Transfer Kinetics of Amphiphilic Porphyrin between Organic Phase and Water Phase

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Amphiphilic porphyrins having a poly(ethylene oxide) chain were prepared. The transfer rates of the amphiphilic porphyrin from benzene to water were biphasic and were accelerated by lowering temperature or by the addition of SDS. Kinetic data suggest that (1) conformational changes of the amphiphilic porphyrin to a polar form give rise to the faster rate at low temperature, and (2) adsorption to the interface leads to the biphasic kinetics.

Kinetic aspects of material transport across different phases are fundamental in understanding biological processes.[1] Changes in conformation and solvation are key to determine the kinetics of such a phase transfer process. To elucidate the mechanism of it, a model study using a simple system is expected to be helpful. We prepared porphyrins having poly(ethylene oxide) and studied the kinetics of transport of these amphiphilic porphyrins from organic phase to water phase.

Two amphiphilic porphyrins, **1** and **2**, were prepared by the Williamson coupling of 5-(*p*-bromomethylphenyl)-10,15,10-tri-*p*-tolylporphyrin with poly(ethylene glycol) methyl ether (abbreviated as PEG) with the molecular weight of 2000 and 750, respectively.[2-3] The products were characterized by ^{1}H NMR and mass spectroscopy. In ^{1}H NMR, the ratios of β-protons of porphyrin to the methylene protons of PEG were 8/180, and 8/70, for **1** and **2**, respectively. In the mass spectrum, the parent peaks were observed at 2681 (M^+) and 1405, for **1** and **2**, respectively. Both **1** and **2** are soluble in most solvents such as water, alcohol, chloroform and benzene. The UV-vis spectrum of **1** showed a sharp Soret band at 420 nm (log ε = 5.6), and Q-bands at 648 nm (log ε = 3.9) in benzene, indicating that **1** is monomeric in it. These peaks become broader in water,[4] suggesting that aggregation occurs in water.

To determine the rate of transfer of **1** from organic phase to water phase, **1** was dissolved in benzene (1.3×10^{-5} M, 1.5 mL), placed in a cuvette (1 cm × 1 cm) and water (2.5 mL) was added. The absorbance change at 648 nm in the water phase was monitored as a function of time. The representative results are shown in Figure 1. Clearly the transfer kinetics is biphasic, the faster process proceeds within several hours, and the slower process lasts for days. Another interesting feature is the rate becomes faster as the temperature is lower. Figure 2 illustrates the effects of sodium dodecyl sulfate (SDS) on the transfer rate. The rate is much faster when SDS was added to the two-phase system.

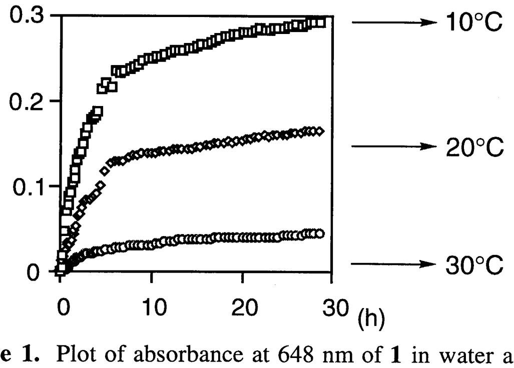


Figure 1. Plot of absorbance at 648 nm of **1** in water against time; initially [**1**] = 1.8×10^{-1} mM in benzene, benzene = 1.5 mL; water = 2.5 mL.

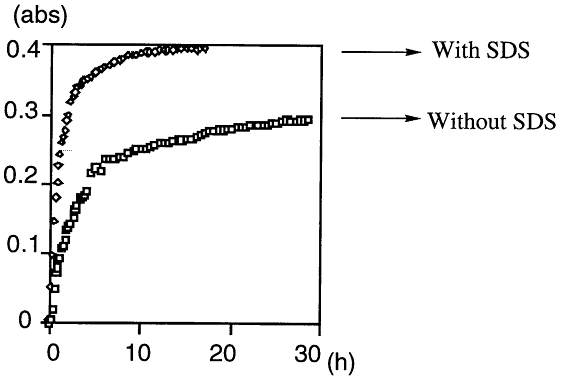
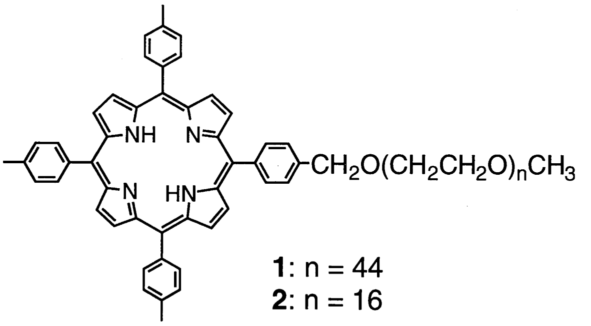
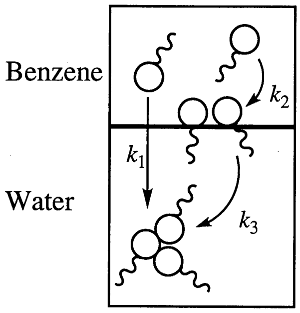


Figure 2. Plot of absorbance at 648 nm of **1** in water against time; initially, [**1**]= 1.8×10^{-1} mM in benzene, benzene = 1.5 mL; water = 2.5 mL; 10 °C; [SDS]= 0.02 M in water.

We propose a mechanism relevant to these kinetic features, in



1: n = 44
2: n = 16



Scheme 1. Three elementary processes for the transfer of the porphyrin-PEG from benzene to water phase.

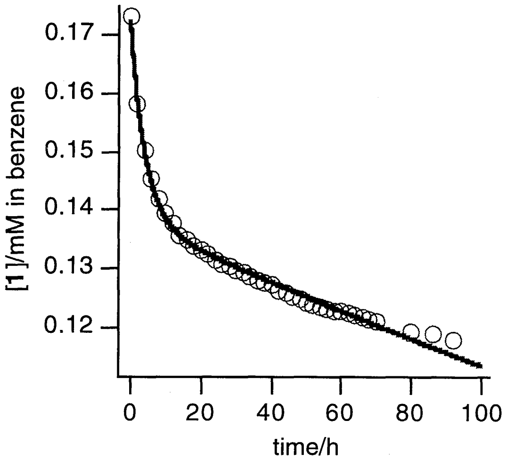


Figure 3. Plot of [**1**] in benzene against time; initially, [**1**]= 1.8 × 10^{-1} mM in benzene (1.5 mL); water = 2.5 mL; 20 °C. The calculated curve according to the equation in ref. 5 is also shown.

which three elementary processes are involved, (1) direct transfer of **1** from benzene to water with a rate constant of k_1, (2) adsorption of **1** to the interface with a rate constant of k_2, and (3) transfer of adsorbed **1** to the water phase (desorption) with a rate constant of k_3.[5] The transfer rate of **1** from water to benzene was very slow and no transfer was observed within 100 h. Therefore, the inverse transfer process was neglected here. We assume that the k_1 process is possible only through the interface domain free from **1**. Curve fitting of the observed time course change to the rate equation[5] was satisfactory (see Figure 3) and gave the rate constants listed in Table 1. By lowering the temperature the k_1 term is more accelerated compared to the k_3 term. Because the k_1 process is dependent on the conformation of **1** in benzene, the temperature dependence of the transfer rate may reflect the conformational equilibrium of **1** in benzene. Addition of SDS (0.02 M in water) accelerates all the three processes by a factor of 3 to 4 at 20 °C.[6] The low molecular weight **2** shows the much slower rate of transfer from benzene to water.[7]

It is known that PEG takes two different conformations, a trans conformation of the OCH_2CH_2O group with an nonpolar character, and a gauche one with a polar character.[8] The trans conformer is favored at high temperature. The anomalous temperature dependence on the transfer rate, a faster rate at lower temperature, suggests that the equilibrium between these two conformations plays an important role.[9] We suppose that the hydrophilic gauche conformation becomes dominant in benzene as the temperature is low, resulting in the faster transfer at low temperature. Thus, the conformational changes affect the energetics of solvation process and then the transfer kinetics in the present system.

Table 1. The rate constants (h^{-1}) of transfer of **1** from benzene to water at 10 °C and 20 °C[a]

	10 °C	20 °C	ratio
k_1 (direct transfer)	1.9×10^{-1}	4.9×10^{-2}	3.9
k_2 (adsorption)	5.0×10^{-1}	1.7×10^{-1}	2.9
k_3 (desorption)	4.0×10^{-3}	2.1×10^{-3}	1.9

[a]These rate constants were obtained on the basis of at least two independent runs. Standard deviations are < 2 %

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References and Notes

1 P. Vanysek, in "*Biomembrane Electrochemistry*," eds. M. Blank and I. Vodyanoy, American Chemical Society, Washington, DC (1994), p.55.

2 a) H. K. Hombrecher and S. Ohm, *Tetrahedron Lett.*, **49**, 2447 (1993). b) N. Ono, H. Tomita, and K. Maruyama, *J. Chem. Soc., Perkin Trans.* 1. **1992**, 2453. c) Y. Takahashi, J. E. Guilett, and M. A. Winnik, *Can. J. Chem.*, **67**, 411 (1989).

3 The coupling reaction was carried out as follows: Poly(ethylene glycol) methyl ether (0.04 mmol) and NaH_2 (0.1 mmol) were dissolved in 2 mL of anhydrous THF and 5-(*p*-bromomethylphenyl)-10,15,10-tri-*p*-tolylporphyrin (0.1 mmol) in 1 mL of THF was added at room temperature. After stirring at room temperature for 24 h, the solvent was evaporated. Purification on Sephadex LH-20 (THF) followed by Sephadex G-10 (water) afforded the product in 40 % yield.

4 In water, the UV-vis spectrum of **1** shows peaks at 422 nm ($\log \varepsilon = 5.4$) and at 648 nm ($\log \varepsilon = 3.8$).

5 We assume that concentration of **1** is the sum of three terms: $[\mathbf{1}] = [\mathbf{1}]_{benzene} + [\mathbf{1}]_{water} + [\mathbf{1}]_{interface}$. The direct transfer process, k_1 process, is assumed to be proportional both to $[\mathbf{1}]_{benzene}$ and to the unoccupied interface area, $([\mathbf{1}]_{interface,max} - [\mathbf{1}]_{interface})/ [\mathbf{1}]_{interface,max}$. The adsorption rate to the interface was assumed to be proportional to $[\mathbf{1}]_{benzene}$. The desorption rate is assumed to be proportional to $[\mathbf{1}]_{interface}$ and to $[\mathbf{1}]_{benzene}$. These assumptions lead to the following time dependence of $[\mathbf{1}]_{water}$: $[\mathbf{1}]_{water} = [\mathbf{1}]_0 \exp(k_1 - k_3) / (k_2 \exp(k_2 t)) - k_3 t) / \exp((k_1 - k_3) / k_2)$. The observed data were fitted to this equation.

6 The rate constants of transfer of **1** from benzene to water in the presence of 0.02 M of SDS in water at 20 °C were: $k_1 = 5.2 \times 10^{-1}\ h^{-1}$, $k_2 = 7.4 \times 10^{-1}\ h^{-1}$ and $k_3 = 7.6 \times 10^{-3}\ h^{-1}$.

7 At 20 °C, the transfer rate constants of **2** from benzene to water are: $k_1 = 5.6 \times 10^{-4}\ h^{-1}$, $k_2 = 1.2 \times 10^{-2}\ h^{-1}$ and $k_3 = 3.8 \times 10^{-4}\ h^{-1}$. The k_1 process is two orders of magnitude slower and the k_2 and k_3 processes are one order of magnitude slower than those of **1**. Thus, the lower molecular weight of PEG affects the k_1 process more strongly than it does the k_2 and k_3 processes.

8 a) G. Karlström, *J. Phys. Chem.*, **89**, 4962 (1985). b) M. Björling, G. Karlström, and P. Linse, *J. Phys. Chem.*, **95**, 6706 (1991). c) K.-J. Liu and J. L. Parsons, *Macromolecules*, **2**, 529 (1969).

9 Preliminary NMR experiments indicated that the chemical shift of the methylene carbons of PEG of **2** moves from 71.003 at 25 °C to 71.184 ppm at 65 °C (in C_6D_6, internal TMS, 0 ppm), indicating the conformational changes occur (ref. 8b).