Micellization and Adsorption of Fluorinated Amphiphiles: Questioning the $1\,CF_2 \approx 1.5\,CH_2$ Rule

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Abstract: The surface activity of a series of partially fluorinated amphiphiles with a dimorpholinophosphate polar head, a perfluoroalkyl terminal and a hydrocarbon spacer, $C_nF_{2n+1}(CH_2)_mOP(O)[N(CH_2CH_2)_2O]_2$ (F*n*C*m*DMP, $m = 1-11$, $n = 4-10$), was investigated, and the contributions of the CF_2 and CH_2 groups to the energies of adsorption and micellization of the amphiphiles were determined. In the literature, such data are only available for amphiphiles with either totally fluorinated or totally hydrogenated hydrophobes. We determined the impact of the fluorocarbon segment on the contribution of the hydrocarbon spacer to the adsorption and micellization processes. ΔG_{mic} and ΔG_{ads} were evaluated as -4.2 ± 0.5 and $-4.1 \pm 0.6\ kJ\,mol^{-1}$ per CF_2 group, consistent with results reported on totally fluorinated surfactants (-3.3 to $-5.2\ kJ\,mol^{-1}$). In contrast, the values for ΔG_{mic} and ΔG_{ads} per CH_2 group (-1.0 ± 0.4 and $-1.0 \pm 0.6\ kJ\,mol^{-1}$, respectively) were substantially lower than those measured for hydrocarbon analogues of the F*n*C*m*DMPs (-2.4 ± 0.4 and $-2.5 \pm 0.5\ kJ\,mol^{-1}$), which fall in the range observed for standard hydrocarbon amphiphiles (-2.4 to $-3.05\ kJ\,mol^{-1}$). These results show that a hydrocarbon chain grafted to a fluorinated chain does not fully participate in the micellization and adsorption processes, and behaves as if it were shorter by a factor of about three. Thus it is primarily the length of the fluorinated chain that controls micellization and adsorption of such surfactants; the spacer plays only a minor role, and great caution must be exercised when applying the $1\,CF_2 \approx 1.5\,CH_2$ rule. It is proposed that the hydrocarbon spacer adopts a folded conformation in order to better occupy the void volume which results from the difference in cross-sections between fluorocarbon and hydrocarbon chains (ca. 30 vs. 20 Å^2, respectively).

Keywords: adsorption • amphiphiles • fluorocarbons • fluorosurfactants • micelles • surfactants

Introduction

Fluorinated chains are significantly more hydrophobic than their hydrogenated counterparts, and they are lipophobic as well. Fluorinated surfactants are highly surface-active and can lower the surface tension of water to levels that cannot be reached with standard hydrocarbon surfactants.[1–6] They also have much lower critical micellar concentrations (cmc), typically by around two orders of magnitude, and an exceptional tendency to collect at interfaces. The cmc values for fluorosurfactants are roughly equivalent to those of hydrocarbon surfactants with a 50% longer chain.[1, 2] Extensive data have been reported on salts of carboxylic acids[7, 8] and nonionic surfactants based on ethoxylated alcohols with various ethylene oxide group numbers.[9, 11] A gradual change in the hydrophilic character of the latter surfactants allowed the determination of some intrinsic properties of the fluorinated chain. In some cases the energetic contributions to adsorption and micellization per CF_2 group, for fluorinated surfactants, and that per CH_2 group for their hydrogenated analogues, were calculated.[8, 9]

In the above carboxylic acids and ethoxylated alcohols, the perfluoroalkyl chain was always directly grafted onto the polar head. We wondered if, in the case of half-fluorinated, half-hydrogenated hydrophobic chains, each of the segments would participate in the micellization and adsorption processes as if it were independent, or if more subtle effects would arise as a result of the forced confinement of the two antinomic fluorocarbon and hydrocarbon segments within the same chain. For this purpose we undertook a study of the surface activity of a series of nonionic semifluorinated

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amphiphiles with a dimorpholinophosphate polar head: $C_nF_{2n+1}(CH_2)_mOP(O)[N(CH_2CH_2)_2O]_2$, $m = 1-11$, $n = 4-10$ (F*n*C*m*DMP).

Although these amphiphiles are single-tailed and nonchiral, they were found to exhibit a strong proclivity to self-assemble into vesicles as well as microtubules.[12] They also permitted the preparation of stable water-in-fluorocarbon reverse emulsions with potential as controlled-release drug-delivery systems.[13] In this paper, we report on the surface tensions of F*n*C*m*DMPs, their cmc, polar head surface area, maximal surface pressure, and energy of micellization and adsorption, and we compare these data to those found for their hydrocarbon analogues, $C_mH_{2m+1}OP(O)[N(CH_2CH_2)_2O]_2$, $m = 10$ and 15 (C*m*DMP).

The contributions of the CF_2 and CH_2 groups to the energies of micellization and adsorption of these surfactants are collected and discussed.

Results

F*n*C*m*DMP surface activity data: Figure 1 shows $\gamma_s/\log C$ curves for the F*n*C*m*DMPs and C*m*DMPs listed in Table 1; γ_s is the surface tension of the surfactant and C its concentration. The clearly marked break points correspond to the cmcs. The high purity of the amphiphiles is evidenced by the plateau observed for concentrations above the cmcs.

The simplified Gibbs adsorption equation allows calculation of the surface excess concentration $\Gamma = -1/(2.3RT)\,\mathrm{d}\gamma_s/\mathrm{d}\log C$; $\mathrm{d}\gamma/\mathrm{d}\log C$ is determined from the slope of the linear portion of the $\gamma/\log C$ curve below the cmc.[14] The minimal area per molecule, σ, is equal to $10^{23}/N\Gamma$.

The free energy of micellization is given by $\Delta G_{mic} = 2.3RT\log x_{cmc}$, where x_{cmc} is the mole fraction of the surfactant in the liquid phase at the cmc. Since the cmc is always small compared with the molar concentration of water (w), x_{cmc} can be taken as cmc/w.[15] Therefore, $\Delta G_{mic} = 2.3RT(\log \mathrm{cmc} - \log 55.5)$ [Eq. (1)]. The surface pressure Π_{cmc} is the difference between the surface tension of pure water γ_o and that of the solution at the cmc, γ_{cmc}. The standard chemical potential of adsorption, ΔG_{ads}, is equal to $2.3RT(\log \mathrm{cmc} - \log 55.5) - \Pi_{cmc}\sigma$.[16]

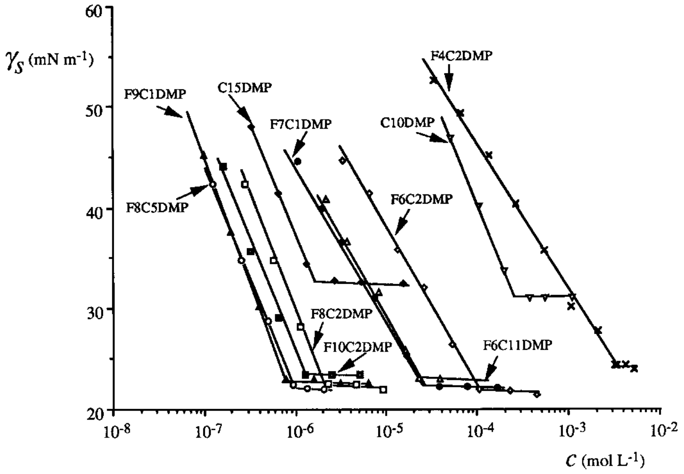

Figure 1. Variation of the surface tension γ_s at 25 °C (60 °C in the case of F10C2DMP) of aqueous solutions of F*n*C*m*DMPs as a function of concentration *C*.

Table 1 displays the values of critical micelle concentration (cmc), surface excess concentration (Γ), polar head surface (σ), surface tension at the cmc (γ_{cmc}), surface pressure (Π_{cmc}), energy of micellization (ΔG_{mic}), and energy of adsorption (ΔG_{ads}) of the F*n*C*m*DMPs and C*m*DMPs. The γ_{cmc} values for the F*n*C*m*DMPs are in the 22.1–24.4 mN m^{-1} range, that is, much lower than those of the C*m*DMPs (30.0 and 32.5 mN m^{-1}), showing higher effectiveness, in line with previous data on fluorinated surfactants.[3–5, 17, 18] The length of the hydrophobic chain has little influence on the γ_{cmc} values, in line with what is known for nonionic surfactants in general.

The maximum surface pressure, Π_{cmc}, is related to lateral interactions between hydrophobic chains, in other words to the cohesion of the surfactant film.[19] The Π_{cmc} values were in the 47.6–49.9 mN m^{-1} range for the F*n*C*m*DMPs, while they did not exceed 42 mN m^{-1} for the C*m*DMPs. This demonstrates a closer packing of the fluorinated amphiphiles and supports our view that lateral interactions are stronger among fluorinated chains than among hydrogenated ones, in spite of lower van der Waals interactions.[18]

For F*n*C*m*DMPs, the values of the head surface area, σ, appear to be primarily determined by the length of the fluorinated chain (independently from the length of the

Table 1. Critical micellar concentration, surface excess concentration, polar head area, surface tension at the cmc, surface pressure, energy of micellization, and energy of adsorption of the perfluoroalkylated dimorpholinophosphates, F*n*C*m*DMPs, and of their hydrogenated analogues, C*m*DMPs, at 25 °C.

Compounds	cmc ($\times 10^{-6}$) mol L^{-1}	Γ ($\times 10^{-3}$) mol 1000 m^{-2})	σ Å^2 molec^{-1}	γcmc mN m^{-1}	Πcmc mN m^{-1}	$-\Delta G_{mic}$ kJ mol^{-1}	$-\Delta G_{abs}$ kJ mol^{-1}
F4C2DMP	2950	2.52	65.9	24.4	47.6	24.4	43.2
F6C2DMP	97.3	2.75	60.3	22.1	49.9	32.8	50.9
F6C11DMP	25.4	2.76	60.1	23.5	48.5	36.0	53.6
F7C1DMP	26.3	2.77	59.9	22.5	49.5	36.1	53.9
F8C2DMP	2.5	4.20	39.5	22.5	49.5	41.9	53.6
F8C5DMP	0.9	3.96	42.0	22.5	49.5	44.4	56.9
F8C11DMP[a]	0.8	nd	≈40	nd	nd	nd	nd
F9C1DMP	0.7	4.22	39.3	23	49.0	45.0	56.6
F10C2DMP[b]	1.0	4.42	41.9	23.5	48.5	49.3	61.5
C10DMP	250	4.10	40.5	30.0	42.0	30.5	40.7
C15DMP	1.63	3.97	41.8	32,5	39.5	42.9	52.9

[a] Calculated. [b] At 60 °C.

hydrocarbon spacer) and present an as yet unexplained break when the number of fluorinated carbon atoms reaches 8 ($\sigma \approx$ 60–66 Å^2 for $n \leq 7$, and $\sigma \approx 39-42$ Å^2 for $n \geq 8$).

Micellization: In line with previous works,[8–10, 18] the data presented in Table 1 show that the fluorinated F*n*C*m*DMPs have a higher tendency to form micelles than do their direct hydrogenated analogues C*m'*DMPs ($m' = m + n$, same number of carbon atoms). This is exemplified by comparing the ΔG_{mic} values of F8C2DMP and C10DMP (−41.9 and −30.5 kJ mol^{-1}, respectively). The ΔG_{mic} of C15DMP (−42.9 kJ mol^{-1}) is comparable to that of F8C2DMP; F8C2DMP was indeed considered as a perfluorinated surfactant (the two methylene groups of its spacer being too short to play any significant role), for which the $1\,CF_2 \approx 1.5\,CH_2$[1] equivalency rule is applicable. Figure 2 shows the variation of ΔG_{mic} as a function of the number of CF_2 groups present in the hydrophobic tails. One can see that for short hydrocarbon spacers ($m = 1$, 2), ΔG_{mic} decreases linearly ($r = 0.997$) with the number of fluorinated carbons. However, it can also be noted that the F*n*C*m*DMPs with longer hydrocarbon spacers, such as F6C11DMP and F8C5DMP, can be positioned on this line with a still acceptable r of 0.960. This appears to indicate that the length of the hydrocarbon spacer has little influence on ΔG_{mic}.

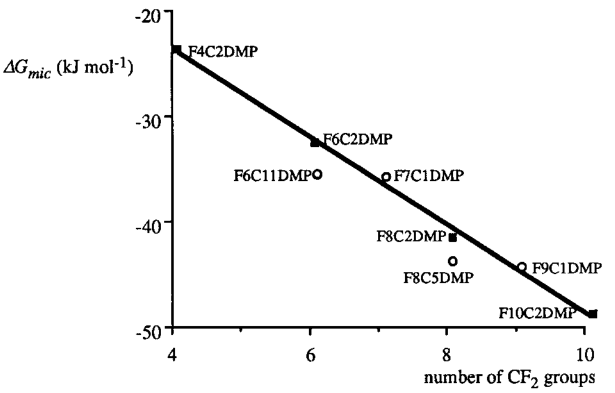

Figure 2. Variation of ΔG_{mic} as a function of the number of CF_2 groups.

In order to quantify this phenomenon, ΔG_{mic} can be split into contributions from the various groups that compose the surfactant, as in Equation (2), for a fluorinated surfactant, and Equation (3), for a hydrocarbon surfactant, where W represents the hydrophilic group.[14]

$$\Delta G_{\text{mic}} = \Delta G_{\text{mic}}CF_3 + (n-1)\Delta G_{\text{mic}}CF_2 + m\Delta G_{\text{mic}}CH_2 + \Delta G_{\text{mic}}W \qquad (2)$$

$$\Delta G_{\text{mic}} = \Delta G_{\text{mic}}CH_3 + (n-1)\Delta G_{\text{mic}}CH_2 + \Delta G_{\text{mic}}\text{W} \qquad (3)$$

For the F*n*C*m*DMPs, we calculated that $\Delta G_{\text{mic}}CF_2 = -4.2$ kJ mol^{-1}, and $\Delta G_{\text{mic}}CH_2 = -1.0$ kJ mol^{-1}. The values are essentially identical whether σ is taken as 40 or as 60 Å^2. On the other hand, $\Delta G_{\text{mic}}CF_3 + \Delta G_{\text{mic}}W$ depends of course on the value of σ (−11.6 or −9.9 kJ mol^{-1} for $\sigma = 40$ or 60 Å^2, respectively). For the C*m*DMPs, $\Delta G_{\text{mic}}CH_2$ was found to be −2.4 kJ mol^{-1}. Knowing from published data that $\Delta G_{\text{mic}}CH_3 = -8.8$ kJ mol^{-1},[20] the free energy for a 40 Å^2 polar head was calculated to be approximately +0.9 kJ mol^{-1}. This enabled us to calculate the energy due to the terminal fluorinated group, $\Delta G_{\text{mic}}CF_3$, to be about −12.5 kJ mol^{-1} for a 40 Å^2 polar head, assuming that the energetic impact of the head does not change whether the chain is fluorinated or not. It is indeed likely that $\Delta G_{\text{mic}}CF_3$ does not vary with the size of the polar head.

Adsorption: The capacity of F*n*C*m*DMPs to adsorb at the surface was found to be much higher than that of C*m*DMPs. One can compare, for example, the ΔG_{ads} of F4C2DMP and F6C2DMP (−43.2 kJ mol^{-1} and −50.9 kJ mol^{-1}, respectively) with that of C10DMP (−40.7 kJ mol^{-1}) (Table 1). Figure 3 illustrates the variation of ΔG_{ads} as a function of the number of CF_2 groups. It can be seen in particular that F*n*C*m*DMPs with short hydrocarbon spacers ($m = 1, 2$) fit correctly on a straight line. Again the ΔG_{ads} values for F6C11DMP and F8C5DMP are quite close to this line.

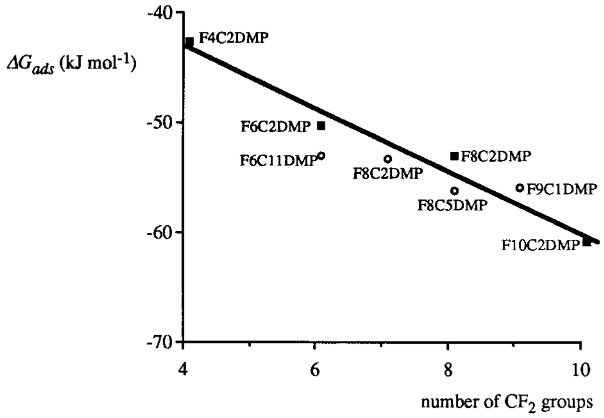

Figure 3. Variation of ΔG_{ads} as a function of the number of CF_2 groups.

As for micellization, the adsorption energy of the amphiphile can be considered as the sum of contributions of the groups which constitute the molecule: $\Delta G_{\text{ads}} = \Delta G_{\text{ads}}CF_3 + (n-1)\ \Delta G_{\text{ads}}CF_2 + m\,\Delta G_{\text{ads}}CH_2 + \Delta G_{\text{ads}}W$. Calculations performed considering $\sigma = 40$ or 60 Å^2 lead to values of $\Delta G_{\text{ads}}CF_2 = -4.1$ kJ mol^{-1} and $\Delta G_{\text{ads}}CH_2 = -1.0$ kJ mol^{-1} in both cases. The energy due to the hydrophilic group was lower (by −6.9 kJ mol^{-1}) for F4C2DMP, F6C2DMP, and F7C1DMP than for F8C2DMP, F8C5DMP, and F9C1DMP. The larger the head surface area, the higher the adsorption.

Discussion

The above series of partially fluorinated, partially hydrogenated amphiphiles allowed us to establish that the CH_2 groups of a hydrocarbon spacer located between the dimorpholinophosphate polar head group and the terminal, highly hydrophobic fluorinated chain do not, by far, have the same impact on micellization and adsorption than when the hydrophobic chain is totally hydrogenated. Table 2 contains the values of adsorption and micellization free energies found for

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Table 2. Free energies of micellization and adsorption of the hydrophobic groups at 25 °C.

	ΔG_{mic} (kJ mol^{-1})		ΔG_{ads} (kJ mol^{-1})	
	This work	Literature	This work	Literature
CF_2	-4.2[c] (± 0.5)	-4.5,[d] -4.7,[e] -5.2[f]	-4.1[c] (± 0.6)	-3.3,[d] -5.1[i]
CH_2[a]	-1.0[c] (± 0.4)		-1.0[c] (± 0.6)	
CH_2[b]	-2.4[g] (± 0.4)	-2.9,[h] -3.05[f]	-2.5[g] (± 0.5)	-2.4,[f] -2.6,[i] -2.9[d]

[a] In partly fluorinated hydrophobic tails. [b] In standard hydrogenated tails. [c] F*n*C*m*DMP (this work). [d] Calculated from ref. [10]. [e] Calculated from ref. [11]. [f] From ref. [9]. [g] C*m*DMP (this work). [h] From ref. [20]. [i] From ref. [8].

the dimorpholinophosphate derivatives, along with those published in the literature for either totally fluorinated or totally hydrogenated surfactants.

The contribution of the CH_2 groups to the micellar free energy was found to be only -1.0 ± 0.4 kJ mol^{-1} when they are present as a spacer in a fluorinated surfactant, while it is known to be in the -2.9 to -3.05 kJ mol^{-1} range when it is part of the hydrophobic chain of a nonfluorinated surfactant.[9, 20] In the case of the hydrogenated dimorpholinophosphates, $\Delta G_{mic}CH_2$ was measured to be -2.4 kJ mol^{-1}. These values suggest that $4\,CH_2$ groups within the spacer are equivalent to only $1\,CF_2$, which is dramatically different from the standard accepted $1.5\,CH_2$ for $1\,CF_2$ ratio, which was determined when comparing perfluoroalkylated surfactants to hydrogenated ones. The energetic contribution to micellization of a CH_2 group inside a partially fluorinated amphiphile can thus be aproximately three times lower than when it is part of a totally hydrogenated hydrophobic chain.

Where adsorption of the surfactant is concerned, the value found for $\Delta G_{ads}CH_2$ is -1.0 ± 0.6 kJ mol^{-1} for CH_2 groups taken within the F*n*C*m*DMP series, compared to $\Delta G_{ads}CH_2 = -2.5$ kJ mol^{-1} for CH_2s belonging to totally hydrogenated analogues. These values show the same trends as those determined for the micellization process: $\Delta G_{ads}CF_2$ is in agreement with the literature values (from -3.3 kJ mol^{-1}[10] to -5.1 kJ mol^{-1}[8]), and $\Delta G_{ads}CH_2$ is always much lower than the value measured or reported for the hydrogenated surfactant (-2.4, -2.6, and -2.9 kJ mol^{-1}[8–10]). Here again, these values suggest that the impact of four CH_2 groups located in the spacer are equivalent to only one CF_2.

Conclusion

The main results from this study can be summarized as follows: 1) the $\Delta G_{mic}CF_2$ and $\Delta G_{ads}CF_2$ values found for the F*n*C*m*DMPs are comparable to those reported for totally fluorinated surfactants;[8–11] 2) on the other hand, the $\Delta G_{mic}CH_2$ and $\Delta G_{ads}CH_2$ values are substantially lower than those reported for hydrocarbon amphiphiles; 3) the $\Delta G_{mic}CH_2$ and $\Delta G_{ads}CH_2$ values calculated for the C*m*DMPs are in good agreement with standard values reported for hydrocarbon amphiphiles. Taken together, these results show that, when located between a fluorinated chain and the polar head, a hydrocarbon chain does not fully participate in the micellization and adsorption processes of the surfactant, and behaves as if it were shorter by a factor of 3. This means that the length of the fluorinated chain actually controls the micellization and adsorption of the surfactant, the spacer making only a minor contribution to these processes. It is likely that the hydrocarbon spacer adopts a folded conformation in order to better occupy the void volume that results from the difference in cross-section between fluorocarbon and hydrocarbon chain (ca. 30 vs. 20 Å^2, respectively). Our results indicate that due caution must be exercised when applying the $1\,CF_2 \approx 1.5\,CH_2$ rule.

Experimental Section

Materials: The (*F*-alkyl)alkyldimorpholinophosphates investigated here and their hydrogenated analogues were synthesized and purified as reported previously.[21, 22]

Methods: The surface tensions (γ_s) of aqueous solutions of the F*n*C*m*DMPs were measured with an automatic Lauda tensiometer (Lecomte du Noüy method; platinum ring). Deionized water ($\gamma_s = 72$ mN m^{-1}) came from an Elgastat purification system. The solutions were equilibrated for 24 h in an incubator at 25 °C. They were then placed in a double-walled thermostated vessel (± 0.1 °C). The Harkins–Jordan correction was applied.[23] Experimental errors were in the 0.2 mN m^{-1} range. All measurements were made at 25 °C, except those for F10C2DMP, for which a temperature of 60 °C was required in order to be above the Krafft point. The errors in the determination of the energies of micellization and adsorption were determined from the estimated errors in the cmc measurements.

Equilibration of aqueous solutions of F*n*C*m*DMPs: Surface tension values were measured after equilibration of the surface, that is, when the γ_s values remained constant with time. This requires careful monitoring, since it takes significantly longer for fluorinated surfactants to equilibrate than for their hydrogenated analogues. The variation of γ_s vs. time for aqueous solutions of F8C5DMP shows, for example, that two to four hours are needed, depending on concentration, to reach equilibrium. In addition, before each measurement the surface of the solution was carefully pulled out with the ring, then allowed to relax without breaking the film. This operation was repeated three to five times to allow faster diffusion of the surfactant on the meniscus. The need for such precautions was reported for other hydrophobic surfactants and attributed to the slower formation of the monolayer.[19] In the case of F8C11DMP, it was not possible to obtain reproducible values of γs at concentrations below 5×10^{-6} mol L^{-1}. As a consequence, the cmc of this surfactant could not be determined experimentally and was calculated (see below).

Determination of cmcs by means of an empirical equation: We have found that the ΔG_{mic} of the amphiphiles investigated decreases as the number of fluorinated carbons increases. Such an effect has been reported for other homologous series of perfluoroalkylated or hydrogenated surfactants by monitoring the variation of ΔG_{mic} with the number of CF_2 or CH_2 groups.[10] The relation between the cmc and the number of carbon atoms of the hydrophobic chain can be deduced by combining Equations (1) and (2)[14] to give Equation (4), where $A = \log 55.5 + (\Delta G_{mic}W + \Delta G_{mic}CF_3)/2.3RT$, $B = -\Delta G_{mic}CF_2/2.3RT$, and $C = -\Delta G_{mic}CH_2/2.3RT$.

$$\log \mathrm{cmc} = A - (n-1)B - mC \tag{4}$$

At 25 °C, the calculation gives: $\log \mathrm{cmc} = -0.20 - 0.73(n-1) - 0.16m$, if $(n+m) \geq 8$, and $\log \mathrm{cmc} = 0.09 - 0.73(n-1) - 0.16m$, if $(n+m) \leq 7$. This equation allowed the calculation of the cmc of F8C11DMP (8.5×10^{-7} mol L^{-1}) which cannot be determined experimentally.

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[1] K. Shinoda, M. Hato, T. Hayashi, *J. Phys. Chem.* **1972**, *76*, 909–914.
[2] P. Mukerjee, *J. Am. Oil Chem. Soc.* **1982**, *59*, 573–578.

[3] E. Kissa, *Fluorinated Surfactants, Synthesis, Properties, Applications*, M. Dekker, New York, **1993**.

[4] J. Greiner, J. G. Riess, P. Vierling, in *Organofluorine Compounds in Medicinal Chemistry and Biomedical Applications* (Eds.: R. Filler, Y. Kobayashi, L. M. Yagupolskii), Elsevier, Amsterdam, **1993**, pp. 339–380.

[5] J. G. Riess, M. P. Krafft, *Biomaterials* **1998**, in press.

[6] M. P. Krafft, J. G. Riess, *Biochimie* **1998**, in press.

[7] H. Kunieda, K. Shinoda, *J. Phys. Chem.* **1976**, *80*, 2468–2470.

[8] P. Mukerjee, T. Handa, *J. Phys. Chem.* **1981**, *85*, 2290–2303.

[9] J. C. Ravey, M. J. Stébé, *Colloids Surf.* **1994**, *84*, 11–31.

[10] J. C. Ravey, A. Gherbi, M. J. Stébé, *Prog. Colloid Polym. Sci.* **1988**, *76*, 234–241.

[11] C. Selve, J. C. Ravey, M. J. Stébé, C. El Moudjahid, E. M. Moumni, J. J. Delpuech, *Tetrahedron* **1991**, *47*, 411–428.

[12] F. Giulieri, M. P. Krafft, J. G. Riess, *Angew. Chem.* **1994**, *106*, 1583–1584; *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 1514–1515.

[13] V. M. Sadtler, M. P. Krafft, J. G. Riess, *Angew. Chem.* **1996**, *108*, 2106–2108; *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 1976–1978.

[14] M. J. Rosen, *Surfactants and Interfacial Phenomena*, Wiley, New York, **1978**.

[15] P. Molyneux, C. T. Rhodes, J. Swarbrick, *Trans. Faraday Soc.* **1965,** *61*, 1043–1052.

[16] J. L. Katz, *J. Coll. Interface Sci.* **1976**, *56*, 179–180.

[17] J. G. Riess, *Colloids Surf.* **1994**, *84*, 33–48.

[18] F. Giulieri, M. P. Krafft, J. G. Riess, *Colloids Surf.* **1994**, *84*, 121–127.

[19] A. W. Adamsom, *Physical Chemistry of Surfaces*, Wiley Interscience, **1990**, pp. 131–145.

[20] C. Tanford, *The Hydrophobic Effect*, Wiley, New York, **1980**, pp. 42–59.

[21] M. P. Krafft, P. Vierling, J. G. Riess, *Eur. J. Med. Chem.* **1991**, *26*, 545–550.

[22] V. M. Sadtler, F. Jeanneaux, M. P. Krafft, J. Rabai, J. G. Riess, *New J. Chem.* **1998**, 609–613.

[23] W. D. Harkins, H. F. Jordan, *J. Am. Chem. Soc.* **1930**, *52*, 1751–1758.

0947-6539/98/0410-1956 $ 17.50+.50/0