Table I. Values of Δ_{opt} To Give the Maximum Decoupled Enhancement E_{dopt} as a Function of the Number of Scalar Coupled Protons[a]

n	1	2	3	4	6	8	9	12	15	18
Δ_{opt}[b]	0.50	0.25	0.196	0.167	0.134	0.115	0.108	0.093	0.083	0.076
E_{dopt}[c]	1.0	1.0	1.155	1.299	1.553	1.772	1.873	2.147	2.389	2.610

[a] τ is set equal to $0.25J^{-1}$. [b] In units of J^{-1}. [c] In units of γ_H/γ_I.

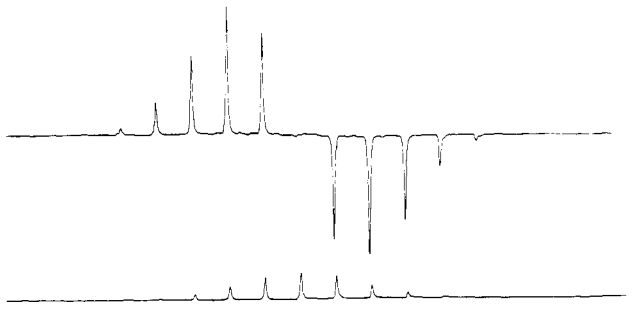

Figure 1. A comparison between the coupled FT NMR spectrum (lower) of $Sn(CH_3)_4$ with the proton polarization-transfer spectrum (upper) determined with τ = 4.66 ms, Δ = 0. Each spectrum is the average of 16 scans. Pulse times were t_{90}^{Sn} = 15 μs, t_{90}^{H} = 24 μs.

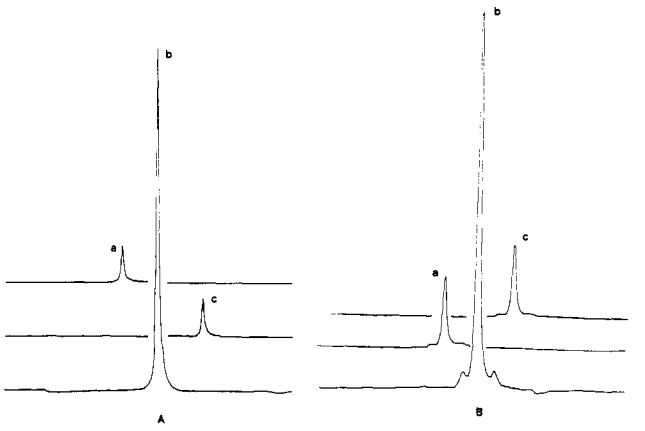

Figure 2. (A) FT (a), PT (b), and reverse proton-decoupled FT (c) spectra of $Si(CH_3)_4$. t_{90}^{Si} was 13 μs. Each spectrum is the average of four scans. E_{dopt} = 9.2 (theory 10.8). (B) Reverse proton decoupled FT (a), PT (b), and FT (c) spectra of $Sn(CH_3)_4$. Each spectrum is the average of four scans. E_{dopt} = 5.3 (theory 5.76).

3.2 (expt) and 4.2 (theory), respectively. The reductions appear to arise from the short ^{119}Sn T_2 values for these compounds. For all three compounds there is no NOE on proton decoupling.

The enhancement factors[8] for the ^{29}Si resonances in $(CH_3)_4Si$ and $(CH_3)_3SiCl$ are much closer to the theoretical value, being 9.2 (expt) (10.8, theory) and 8.5 (expt) (9.4, theory), respectively (Figure 2). The experimental value for $(CH_3)_2SiCl_2$ is 5.0, again somewhat less than the theoretical value of 7.8. For this compound the ^{29}Si T_2 is short and a loss of intensity is to be expected by using the PT sequence.

The enhancement factors presented in this paper are clearly dependent on the number of attached protons; S/N gains of the orders of magnitude measured represent a time-saving factor of 10–100 in obtaining ^{29}Si and ^{119}Sn NMR spectra. It is clear that the PT sequence will be particularly useful for obtaining metal NMR signals (e.g., ^{103}Rh, ^{183}W, ^{57}Fe, ^{199}Hg, ^{29}Si, ^{119}Sn, ^{207}Pb, etc.) in a variety of compounds provided there is a resolvable scalar coupling and the relaxation times (T_i) are not too short, that is, for $(\Delta,\tau) < T_i^{-1}$. Experiments are being performed on a variety of compounds to test the generality of PT NMR to obtain metal NMR spectra.

Acknowledgment. This research was supported by capital equipment grants from the Australian Research Grants Committee. We thank Dr. Kitching, University of Queensland, for a loan of the Sn compounds. We are grateful to a referee for pointing out the analytic simplification to the first equation.

(8) ^{29}Si NMR spectra were determined at 17.88 MHz.[7] Values of $J_{^{29}Si-H}$ were (50% in benzene-d_6) $(CH_3)_4Si$, 6.6 Hz; $(CH_3)_3SiCl$, 6.8 Hz; $(CH_3)_2SiCl_2$, 7.7 Hz.

(9) Doddrell, D. M.; Pegg, D. T. *J. Am. Chem. Soc.* **1980**, *102*, 6388–6390.
(10) Burum, D. P.; Ernst, R. R. *J. Magn. Reson.* **1980**, *39*, 163–168.
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Functionalized Vesicular Assembly. Enantioselective Catalysis of Ester Hydrolysis

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Several studies on micellar catalysis[1] have been carried out in order to develop stereoselective reaction sites for the hydrolysis of enantiomeric esters and understand the origins of stereoselectivity in proteolytic enzymes,[2] and some of those micellar systems having chiral centers[1b,c] exercised moderate enantioselectivity. We have reported[3] that a zwitterionic double-chained amphiphile involving an amino acid residue may form stable single-compartment bilayer vesicles in aqueous media and suggested that such vesicles may provide asymmetric recognition sites for various guest molecules. In this communication, we report the stereoselective hydrolysis of *simple* enantiomeric esters, L- and D-*N*-benzyloxycarbonylphenylalanine *p*-nitrophenyl esters [L-/D-(*Z*)-Phe-PNP],[4] as catalyzed by a *synthetic functionalized membrane* formed with *N,N*-didodecyl-N^{α}-[6-(trimethylammonio)hexanoyl]histidinamide bromide (**1**).[5] The present substrates would be favorably incorporated into vesicles by their intermolecular hydrogen-bonding interaction[6] with an amino acid moiety placed at the hydrogen belt region and by hydrophobic

(1) (a) Moss, R. A.; Sunshine, W. L. *J. Org. Chem.* **1974**, *39*, 1083–1089. (b) Brown, J. M.; Bunton, C. A. *J. Chem. Soc., Chem. Commun.* **1974**, 969–971. (c) Ihara, Y. *Ibid.* **1978**, 984–985. (d) Moss, R. A.; Lukas, T. J.; Nahas, R. C. *Tetrahedron Lett.* **1977**, 3851–3854. (e) Moss, R. A.; Nahas, R. C.; Lukas, T. J. *Tetrahedron Lett.* **1978**, 507–510. (f) Moss, R. A.; Lee, Y.-S.; Lukas, T. J. *J. Am. Chem. Soc.* **1979**, *101*, 2499–2501.

(2) Ingles, D. W.; Knowles, J. R. *Biochem. J.* **1968**, *108*, 561–569.

(3) Murakami, Y.; Nakano, A.; Fukuya, K. *J. Am. Chem. Soc.* **1980**, *102*, 4253–4254.

(4) (a) L-/D-(*Z*)-Phe-PNP were synthesized from the corresponding *N*-benzyloxycarbonylphenylalanine and *p*-nitrophenol in the presence of dicyclohexylcarbodiimide. L-(*Z*)-Phe-PNP: mp 128–130 °C (lit.[4b] 126.5–127.5 °C), $[\alpha]^{25}_D$ −9.0° (*c* 2.2, ethyl acetate) [lit.[4b] −8.9° (*c* 2.2, ethyl acetate)]. Anal. ($C_{23}H_{20}N_2O_6$) C, H, N. D-(*Z*)-Phe-PNP: mp 129–131 °C, $[\alpha]^{25}_D$ +8.8° (c 2.2, ethyl acetate). Anal. ($C_{23}H_{20}N_2O_6$) C, H, N. (b) Goodman, M.; Stueben, K. C. *J. Am. Chem. Soc.* **1959**, *81*,3980–3983.

(5) (a) Amphiphile **1** (abbreviated as $N^+C_5His2C_{12}$): liquid crystal with final mp 117 °C; Pauly (for detection of free imidazolyl and phenolic groups)[5b] and Dragendorff (for detection of quaternary ammonium group)[5c] positive; R_f (silica gel 1B of Baker-flex) 0.31 (with 1-butanol–water–acetic acid, 4:2:1 v/v) and 0.22 (with methanol); $[\alpha]^{25}_D$ +40.0° (*c* 1.0, EtOH); ^1H NMR ($CDCl_3$, Me_4Si) δ 0.86 (6 H, t, $(CH_2)_{11}CH_3$), 1.25 (40 H, s, CH_2-$(CH_2)_{10}CH_3$), ~2.00 (6 H, m, $N^+CH_2(CH_2)_3CH_2CO$–), 2.35 (2 H, br t, $N^+(CH_2)_4CH_2CO$–), 2.80–3.62 (8 H, m, $N^+CH_2(CH_2)_4CO$–, $CHCH_2Im$, and $-NCH_2(CH_2)_{10}CH_3$), 3.33 (9 H, s, $(CH_3)_3N^+$–), 5.04 (1 H, br t, –CH–), 6.97 (1 H, s, Im 5-H), and 8.22 (1 H, s, Im 2-H). Anal. ($C_{39}H_{76}BrN_5O_2$·2.5H_2O) C, H, N. (b) Hunter, G. *J. Chem. Soc.* **1930**, 2343–2346. (c) Beiss, U. *J. Chromatogr.* **1964**, *13*, 104–110.

(6) Brown and Bunton[1b] suggested that the ability of amide bonds of functional micelles to form intermolecular hydrogen bonds must bring about the high stereoselectivity in the hydrolysis of *N*-acetylphenylalanine *p*-nitrophenyl ester.

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Table I. Micelle- and Vesicle-Catalyzed Hydrolysis of L-/D-(*Z*)-Phe-PNP[a,b]

amphiphile	temp, °C	$k_{obsd}(L) \times 10^2$, s^{-1}	$k_{obsd}(D) \times 10^2$, s^{-1}	$k_{obsd}(L)/k_{obsd}(D)$	$k_{obsd}(L)/k_{sp}$
$N^+C_5His2C_{12}$ (1)	20	7.08	2.15	3.3	22100
	4	1.78	0.401	4.4	
$N^+C_5HisC_{12}$ (2)	20	1.82	0.733	2.5	5690
	4	0.35	0.131	2.7	

[a] At pH 6.55 in 0.05 M phosphate buffer containing 1% (v/v) dioxane and 1% (v/v) methanol. Initial concentrations: $N^+C_5His2C_{12}$, 2.01×10^{-3} M; $N^+C_5HisC_{12}$, 2.03×10^{-3} M; L-(*Z*)-Phe-PNP, 0.995×10^{-5} M; D-(*Z*)-Phe-PNP, 0.999×10^{-5} M. [b] $k_{obsd}(L)$, observed rate constant for the hydrolysis of L-(*Z*)-Phe-PNP; $k_{obsd}(D)$, observed rate constant for the hydrolysis of D-(*Z*)-Phe-PNP; k_{sp}, apparent rate constant for the alkaline hydrolysis of L-/D-(*Z*)-Phe-PNP at 20 °C (3.2×10^{-6} s^{-1}).

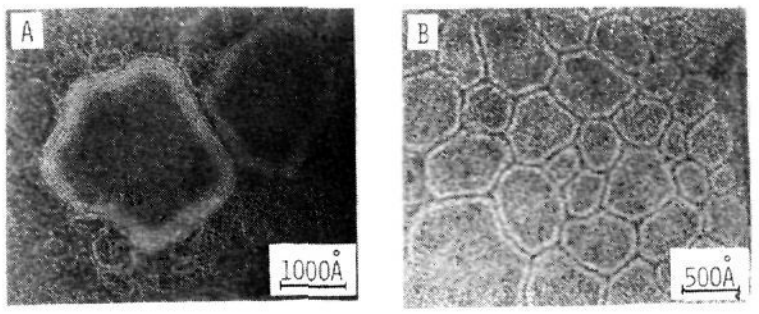


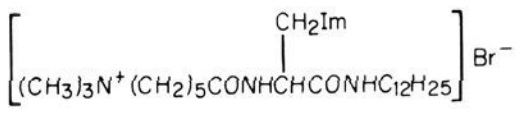
Figure 1. Electron micrographs negatively stained with uranyl acetate: (A) 5 mM aqueous dispersion of **1** (magnification, ×67 000); (B) 5 mM aqueous solution of **1** sonicated for 1 min with a probe-type sonicator at 30-W power (W-220F, Heat Systems-Ultrasonics) and allowed to stand for 10 min at 5 °C (magnification, ×110 000).

interaction as well. As a reference catalyst, *N*-dodecyl-N^{α}-[6-(trimethylammonio)hexanoyl]histidinamide bromide (**2**)[7] was used in micellar state. Amphiphiles **1** and **2** are structurally related to each other even though their aggregated forms are not identical. Consequently, an enantioselectivity exercised by the vesicular assembly is more critically characterized in reference to that by the corresponding micellar aggregate.

Amphiphile **1** was prepared according to Scheme I.

Double-chained peptide surfactant **1** was found to form functional vesicles in aqueous media. An aqueous dispersion of **1** (slightly turbid solution) was negatively stained, applied on a carbon grid, and dried in a vacuum desiccator. The sample was examined by electron microscopy[8] as shown in Figure 1A. Multilayered vesicles observed here have diameters distributed from 1000 to 4000 Å. Figure 1B shows an electron micrograph for the ultrasonicated solution of **1** (clear solution). Small particles (250–1200 Å) observed in this micrograph are apparently single-layered vesicles and were used for the hydrolysis of L-/D-(*Z*)-Phe-PNP as a catalyst. The sonicated buffer solutions of **1** were maintained at a clear state over a month without any additives, analogous to the behavior of a zwitterionic amphiphile reported previously.[3]

The catalytic activity of **1** in the state of single-layered vesicles and that of **2** in globular micelles for the hydrolysis of L-/D-(*Z*)-Phe-PNP were studied in 0.05 M phosphate buffer at pH 6.55.



2 (Im for an imidazolyl group)

Pseudo-first-order rate constants were evaluated by monitoring the appearance of *p*-nitrophenoxide ion at 400 nm, and the first-order kinetics was found to hold up to 90% conversion of the substrate for each kinetic run. Concentrations of the surfactants were fixed at 2.0×10^{-3} M,[9] while the initial substrate concentrations were maintained at 1.0×10^{-5} M. The kinetic data are summarized in Table I. The enantioselectivity, $k_{obsd}(L)/k_{obsd}(D)$, obtained for the micellar catalysis of **2** is comparable to those for the micelle-catalyzed hydrolysis of *N*-acetylphenylalanine *p*-nitrophenyl esters,[1b,c] and remains nearly the same in a temperature range studied here, as shown in Figure 2. On the other hand, the functionalized membrane formed with **1** enhanced the hydrolysis of L-/D-(*Z*)-Phe-PNP much more effectively than the micelles of **2**. Moreover, the extent of enantioselectivity is greater than that of the micelles of **2**; it increases as the temperature is

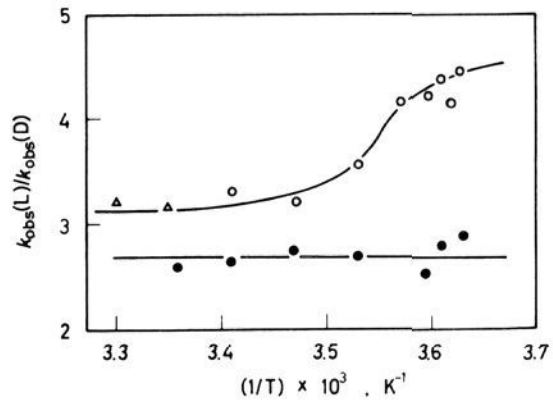


Figure 2. Correlations of enantioselectivity with temperature for the hydrolysis of L-/D-(*Z*)-Phe-PNP as catalyzed by **1** (○ and △) and **2** (●) at pH 6.55 in 0.05 M aqueous phosphate buffer containing 1% (v/v) dioxane and 1% (v/v) methanol. Initial concentrations: L-(*Z*)-Phe-PNP, 0.995×10^{-5} M; D-(*Z*)-Phe-PNP, 0.999×10^{-5} M; $N^+C_5His2C_{12}$ (**1**), 5.33×10^{-4} M (△) and 2.01×10^{-3} M (○); $N^+C_5HisC_{12}$ (**2**), 2.03×10^{-3} M.

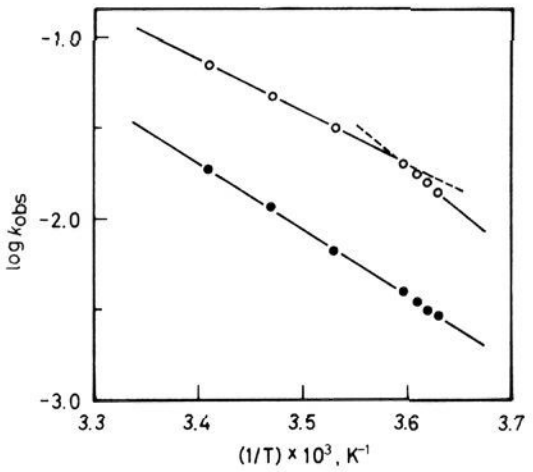


Figure 3. Arrhenius plots for the hydrolysis of L-(*Z*)-Phe-PNP as catalyzed by **1** (○) an **2** (●) at pH 6.55 in 0.05 M aqueous phosphate buffer containing 1% (v/v) dioxane and 1% (v/v) methanol. Initial concentrations: L-(*Z*)-Phe-PNP, 0.995×10^{-5} M; $N^+C_5His2C_{12}$ (**1**), 2.01×10^{-3} M; $N^+C_5HisC_{12}$ (**2**), 2.03×10^{-3} M.

Table II. Activation Parameters for the Hydrolysis of L-(*Z*)-Phe-PNP As Catalyzed by $N^+C_5HisC_{12}$ and $N^+C_5His2C_{12}$[a]

amphiphile	$\Delta G^{\ddagger}$, kcal mol^{-1}	$\Delta H^{\ddagger}$, kcal mol^{-1}	$\Delta S^{\ddagger}$, eu
$N^+C_5HisC_{12}$	19.4[b]	16.2	−11.0
$N^+C_5His2C_{12}$ ($>T_c$)	18.6[b]	13.2	−18.6
$N^+C_5His2C_{12}$ ($<T_c$)	18.3[c]	19.8	5.3

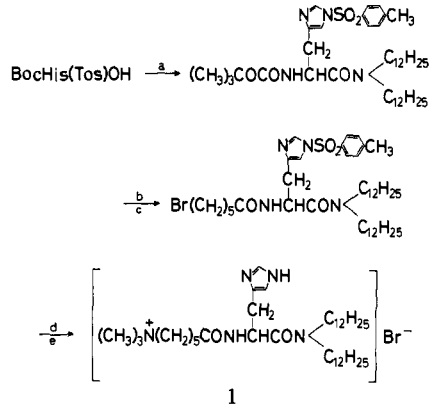
[a] The kinetic data given in Figure 3 were used. [b] At 293 K. [c] At 277 K.

(7) Amphiphile **2** (abbreviated as $N^+C_5HisC_{12}$) was prepared in a manner similar to the synthetic procedure of **1** and the detail is to be reported elsewhere (Murakami, Y.; Nakano, A.; Yoshimatsu, A.; Matsumoto, K. *J. Am. Chem. Soc.*, in press): mp 128–130 °C; Pauly and Dragendorff positive; $[\alpha]^{25}_D$ + 4.2° (*c* 1.0, EtOH). Anal. ($C_{27}H_{52}BrN_5O_2 \cdot H_2O$) C, H, N.

(8) Electron micrographs were taken on a JEOL JEM-200B electron microscope installed at the Research Laboratory of High Voltage Electron Microscope, Kyushu University.

(9) The critical micelle concentrations were determined by the surface tension method based on the Wilhelmy principle: $N^+C_5His2C_{12}$, 1.6×10^{-5} M; $N^+C_5HisC_{12}$, 6.0×10^{-4} M in water.

Scheme I[a]



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[a] Reagents: (a) $(C_{12}H_{25})_2NH$-DCC/CH_2Cl_2; (b) CF_3COOH/CH_2Cl_2; (c) $Br(CH_2)_5COCl/CH_2Cl_2$; (d) $(CH_3)_3N/C_6H_6$; (e) $(CH_3)_3N/\{H_2O, (CH_3)_2CO, C_6H_6\}$.

lowered and reaches 4.4 below the phase-transition temperature.[10] A stereoselectivity as large as 4.4 is the largest one ever encountered for the hydrolysis or degradation of *simple* enantiomeric esters as catalyzed by chiral molecular assemblies composed of a single molecular species.[11]

An Arrhenius plot for the hydrolysis of L-(*Z*)-Phe-PNP as catalyzed by **2** provides only a single straight line for the whole temperature range studied, while such a plot for the catalytic hydrolysis of the same ester by **1** is not correlated with a single line, and a break is observed in the 5–10 °C range as shown in Figure 3; this is referred to the kinetic T_c value. The thermodynamic parameters evaluated for the hydrolysis of L-(*Z*)-Phe-PNP as catalyzed by both micelle and membrane are listed in Table II. These parameters suggest that the mobility of both vesicular assembly of **1** and incorporated substrate (L-(*Z*)-Phe-PNP) is effectively restricted in a temperature range below T_c at the ground state, as reflected on the activation entropy change. This is primarily due to the tight structure of vesicular assembly in the crystalline state provided by efficient hydrogen bonding and hydrophobic interactions.

The vesicular assembly formed with amphiphile **1** in aqueous media can be called *functionalized membrane* since active imidazolyl groups are located in an interface region between the hydrophobic region with aliphatic double-chained moieties and the hydrophilic layer involving charged head groups. It should be noted for the present work that not only the catalytic activity but also the enantioselectivity were exercised by the functionalized membrane in the hydrolysis reaction, both effects being largely controlled by the phase-transition temperature.

(10) The phase-transition temperature for vesicular assembly of $N^+C_5His2C_{12}$ in aqueous media containing 1.6% (v/v) ethanol was estimated by using pyrene excimer fluorescence according to the method developed by Smith et al.: pyrene, 5.15×10^{-6} M; $N^+C_5His2C_{12}$, 1.31×10^{-3} M. The ratio of fluorescence intensities, I_e/I_m, was correlated with temperature, where I_e and I_m stand for fluorescence intensities of excimer and monomer at 470 and 393 nm, respectively. The correlation indicated that the phase transition must occur below 15 °C, consistent with the value obtained by the kinetic method (Arrhenius plot). Refer to: Soutar, A. K.; Pownall, H. J.; Hu, A. S.; Smith, L. C. *Biochemistry* **1974**, *13*, 2828–2836.

(11) (a) Moss et al.[1f] observed stereoselectivity as high as 4.33 for the hydrolysis of diastereomeric substrates, LL- and DL-*N*-carbobenzyloxyalanylproline *p*-nitrophenyl esters. They claim that the stereoselectivity was provided by the conformational difference between the LL and DL species when incorporated into micelles. However, the enantiomeric recognition exercised by the vesicular assembly must be a sole origin of the selectivity in the present study. (b) Recently, high enantioselectivity (5.5–5.7) has been reported for the deacylation of *p*-nitrophenyl esters possessing a long alkyl chain by comicelles of *N*-(*N*-dodecanoyl-L-histidyl)-L-leucine and (*R*)-(+)-*N*-(α-methylbenzyl)-*N*,*N*-(dimethyloctadecyl)ammonium bromide: Ohkubo, K.; Sugahara, K.; Yoshinaga, K.; Ueoka, R. *J. Chem. Soc., Chem. Commun.* **1980**, 637–639. However, their substrates are somewhat more specific since these molecules involve a highly hydrophobic segment besides an enantiomeric center.

Phase-Transfer Free-Radical Reactions: The Crown Ether Potassium Peroxydisulfate Initiator System[1]

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The use of phase-transfer agents to accelerate the rate of two-phase reactions by bringing together chemical reagents which generally do not have a common solvent has become common practice in recent years.[2] Whereas this technique has been concerned for the most part with the transfer of anionic reagents for the purpose of carrying out ionic reactions, and has even been extended into the realm of anionic polymerizations,[3] the concept is believed to be much more general. We wish to report the first examples of the phase-transfer-initiated free-radical polymerization of olefinic monomers.

Recently, we discovered[4] that the presence of 1,4,7,10,13,16-hexaoxacyclooctadecane (18-crown-6, **1**) accelerates the rate of disappearance of aqueous potassium peroxydisulfate. This result suggested, among other things, that it might be possible to conduct free-radical polymerization reactions in organic media under much milder conditions than is possible with typical free-radical initiators such as azobis(isobutyronitrile) (AIBN) or benzoyl peroxide. The only question at the outset seemed to be whether peroxydisulfate could be effectively phase transferred, a notoriously difficult process with divalent anions.[5] Voronkov and co-workers, in an independent study, have recently reported[6] the preparation of a 1:2 $K_2S_2O_8$/18-crown-6 complex characterized as being soluble in methanol, dimethyl sulfoxide, and dimethylformamide and that this complex was useful for initiating polymerizations in methanol solvent. By contrast, we have found that peroxydisulfate may be phase transferred into a variety of solvents, *including hydrocarbon solvents*,[7] with surprising facility and as such can be utilized for the rapid polymerization of acrylic and methacrylic monomers, even at temperatures approaching ambient. In this report we will concentrate on the phase-transfer free-radical polymerization of butyl acrylate mediated by various crown ethers. Results obtained by using quaternary ammonium salts and other phase-transfer agents will be reported elsewhere.

Experimentally, reaction vessels were charged with butyl acrylate as supplied commercially (45 g), acetone (90 mL), potassium peroxydisulfate (0.135 g, 0.5 mmol), and crown ether (1 mmol). The mixtures were sparged for 5 min with argon, and the vessels were sealed and then tumbled in a constant temperature bath maintained at 55 °C for a period of 24 h. Following reaction, the conversion of monomer to polymer was determined by a simple gravimetric technique. Initial results obtained under these conditions seemed to indicate that there was a direct relationship between conversion and the complexing ability of the various crowns for the potassium cation. In fact, when percent conversion was plotted vs. the log of the binding constant in methanol, log *K*, an apparently linear correlation was obtained.[8]

(1) Chemistry of Naked Persulfate. 2.

(2) Starks, C. M.; Liotta, C. "Phase Transfer Catalysis: Principles and Techniques"; Academic Press: New York, 1978.

(3) Weber, W. P.; Gokel, G. W. "Phase Transfer Catalysis in Organic Synthesis"; Springer-Verlag: New York, 1977; pp 130–132.

(4) Rasmussen, J. K.; Heilmann, S. M.; Toren, P. E.; Pocius, A. V.; Kotnour, T. A., submitted for publication.

(5) Reference 2, p 162.

(6) Rakhmatulina, T. N.; Baiborodina, E. N.; Rzhepka, A. V.; Lopyrev, V. A.; Voronkov, M. G. *Vysokomol. Soedin., Ser. B* **1979**, *21*, 229–230. *Chem. Abstr.* **1979**, *90*, 187436v.

(7) Using phase-transfer techniques, we have been able to conduct free-radical polymerizations in acetone, ethyl acetate, *tert*-butyl alcohol, tetrahydrofuran, toluene, heptane, and methanol, as well as mixtures of two or more of these solvents. Additional details will be reported at a later date.

(8) Log *K* for methanol solutions were used in the comparisons due to the ready availability of these values in the literature. Although a linear correlation of log *K* values has not been established in going from one solvent to another, it is generally believed that the correlation is reasonably good: Lamb, J. D.; Christensen, J. J.; Oscarson, J. L.; Nielsen, B. L.; Asay, B. W.; Izatt, R. M. *J. Am. Chem. Soc.* **1980**, *102*, 6820–6824.

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