps were prepared which were derived from fractionated polymers with varying molecular weight and whose dodecyl group content was fixed at ca. 30 mol %. Unfortunately, these polymers showed the same properties as those of the unfractionated polymer: λ_{max} shift of methyl orange, dissociation of 2,6-dichlorophenolindophenol (cmc indicator)[7] and k_d'' value.

Average Side-Chain Length. The catalytic efficiency of polysoaps is a function of both the content and length of the alkyl group. It would be useful to define a generalized parameter which reflects the relative contribution of pendant alkyl groups to the polysoap hydrophobicity. We introduce a new parameter L which is given by eq 4.

$$L = (nx + 2y)/100 \qquad (4)$$

The L value corresponds to the average length of the pendant alkyl group per pyridine unit. Interestingly, the

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Table IV. Transition Composition and
Average Side-Chain Length

poly-soap	transition composn of long-chain alkyl unit, mol %	$\bar{L}^a$	$n\bar{L}^b$
4 VP-C$_8$	40–50	4.4–5.0	35–40
4 VP-C$_{12}$	10–13	3.0–3.3	36–40
4 VP-C$_{18}$	ca. 3	2.5	45

^{a} Calculated based on the assumption that all the pyridine units are quaternized by long-chain alkyl or ethyl groups. ^{b} See text; n is the length of long-chain alkyl groups.

plots of log k_d'' vs. $\bar{L}$ (Figure 5) are approximated by a linear relation (eq 5), although two points deviate to the lower side of the line (see the caption for Figure 5). This

$$\log k_d'' = 0.21L - 4.0 \ (r = 0.945) \quad (5)$$

equation reveals several interesting features of the polysoap catalysis. In the first place, the linearity implies that the hydrophobicity of the polysoap can be related to the average length of the alkyl group incorporated by quaternization. For example, the contribution of one docosyl group (C$_{22}$) is roughly equivalent to that of three octyl groups (3 × C$_8$). The maximal catalytic efficiency is limited by the solubility of polysoaps. The highest $\bar{L}$ value (5.0) for the water-soluble polysoap (30 °C, no added salt) is achieved by the 4VP-C$_8$ polymer, whereas that of the 4VP-C$_{22}$ polymer is at most 3.6. Further incorporation of the docosyl group to the 4VP-C$_{22}$ polymer gave water-insoluble polymers. When compared at the same $\bar{L}$ value, the 4VP-C$_8$ polymer is more water soluble than the 4VP-C$_{22}$ polymer. The octyl side chain produces an optimal balance between the water solubility and the formation of the hydrophobic domain.

Second, the slope of 0.21 in eq 5 implies that the increase in the $\bar{L}$ value by one CH$_2$ unit lowers the free energy of activation by 0.29 kcal/mol. This value is comparable to the hydrophobic contribution of one methylene unit to the free energy of the Michaelis complex formation (ca. 0.25 kcal/mol) observed in some polymer catalyses.[33,34] On the other hand, the intercept (i.e., $\bar{L}$ = 0) may correspond to the rate constant for poly(4-vinylpyridinium), which does not possess the alkyl pendent group. The k_d'' value estimated at $\bar{L}$ = 0 from eq 5 (9.5 × 10^{-5} s^{-1}) is close to the k_d value for 4VP-C$_2$(84) (3.6 × 10^{-5} s^{-1}). The latter polymer shows a typical polyelectrolyte behavior.

We consider at this point the transition phenomenon between the polyelectrolyte and polymer micelle in terms of the $\bar{L}$ value. The transition composition and the corresponding $\bar{L}$ value (for the sake of simplicity, it is assumed that all the pyridine units are quaternized) are summarized in Table IV. It is seen that the polysoap with longer alkyl chains undergoes the transition at lower $\bar{L}$ values. The longer alkyl chain along the polymer backbone may interact with each other more easily than the shorter one. This will lead to shrinking of the polymer coil at low $\bar{L}$ values. Interestingly, the product of $\bar{L}$ times n is almost constant (40 ± 5, Table IV) at the transition. If one applies this value ($n\bar{L}$ = 40) to the polysoap quaternized by the hexyl group, the transition would occur at the hexyl group content of 110 mol %. This is impossible, and even the completely hexylated poly(vinylpyridine) would not behave as polymer micelle. In fact, the 4VP-C$_6$(65) polymer (no

ethylated unit) we prepared previously[7] behaved as a simple polyelectrolyte. The octyl group is probably the shortest alkyl chain which forms the micellar phase.

The concept of the average side-chain length is applicable only when the polysoap is not greatly perturbed by substrates. Thus, if bound reagents are strongly hydrophobic as in the case of the long-chain hydroxamate anion, the local hydrophobicity, but not the overall polymer hydrophobicity, becomes more influential.

Two-Site Model for Substrate Binding.[35] The substrate binding (and consequently the rate acceleration) is observed for polysoaps at the extent of alkyl substitution above and below the transition composition. Below the transition composition, the side-chain aggregation (i.e., formation of the micellar domain) is not appreciable, but substrate binding is obvious from the data of Figure 2. Substituted but randomly coiled (nonmicellar) polymers such as 4VP-C$_6$(65) bind 1 and increase the reaction rate about 30-fold, the same enhancement observed for polysoaps 4VP-C$_8$ and 4VP-C$_{12}$ at a mole percent of alkyl substitution below the transition composition. When the mole percent of alkyl substitution exceeds the transition composition, a new, more condensed polysoap structure (micellar phase) is formed from portions of the polysoap chain, and these more hydrophobic regions also bind 1, producing a further enhancement in rate. The rate increase above the transition composition is gradual rather than discontinuous because the polysoap will have condensed and uncondensed regions that both bind 1 and catalyze its decarboxylation. This supposition is consistent with eq 5 in which log k_d'' is proportional to the average side-chain length. Appearance of the condensed region induces viscosity reduction. The lack of the transition composition for the acyl transfer reaction may also be explained by this model. The hydrophobic nucleophile can induce the transition to the more condensed structure either for the whole polysoap or at least in the vicinity of the substrate binding site.

Concluding Remarks

The poly(4-vinylpyridine) polysoap with systematically varied lengths and contents of the alkyl substituent was prepared for the first time and used as sites of catalysis. Two important conclusions are drawn from the present study: first, the overall hydrophobicity is expressed by the "average side-chain length"; second, the local hydrophobicity is more influential than the overall hydrophobicity when hydrophobic reagents are used. It is interesting that octyl-substituted poly(4-vinylpyridines) provide an optimal balance of water solubility and polymer hydrophobicity. This conclusion gives an important implication for the nature of the amino acid side chain. The interior of enzyme molecules is made to be strongly hydrophobic due to hydrophobic amino acid side chains. These side chains are C$_4$–C$_8$ components, and long alkyl chains are not involved in spite of their abundant availability in nature. The globular conformation of enzymes may be formed more conveniently by aggregation of the amino acid side chain of intermediate hydrophobicity, as implied by the superiority of the 4VP-C$_8$ polymer in the overall hydrophobicity.

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