Rate enhancements of S_N2 reactions of methyl naphthalene-2-sulfonate by sulfobetaine micelles†

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Received (in Cambridge, UK) 18th October 1999, Accepted 8th August 2000
Published on the Web 19th September 2000

Rate constants of S_N2 reactions of methyl naphthalene-2-sulfonate (MeONs) with nucleophilic anions and amines are increased by zwitterionic micelles of tetradecyl-dimethyl-, -dipropyl- and -dibutyl-ammoniopropanesulfonate (SB3-14, SBPr3-14 and SBBu3-14, respectively) when anions are Cl^-, N_3^-, CN^-, HCO_2^- and $S_2O_3^{2-}$ and the amines are *n*-propylamine, di-*n*-propylamine, *n*-butylamine and quinuclidine. On the other hand, reactions of OH^-, SO_3^{2-} and morpholine are inhibited but not suppressed. The rate effects are fitted quantitatively by a pseudophase model that considers the transfer equilibria of both reactants between water and micelles and second-order rate constants in each pseudophase. Second-order rate constants for the ionic reactions in the micellar pseudophase are similar to those in water and, where data are available, to those in cationic micelles. The second-order rate constants for reactions of the amines are lower than those in water. The increased head group bulk in SBBu3-14 over SB3-14 decreases the polarity in the micellar interfacial region favoring reactions of soft anions and disfavoring those of hard ions and of amines.

Introduction

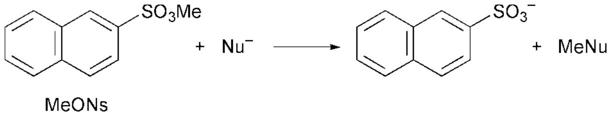
Zwitterionic micelles derived from betaine surfactants, **1**, are formally neutral, but anions are not excluded from their surfaces.[1–3]

$$\underset{\mathbf{1}}{R'N^+R_2CH_2CO_2^-} \qquad \underset{\mathbf{2}}{R'N^+R_2(CH_2)_nSO_3^-}$$

Rates of spontaneous anionic decarboxylations and dephosphorylations are increased by aqueous micellized zwitterionic betaine or sulfobetaine surfactants, **2**.[2] Effects of these surfactants on rates of bimolecular reactions of nucleophilic anions depend on hydrophilicities of the anions. Reactions of very hydrophilic anions, *e.g.*, OH^- and F^- are inhibited, but not suppressed, by sulfobetaine micelles, but reactions of less hydrophilic anions, *e.g.*, Cl^-, Br^- and iodosobenzoate ions are accelerated.[3] Evidence to date indicates that micelles of betaine surfactants are qualitatively similar to cationic micelles in their effects on reaction rates, except that the weaker affinity for anions reduces overall rate enhancements. We planned to obtain other examples of this behavior by examining S_N2 reactions of a relatively hydrophobic substrate with a strong affinity for micelles.

Micelle–ion interactions depend on coulombic forces, which to a first approximation should not be ion-specific, and dispersive forces which are largest for polarizable, low charge-density ions, and follow the Hofmeister series.[4] Consideration of charge densities at surfaces of betaine-derived micelles[1,3] shows that there should be a nonspecific attractive interaction with anions such as OH^- and it has been treated quantitatively.[1a]

In the present work we examine reactions of methyl naphthalene-2-sulfonate (MeONs) with anionic and nonionic nucleophiles of very different hydrophilicities in solutions of tetradecyl-dimethyl-, -dipropyl- and -dibutyl-ammoniopropanesulfonate (SB3-14, SBPr3-14 and SBBu3-14, $R'R_2N^+$-$(CH_2)_3SO_3^-$ with R = Me, n-Pr and n-Bu, $R' = -(CH_2)_{13}CH_3$).



These reactions of MeONs are mechanistically simple and can be followed spectrophotometrically. The substrate is relatively hydrophobic and is transferred extensively from water to micelles. Cationic micelles increase rates of these reactions and rate enhancements are accounted for quantitatively by models that consider the concentration of both reagents at the micelle/water interface.[5] There is a limited amount of work with the longer chain surfactant, SB3-16,[3a,b] but its relatively low solubility in water is a disadvantage. The reaction of Br^- with MeONs has been followed in micellized sulfobetaines and the kinetic work was complemented by physical studies of ion–micelle interactions.[3c] The binding of nonionic long chain amines, unlike ions, to micelles should not be very sensitive to micellar charge but will depend on amine structure. The factors that control micellar binding of nonionic solutes have been analyzed quantitatively.[6]

The anionic nucleophiles used in this work are: OH^-, Cl^-, N_3^-, CN^-, HCO_2^-, SO_3^{2-} and $S_2O_3^{2-}$. The amines are $n\text{-}C_3H_7NH_2$ ($PrNH_2$), $n\text{-}C_4H_9NH_2$ ($BuNH_2$), $(n\text{-}C_3H_7)_2NH$ (Pr_2NH),

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† First-order rate constants for reaction of anions Cl^-, HCO_2^-, CN^- and amines *n*-butylamine, *n*-propylamine, di-*n*-propylamine, quinuclidine and morpholine with MeONs in solution with sulfobetaines SB3-14 and SBBu3-14 are available as supplementary data. For direct electronic access see http://www.rsc.org/suppdata/p2/a9/a908316b/

DOI: 10.1039/a908316b

Table 1 First-order rate constants for reaction of MeONs with various nucleophilic anions in sulfobetaine surfactants[a]

[Sulfobetaine]/ 10^{-3} mol dm^{-3}	$k_{obs}/10^{-4}$ s^{-1}						
	OH^-	SO_3^{2-} [b]	Cl^-	N_3^-	CN^-	HCO_2^-	$S_2O_3^{2-}$
0	1.02	91.6	0.02	0.43	4.10	0.040	37.2
1	0.86 (0.75)[c]	47.0	0.14 (0.29)	2.04 (3.38)	17.2 (33.6)	0.10 (0.16)	68.8 (63.3)
3	—	36.1	0.18 (0.34)	3.08 (5.3)	35.2 (54.4)	0.11	155 (83.8)
5	0.71 (0.68)[c]	30.2	0.22 (0.35)	3.29 (6.06)	42.0 (62.9)	— (0.19)	171 (105)
8	—	30.8	0.23 (0.37)	3.63 (6.80)	46.1 (68.4)	0.12 (0.20)	186 (107)
10	0.64 (0.59)[c]	28.6	0.24 (0.38)	3.93 (6.82)	47.4 (69.5)	0.13	198 (107)
20	0.60 (0.55)[c]	—	—	—	—	—	—
30	—	30.5	0.23 (0.44)	4.08 (6.98)	51.4 (77.4)	0.14 (0.21)	222 (115)
40	0.65 (0.58)[c]	—	—	—	—	—	—
50	0.66 (0.60)[c]	28.2	0.24 (0.45)	4.57 (7.43)	52.9 (79.6)	0.15	236 (113)
80	0.71	—	—	—	—	—	—
100	0.71	28.4	0.26	5.08 (6.95)	52.2 (79.8)	0.19 (0.24)	232 (114)

[a] Values of k_{obs} for SB3-14 and SBBu3-14 (values in parentheses) with [nucleophile] = 0.1 mol dm^{-3} unless specified; values of k_{obs} are corrected for the reaction of H_2O in water or in SB3-14 at various concentrations (ref. 10). [b] [Na_2SO_3] = 0.5 mol dm^{-3}. [c] SBPr3-14.

Table 2 Fitting parameters for reaction of MeONs with various nucleophilic anions in sulfobetaine surfactants[a]

Nucleophile[b]	$k_W/10^{-4}$ dm^3 mol^{-1} s^{-1}	K'_{Nu}/dm^3 mol^{-1}		$k_M/10^{-4}$ s^{-1}		$k^m_2/10^{-4}$ dm^3 mol^{-1} s^{-1}	
		SB3-14	SBBu3-14	SB3-14	SBBu3-14	SB3-14	SBBu3-14
OH^- [c]	10.2	0.35	0.25[c]	20	24[c]	2.6	3.0
SO_3^{2-}	180	0.3	—	200	—	28	—
Cl^-	0.2	1.7	1.2	2.9	4.9	0.4	0.6
N_3^-	4.3	2.6	1.7	22	54	3.1	7.6
CN^-	41	2.1	1.4	320	720	46	73
HCO_2^-	0.4	0.6	0.5	2.5	4.8	0.4	0.7
$S_2O_3^{2-}$	372	0.2	0.1	12000	12000	1680	1680
Br^- [d]	0.82	4.3	1.8	7.0	29	—	—

[a] K_S = 1000 mol dm^{-3}; values of 10^4 M cmc are 2 and 1 and for SB3-14 and SBBu3-14 respectively. [b] Sodium salt, 0.1 mol dm^{-3}. [c] In SBPr3-14 and not in SBBu3-14. [d] Ref. 3*c*.

morpholine and quinuclidine. These nucleophiles differ considerably in their affinities for micelles and reactivities towards alkyl centers,[7] and both factors should control reactivities in micelles relative to water.[5] Data for reaction of MeONs with Br^- are in ref. 3*c*.

Quantitative treatments of micellar rate effects in terms of pseudophase models show that one can compare the kinetic medium effects of the micellar interfacial region with those of bulk solvents, provided that transfer equilibria of reactants are considered, and we apply these concepts to S_N2 reactions in sulfobetaine micelles.

Experimental

Materials

SB3-14 was from Fluka and was purified by recrystallization from acetone. The other sulfobetaines were prepared from propane-1,3-sultone and the corresponding tertiary amine as described.[3c,8] NaOH, NaCl, NaN_3, NaCN, $NaHCO_2$, Na_2SO_3, $Na_2S_2O_3$ were from Aldrich (reagent grade). $PrNH_2$, $BuNH_2$, Pr_2NH, morpholine and quinuclidine (Aldrich) were used without further purification.

The preparation of MeONs has been described previously.[9]

Kinetics

Reactions of MeONs with nucleophiles were followed at 25.0 ± 0.1 °C in either HP diode-array or Shimadzu double-beam spectrometers at 326 nm with 10^{-4} M MeONs.[3b,9] There is a minor contribution from the reaction of MeONs with water, with k_{H_2O} ranging from 1.2×10^{-5} s^{-1} in water to *ca.* 7×10^{-6} s^{-1} in 0.1 M sulfobetaine (all sulfobetaines tested gave approximately the same value).[10] The various sulfobetaines behaved similarly, and our reported values of first-order rate constants, k_{obs}, are corrected for k_{H_2O}.

Results

Kinetics

Reactions of MeONs in water. Second-order rate constants for reaction of MeONs with anions in water, k_W, (Table 2) are consistent with existing scales of nucleophilicities towards alkyl centers in aqueous solution.[7] Allowance was made for the contribution of the spontaneous reaction with water, which is relatively small.

Interpretation of the data for reactions of the basic amines with MeONs (Table 3) is complicated by their protonation by water which generates OH^-. As a result the nucleophile is partially replaced by OH^- which is less reactive. There are compilations of amine nucleophilicities in S_N2 reactions and the results are summarized by Bunting *et al.*[11a] who used methyl 4-nitrobenzenesulfonate as substrate, and examined linear free energy correlations of nucleophilicity with basicity and parameters such as N[11b] and n[11c] which describe nucleophilicities in standard reactions. We have corrected the rate constants in water for protonation of the stronger bases by using literature dissociation constants,[12] neglecting activity coefficient corrections which should be small for solutions of the nonionic amines (Table 4).

The first-order rate constants for reactions of basic nucleophiles in water are given by eqn. (1) where k_W and k_{Nu} are

$$k_{obs} = k_W\,[OH^-] + k_{Nu}\,[Nu] \qquad (1)$$

second-order rate constants for reactions of OH^- and the nucleophile, Nu.

Table 3 First-order rate constants for the reaction of MeONs with various amines in sulfobetaine surfactants[a]

[Sulfobetaine]/ 10^{-3} mol dm^{-3}	$k_{obs}/10^{-3}$ s^{-1} *n*-Propylamine	 Di-*n*-propylamine	 *n*-Butylamine	 Quinuclidine	 Morpholine
0	1.26[b]	2.19[b]	1.38[b]	28.9[b]	2.20[b]
1	1.45 (1.27)	3.96 (3.47)	2.53 (2.03)	37.2 (29.9)	1.41 (1.39)
3	1.65 (1.30)	6.22 (4.18)	3.33 (2.30)	55.1 (33.3)	1.10 (1.10)
5	— (1.26)	7.03 (4.54)	3.90 (2.56)	55.5 (35.8)	1.03 (1.03)
8	1.71	7.72 (4.75)	4.15 (2.57)	— (36.5)	1.01 (0.96)
10	1.78 (1.24)	8.38 (4.84)	4.17 (2.65)	58.9 (36.7)	0.96 (0.93)
30	1.76 (1.23)	8.56 (5.16)	4.25 (2.61)	60.3 (36.9)	0.95 (0.86)
50	1.74 (1.22)	8.22 (4.74)	4.06 (2.56)	60.9 (35.5)	0.95 (0.80)
100	1.77 (1.21)	7.48 (4.14)	4.08 (2.36)	57.1 (34.5)	0.93 (0.80)
200	1.69	—	3.46	42.2	—
300	1.59	—	2.90	35.2	—
500	1.41	—	2.29	26.7	—

[a] Values of k_{obs} for SB3-14 and SBBu3-14 (values in parentheses) with 0.1 mol dm^{-3} amine. [b] Values corrected for the reaction of OH$^-$.

Table 4 Fitting parameters for reaction of MeONs with various amines in sulfobetaine surfactants[a]

Nucleophile[b]	$k_W/10^{-4}$ dm^3 mol^{-1} s^{-1}	K'_N/dm^3 mol^{-1} SB3-14	 SBBu3-14	$k_M/10^{-4}$ s^{-1} SB3-14	 SBBu3-14	$k^m_2/10^{-4}$ dm^3 mol^{-1} s^{-1} SB3-14	 SBBu3-14
Quinuclidine	2500	5	5	2000	1200	280	168
Morpholine	220	0.8	0.8	110	100	15.4	14.0
n-Butylamine	140	2.5	2.5	195	115	27.3	16.1
n-Propylamine	120	1.1	1.1	180	120	25.2	16.8
Di-*n*-propylamine	190	5	5	280	160	39.2	22.4

[a] K_S = 1000 mol dm^{-3}; values of 10^4 M cmc are 2 and 1 and for SB3-14 and SBBu3-14 respectively. [b] [Nucleophile] = 0.1 mol dm^{-3}.

We did not apply corrections for protonation of the weakly basic nucleophiles in reactions of N_3^-, CN$^-$ or morpholine, because values of k_{Nu} would only be changed by <2%.

Micellar reactions. Acid dissociation constants are usually increased by cationic micelles, and the effects are treated quantitatively by the pseudophase ion-exchange model,[5] but we can neglect protonation of the bases in sulfobetaine micelles. Two points should be noted. (i) Sulfobetaine micelles are formally neutral, and, based on Hartley's Rules,[5a] should have little effect on acid–base equilibria. (ii) Amines are more reactive than OH$^-$ towards MeONs and therefore protonation of amines by water in sulfobetaine micelles will decrease k_{obs}, but, as noted above, the effect should be smaller than in water.

The micellar rate effects for reactions with anions accord with earlier results in showing that rate enhancements in sulfobetaine micelles are related to charge densities and hydrophilicities of the anions as well as their nucleophilicities.[3] Raw kinetic data in Table 1 show an ion discrimination induced by sulfobetaine micelles, related to the soft–hard nature of the anions. Reaction of very hydrophilic, strongly nucleophilic, high-charge density ions such as OH$^-$ (Fig. 1) and SO_3^{2-} are inhibited because MeONs is taken up strongly by the micelles and ions remain largely in the water. On the other hand there are rate enhancements with less hydrophilic ions, *e.g.* N_3^- (Fig. 2).

As for the other anions, the marked difference in the behaviors of SO_3^{2-} and $S_2O_3^{2-}$ (Table 1) is due to the higher nucleophilicity and lower charge density of the latter[7,13] and leads to a significant inversion of reactivity order for these nucleophiles. The different micellar effects upon reactions of MeONs with anions are ascribed to differences in hydration of the ions. Hydrophilic ions interact strongly with water and their hydration should be little perturbed by micelles, but hydration of soft ions is decreased when they interact with the ammonium center, with a consequent increase in nucleophilicity. Evidence of water modification around soft ions at the surface of sulfobetaine micelles comes from NMR measurements[3c] and also from kinetic data showing a decrease in hydrolysis rate for MeONs in SB3-14 by addition of soft perchlorate ions (whereas almost no effect was induced by hydrophilic mesylate).[10]

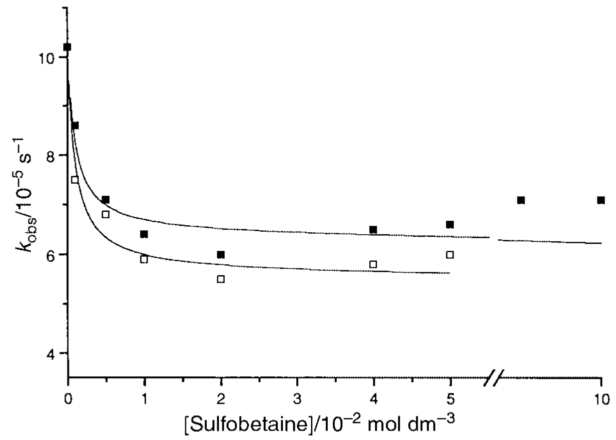

Fig. 1 First-order rate constants of reaction of MeONs with 0.1 mol dm^{-3} OH$^-$ at 25.0 °C in sulfobetaine surfactants: SB3-14 (■); SBBu3-14 (□).

An increase in surfactant head group bulk, going from SB3-14 to SBBu3-14 leads to an increase in ion discrimination. In fact reactivity of hydroxide is slightly decreased (Table 1 and Fig. 1) whereas reactivity of soft ions increases by a factor of *ca.* 2. However for the bivalent anion $S_2O_3^{2-}$ the reactivity is decreased by a factor of *ca.* 2 with increasing head group bulk.

This kind of ion discrimination can be important preparatively. Bromide–hydroxide ion discrimination induced by SB3-14 has been "used" to induce chemoselectivity in reactions

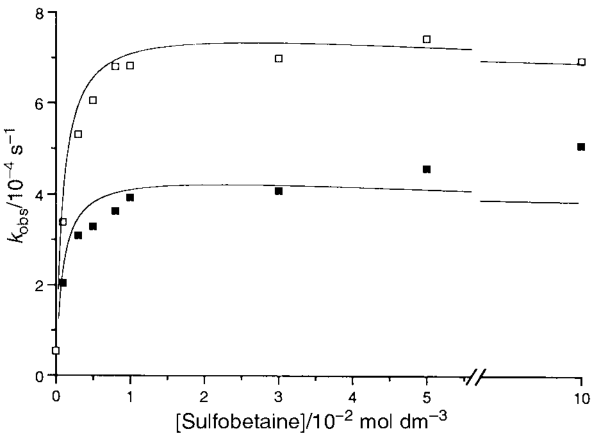

Fig. 2 First-order rate constants of reaction of MeONs with 0.1 mol dm^{-3} N_3^- at 25.0 °C in sulfobetaine surfactants: SB3-14 (■); SBBu3-14 (□).

with various sulfonate esters: in water reaction with OH^- is dominant, but in SB3-14 only the alkyl bromide forms.[14] Furthermore experimental evidence shows that sulfobetaine micelles also induce discrimination between transition states of different softness. Elimination from *p*-X-phenethyl bromides is inhibited by SB3-14 for X = H, whereas it is accelerated when $X = NO_2$, *i.e.*, when a softer transition state forms,[15] and an increase in head group size increases the reactivity difference for the two substrates. Also this kind of effect can be useful preparatively, for instance to induce S_N2–E2 chemoselectivity controlled by micelles. Similar ion discrimination has also been observed in the presence of functionalized synthetic cationic micelles,[14] but we need to consider that sulfobetaines can be useful preparatively because they have more solubilizing power than otherwise similar cationic surfactants.

As regards micellar effects upon reactions with amines (Table 3), reaction of the hydrophilic, weakly nucleophilic, morpholine is inhibited by micelles of SB3-14 and SBBu3-14 as with ionic micelles,[5a,c] whereas there are modest rate enhancements of reactions of the other amines.

The reaction with *n*-propylamine is slightly accelerated by micellized SB3-14 and SBBu3-14 and rate enhancements are larger with the bulkier, more hydrophobic, amines (Table 3). Particularly with the more hydrophobic amines, values of k_{obs} go through maxima with increasing [SB3-14] and [SBBu3-14], as is typical of bimolecular reactions in ionic micelles,[9] depending on hydrophobicities of the amines. It therefore seems that sulfobetaine induced discrimination also applies to amines, related to the different hydrophilic–hydrophobic nature of the amines, with relative values of k_{obs} for di-*n*-propylamine and morpholine changing by a factor of *ca.* 10 going from water to SB3-14 (Table 3).

There are significant differences in the relative effects of SB3-14 and SBBu3-14 on reactions of anions and amines with MeONs. Values of k_{obs} are higher in SBBu3-14 than in SB3-14 for the reactions of soft anions and lower for reactions of all the amines used here, and the significance of these observations is discussed later.

Quantitative treatment of micellar reactions. We treated micellar rate effects in terms of the pseudophase model.[5,9] Substrate, $MeONs_W$, reacts in water with a first-order rate constant, k'_W, and in the micelles, as $MeONs_M$, with a first-order rate constant, k'_M. K_S is the association constant written in terms of micellized surfactant, SB_n, whose concentration is assumed to be the total concentration minus the critical micelle concentration, cmc, under the kinetic conditions. We can write $k'_W = k_W[Nu_W]$ and $k'_M = k_M[Nu_M]/[Dn]$ (where Dn is the micellized surfactant concentration), giving eqn. (2).[5c,f,9]

$$k_{obs} = \frac{k_W[Nu_W] + k_M K_S[Nu_M]}{1 + K_S[SB_n]} \qquad (2)$$

The first-order rate constants depend on concentrations of the nucleophiles, Nu, in the aqueous and micellar pseudophases, denoted by subscripts S and M respectively. Concentration in the former is written as molarity and concentration in the micellar pseudophase can be written as a mole ratio $[Nu_M]/[Dn]$ or as a local molarity, Nu_M, and calculated second-order rate constants then have different concentration units and are related by eqn. (3), where V_M is the molar volume of the reaction region at the micelle/water interface.[5c,f,9]

$$k^m_2 = k_M V_M \qquad (3)$$

Quantities in square brackets are molarities written in terms of total solution volume, and V_M is assumed to be independent of the nature of the reaction region. Assumed values of V_M are typically in the range 0.14–0.37 dm^3 mol^{-1} for ionic micelles.[5b,c,f,16]

We write the transfer equilibrium of the nucleophiles between water and micelles in terms of eqn. (4) for the

$$\text{Anions: } K'_{Nu} = [Nu_M^-]/([Nu_W^-]([SB_n] - [Nu_M^-])) \qquad (4)$$

anions[1b,9,16] and eqn. (5) for nonionic amines, as for other

$$\text{Amines: } K'_N = [Nu_M]/([Nu_W][SB_n]) \qquad (5)$$

nonionic solutes,[6] on the assumption that incorporation of an anion reduces the affinity of the micelle for anions, and that dilute nonionic amines do not have this effect. For divalent anions eqn. (4) has been properly modified.

Eqns. (2)–(5) have been used to fit rate effects of ionic and zwitterionic surfactants.[3b,5c,f,9,17] They are reasonably satisfactory for dilute electrolytes, but underestimate binding at higher concentrations where entropy drives ions into the micelle. There is a spontaneous reaction of MeONs with H_2O which is slightly inhibited by SB3-14 and k_{obs} values have been corrected for this contribution[10] (Tables 1 and 3). Rate effects are fitted by combining eqns. (2) and (4) with the rate and equilibrium constants given in Table 2: most fits are given as supplementary material, apart from two cases (OH^- and N_3^-) reported in Figs. 1 and 2.

Rate effects of SB3-14 and SBBu3-14 agree qualitatively with results obtained for SB3-16[3b] with which comparisons can be made.

The kinetically estimated values of K'_{Nu} are larger in SB3-14 than in SBBu3-14 (Table 2), but values of k_M are consistently larger in the latter. These effects of head group bulk upon the ionic binding constants, K'_{Nu}, and the rate constants, k_M, are as for cationic micelles and have similar origins, *viz.*, bulk reduces the affinity of the cationic centre for anions, as given by K'_{Nu},[5] but by decreasing the local polarity it increases anionic nucleophilicities.[18] Values of K'_{Nu} (Table 2) follow the same sequence as anion affinities for cationic micelles which closely follow ionic charge densities and extents of hydration.[5] The relatively high affinities of ions such as Br^- and N_3^- for cationic micelles have been noted,[5] and their S_N2 reactions occur readily in cationic, as in sulfobetaine, micelles.

The data for reactions of the amines with MeONs (Table 3) are fitted by combining eqns. (2) and (5) with the rate and association constants in Table 4. Incorporation of amines in the micelles does not affect charge and with the less hydrophilic amines the surfactant rate profiles are similar to those observed for other reactions of nonionic reagents in solutions of ionic micelles.[9] The aliphatic amines bind weakly to micelles, and uncertainties in K'_N [eqn. (5)] are reflected in estimated values of k_M. As a test of our fitting procedure for the reaction of quinuclidine in SB3-14 we varied K'_N between 2.5 and 3.5 dm^3 mol^{-1}, and then k'_M was found to vary between 0.26 and 0.20 s^{-1}, and the fits were practically undistinguishable. These uncertainties in values of K'_N or K'_{Nu} are much less serious for reactions of the more strongly bound nucleophiles.

Quantitative treatment of micellar effects upon reactions of aliphatic amines is complicated by their relatively high basicities[12] and in some cases their weak binding to micelles. In water, without surfactant, values of the pK_a are in the range 10.6–11.1 (except for morpholine), but in 0.1 M amine solutions protonation will be less than 10%, and as noted earlier will be less in sulfobetaine micelles; the reaction with OH^- is micellar-inhibited (Fig. 1).

Rate constants in the micellar pseudophase. Values of k_M are estimated in terms of K_S, K'_{Nu} and k_W, which is measured directly, and because MeONs is bound almost quantitatively, fits are insensitive to the value of K_S. Values of K'_{Nu}, and therefore of k_M, are estimated from the rate–surfactant profiles, and the fitting depends on the validities of eqns. (4) and (5). However, it seems reasonable to compare values of k_M for the various nucleophiles and if we select a value of V_M, eqn. (3), we can also compare k^m_2 in the micelles with k_W in water. Where we can make comparisons our values of k_M, or k^m_2 for reactions of anions, in sulfobetaine micelles are similar to those in cationic micelles.[5] For example, values of k^m_2/k_W (or k_M) in SB3-14 micelles are compared with those in cationic, cetyltrialkylammonium (CTA^+), micelles (in parentheses) for the following reagents:[5c,d] OH^-, 0.26 (0.3); Cl^-, 2.0 (1.7). The values in parentheses were calculated by using eqns. (2) and (3), but similar values have been obtained by using an alternative treatment of nucleophilic reactivities in cationic micelles with solution of the Poisson–Boltzmann equation, despite the presence of inert anions in some of the reactions.[19] For reaction of N_3^- in cationic micelles with $PhSO_3Me$ $k^m_2/k_W = 0.4–0.7$ depending on the presence of $MeSO_3^-$ in the solution,[20] and these values are not very different from that of *ca.* 0.8 for the reaction with MeONs in SB3-14.

These observations show that second-order rate constants of reactions of anionic nucleophiles at micelle/water interfaces are only modestly affected by a change of the head group from cationic to zwitterionic.

Overall rate constants of bimolecular anionic reactions are generally much lower in zwitterionic than in cationic micelles, simply because of less favorable transfer of anions between water and micelles. Comparisons of reactivities based on overall rate constants tend to be quantitatively uninformative for bimolecular reactions in micelles and other association colloids. Although the fitting parameters for reactions of the amines (Table 3) are, as noted, based on an approximate treatment the trends in values of K'_N and k_M are qualitatively reasonable. The binding constants follow the number of alkyl groups, except for morpholine where the ring oxygen increases hydrophilicity, and values of k_M, or k^m_2, follow those of k_W in water. Comparison of second-order rate constants in the aqueous and micellar pseudophases depends on the value of V_M [eqn. (3)]. Values of k^m_2/k_W (Tables 2 and 4) are based on $V_M = 0.14$ dm^3 mol^{-1} for both sulfobetaine surfactants on the assumption that the location and volume of the reaction region are independent of structures of the nucleophiles and the surfactant head groups.

We do not have data for S_N2 reactions of amines with MeONs in ionic micelles, but local second-order rate constants for nucleophilic reactions of amines are generally slightly smaller in micellar pseudophases than in water,[5a,c,9] as for reactions in sulfobetaine micelles (Table 4). Polarities of micellar surfaces are slightly lower than that of water, based on spectroscopic probes,[21] so relative rate constants of S_N2 reactions in water and in micelles are consistent with the Hughes–Ingold rules which predict that a decrease in solvent polarity should inhibit reactions of nonionic nucleophiles and slightly increase, or have no effect on, rates of reactions of anionic nucleophiles. These generalizations apply to reactions in SB3-14 and SBBu3-14. The increased bulk of a butyl over a methyl group should make the interfacial region of an SBBu3-14 micelle less polar than that of an SB3-14 micelle. In our experiments values of k_M for reactions of soft anions are higher in SBBu3-14 than in SB3-14, and we see the opposite behavior in reactions of the amines (Tables 2 and 4). The same qualitative trends are observed if comparisons are based on values of k_{obs} for the overall reactions.

Acknowledgements

Support of this work by the Italian National Research Council (CNR), Rome, the Ministero dell'Università e della Ricerca Scientifica, MURST, Rome, and the US Army Office of Research is gratefully acknowledged.

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