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MICELLAR CATALYSIS OF ORGANIC REACTIONS. 24.* COMPARISON OF S_NAr REACTIONS IN HYDROXY-FUNCTIONALIZED MICELLES AND IN THE PRESENCE OF CYCLODEXTRINS

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ABSTRACT

The basic hydrolysis of 2,4-dinitrochlorobenzene (DNCB) and 2,4-dinitrofluorobenzene (DNFB) was studied in the presence of β-cyclodextrin (CDOH) and in the presence of hydroxy-functionalized micelles containing either a primary hydroxy group [hexadecyl-2-hydroxyethyldimethylammonium bromide (CHEDAB)] or a secondary hydroxy group [headecyl-2-hydroxypropyldimethylammonium bromide (CHPDAB) and 2-hydroxyhexadecyltrimethylammonium bromide (2-OHCTAB].

In all systems a biphasic reaction was observed. The first phase consisted of a competition between the additive (either micelle or cyclodextrin) and hydroxide ion for the aromatic substrate, and the second phase consisted of the hydrolysis of the trapped aryl micellar or cyclodextryl ether.

The percentage of trapping of the aromatic substrate by the cyclodextrin was similar to that found for reactions in the hydroxy-functionalized micelles (CHPDAB and 2-OHCTAB) which contained secondary hydroxy groups. The relative rates of reaction for DNFB and for DNCB, i.e. F/Cl rate ratios, in the presence of CDOH were similar to those obtained in the presence of 2-OHCTAB but less than that obtained in the presence of CHEDAB. These results support the assumption that in CDOH the secondary hydroxy groups of C-2 or C-3 are involved in covalent bond formation with the aromatic substrate rather than the primary hydroxy group of C-6. All the reactions studied proceed much more slowly in the presence of CDOH than in the presence of the hydroxy-functionalized micelles. This may reflect a catalytic effect of the positively charged surface present in the micelles but not in the cyclodextrin.

The study of nucleophilic aromatic substitution reactions in the presence of hydroxy-functionalized micelles is currently of interest.[1,2] The functionalized surfactant itself can act as a nucleophile in competition with hydroxide ion and the micellar aryl ether produced initially subsequently decomposes to give the phenolic product and to regenerate the functionalized surfactant (Scheme 1).

Obvious similarities exist between the reaction in hydroxy-functionalized surfactants and that proposed for reaction in the presence of cyclodextrins. (Scheme 2).[3,4] Cyclodextrins are oligomers of glucose containing six, seven or eight glucose units. We are concerned with β-cyclodextrin (CDOH), which consists of seven glucose units.

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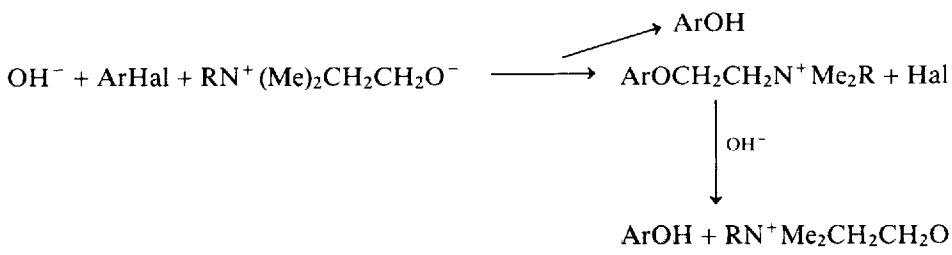
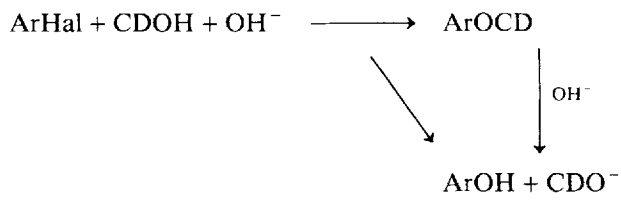


where $R = C_{16}H_{33}$ (e.g. for compound **1**), Ar = 2,4-dinitrophenyl and Hal = F or Cl

Scheme 1



where CDOH = β-cyclodextrin

Scheme 2

Both the hydroxy-functionalized micelles and β-cyclodextrin contain a hydrophobic interior/cavity and a polar exterior on which the hydroxy groups are located. In both systems there is a biphasic reaction with an initial competition leading either to dinitrophenol directly or to a trapped aryl ether which is subsequently hydrolysed. We now compare these reactions for 2,4-dinitrohalobenzenes in the presence of hydroxy-functionalized micelles (**1**–**3**) and in the presence of β-cyclodextrin (CDOH).

$C_{16}H_{33}N^+Me_2CH_2CH_2OH\ Br^-$

CHEDAB (hexadecyl-2-hydroxyethyldimethylammonium bromide) **(1)**

$C_{16}H_{33}N^+Me_2CH_2\underset{\displaystyle OH}{\underset{|}{C}}HCH_3\ Br^-$

CHPDAB (hexadecyl-2-hydroxypropyldimethylammonium bromide) **(2)**

$C_{14}H_{29}\underset{\displaystyle OH}{\underset{|}{C}}HCH_2N^+Me_3\ Br^-$

2-OHCTAB (2-hydroxyhexadecyltrimethylammonium bromide) **(3)**

Specifically we compare the rates of the individual reactions (phases 1 and 2) and the percentage trapping of the aromatic substrate by the hydroxyl groups of the micelles and the cyclodextrin. With 2,4-dinitrofluorobenzene (DNFB) as a substrate the first phase of reaction is very rapid and it is convenient to follow at 358 nm the subsequent breakdown of the aryl ether to give dinitrophenol. This allows the determination of the rate constants for the second phase of reaction and also the isosbestic point (323 nm) for the second phase of reaction. With

2,4-dinitrochlorobenzene (DNCB) as substrate the first phase of reaction is much slower but the rate of this process can be determined without complication by the second phase by following the reaction at the isosbestic point for the second phase of reaction (i.e. 323 nm). Since the first phase (loss of ArHal) is very fast for the fluoro compound, it is possible to determine the relative amounts of hydrolysis and trapping without added complications caused by the subsequent decomposition of the trapped aryl ethers. For the chloro compound the rates of phase 1 (loss of DNCB) and phase 2 (loss of micellar aryl ether) are similar and hence it is necessary to correct for the subsequent reaction when determining the percentage trapping that occurs in the first phase. In the absence of this correction the results obtained for the percentage trapping are low owing to the contribution of the second phase of reaction, which consumes the micellar aryl ether.

It has been reported[5,6] that β-cyclodextrin has a round, slightly conical form, with the primary hydroxy groups of C-6 at the smaller opening and the secondary hydroxy groups of C-2 and C-3 in the wider opening. Using partially substituted cyclodextrins, Tonellato and co-workers[7,8] have shown that for ester hydrolysis it is the secondary hydroxy groups that are involved in covalent bond formation between the substrate and the cyclodextrin. De Rossi *et al.*[4] assumed that this is also the case for S_NAr reactions. It seems reasonable to assume[4] that the aromatic substrates residing in the cyclodextrin cavity would be near the wider opening and hence covalent bond formation between the substrate and the hydroxy groups of the cyclodextrin would involve the secondary hydroxy groups of C-2 and C-3. To probe this assumption we investigated reactions in hydroxy-functionalized micelles containing either primary hydroxy groups (**1**) or secondary hydroxy groups (**2** and **3**).

RESULTS AND DISCUSSION

Phase 1 (partitioning of the aryl halide)

Rate constants for the first phase of the reaction of 2,4-dinitrochlorobenzene (DNCB) in the various sufactant and cyclodextrin solutions are given in Table 1 and those for 2,4-

Table 1. First-order rate constants ($10^3 k_1/s^{-1}$) for the first phase of the hydrolysis of DNCB (6×10^{-5} M) at 30 °C

[Surfactant]/mM	2-OHCTAB[a]	CHPDAB[b]	CHEDAB[c]	CDOH[a]
0·4	0·175	0·88	0·88	—
0·6	0·46	1·54	2·53	0·033
0·8	0·59	2·22	4·25	0·03
1·0	0·79	2·79	5·65	0·038
2·0	1·61	5·23	11·1	0·052
4·0	2·41	8·14	14·3	0·083
8·0	3·70	11·1	16·6	0·128
13·3	3·59	11·3	17·1	0·158
20·0	3·82	11·7	12·7	0·201
30·0	3·95	10·2	9·9	—
40·0	3·88	8·7	7·7	—

[a] 0·1 M NaOH.
[b] 0·05 M NaOH.
[c] 0·005 M NaOH.

Table 2. First-order rate constants ($10^3 k_1/s^{-1}$) for the first phase of the hydrolysis of DNFB (6×10^{-5} M) at 30 °C in the presence of 0·01 M NaOH[a]

[Surfactant]/mM	2-OHCTAB	CHPDAB	CHEDAB	CDOH
0	1·87	1·87	1·87	1·87
1·0	—	—	—	3·42
2·0	—	—	—	4·67
3·0	140	787	6770	5·24
4·0	—	—	—	6·83
6·0	223	1130	9870	7·77
10·0	306	1340	12270	11·0
13·3	—	—	—	14·8
15·0	336	1390	12500	14·5
20·0	344	1330	13020	19·2
25·0	345	1290	12480	19·9
30·0	346	1250	12140	22·5
35·0	336	1240	11080	22·5
40·0	335	1160	10490	26·2

[a] All reactions followed at 323 nm, the isosbestic point for the second phase of reaction.

dinitrofluorobenzene (DNFB) in Table 2. It can be seen that the rate of reaction for DNFB is much faster than that for DNCB, as is commonly found in S_NAr reactions.[9a] After allowing for differences in hydroxide ion concentrations, it was found that the F/Cl rate ratio ranged from 500 (in 20 mM CHEDAB) to 960 (in 20 mM CDOH). Of the hydroxy-functionalized micelles the F/Cl rate ratio in 2-OHCTAB (860) was closest to that in CDOH. The larger F/Cl rate ratios observed in the hydroxy-functionalized micelles containing secondary hydroxy groups and in CDOH compared with that obtained in CHEDAB (primary hydroxy groups) supports the contention[4] that covalent bond formation between the aryl halide and CDOH occurs at the secondary hydroxy groups of C-2 or C-3 rather than at the primary hydroxy group of C-6.

The rates in Tables 1 and 2 represent the total rate of loss of aryl halide, i.e. the sum of the rate of direct hydrolysis (formation of ArOH) and the rate of reaction with the hydroxy micelle or cyclodextrin (trapping).

The percentage trapping by the micelle or cyclodextrin for DNFB as a function of detergent or cyclodextrin concentration and as a function of hydroxide concentration are given in Figure 1 and Table 3, respectively. The percentage trapping was determined by measuring the absorbance at 300 and 358 nm immediately after mixing the solutions. These two wavelengths correspond to the I_{max} of the trapped micellar or cyclodextryl ether and dinitrophenolate, respectively, as shown by repetitive scans of the reaction mixture using an $X-Y$ recorder. Spectra of samples of 2,4-dinitrophenolate and the aryl micellar ether produced from CHEDAB were obtained independently and the molar absorptivity of each compound was determined at each wavelength (300 and 358 nm). It was assumed that the molar absorptivity of the aryl ethers formed from micelles **1–3** and from CDOH would be identical, within experimental error, since they each contain the same chromophore, the 2,4-dinitrophenyl group, and differ only in the aliphatic region of the molecule which should not greatly affect the UV–visible spectrum.

The proportion of micellar or cyclodextryl ether and 2,4-dinitrophenolate formed in each case was determined from absorbance measurements at the above wavelengths using the molar

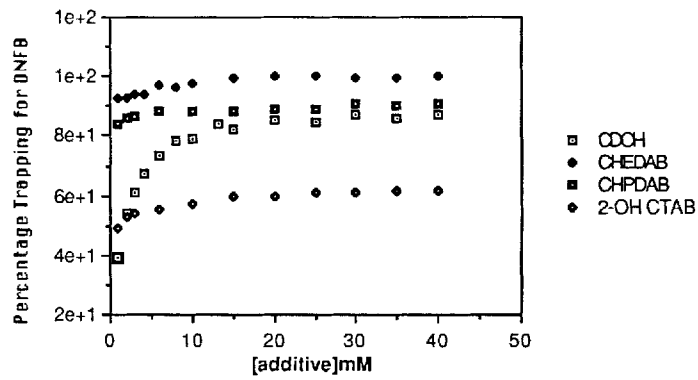


Figure 1. Percentage trapping (formation of aryl micellar or cyclodextryl ether) as a function of surfactant concentration for DNFB (6×10^{-5} M) at 30·4 °C in the presence of 0·01 M NaOH.

Table 3. Percentage trapping (formation of aryl micellar or cyclodextryl ether) as a function of hydroxide concentration for DNFB (6×10^{-5} M) at 30·4 °C

	[NaOH]/mM				
Additive	1·0	5·0	10·0	50·0	100·0
CHEDAB (8 mM)	100	100	100	—	—
CHPDAB (8 mM)	86·5	86·8	87·1	86·2	87·0
2-OHCTAB (8 mM)	56·9	55·6	57·3	52·2	52·0
CDOH (8 mM)	—	—	78·1	67·5	63·2
CDOH (1 mM)	45·8	41·4	39·5	25·1	19·8
CDOH (1 mM in D_2O)	51·0	—	41·5	—	22·8

absorptivity of each species at the two wavelengths and equations 1 and 2, where ArOM is the trapped aryl micellar or cyclodextryl ether.

$$A^{358}_{Obsd} = \varepsilon^{358}_{ArOM}[ArOM] + \varepsilon^{358}_{ArO^-}[ArO^-] \quad (1)$$

$$A^{300}_{Obsd} = \varepsilon^{300}_{ArOM}[ArOM] + \varepsilon^{300}_{ArO^-}[ArO^-] \quad (2)$$

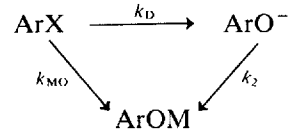
The trapping results for DNFB shown in Figure 1 and Table 3 differ in some respects from those reported by de Rossi *et al.*[4] At 1 mM NaOH in 1 mM CDOH we agree with 45% trapping (55% ArOH).[4] However, at 10 mM NaOH our results show more trapping than do those obtained by de Rossi *et al.*[4] At 1 mM CDOH we obtained 40% trapping whereas de Rossi *et al.*[4] reported only 14% and at 8 mM CDOH we obtained 78% trapping whereas de Rossi *et al.*[4] reported only 45%. These variations can be explained by differences in technique. Whereas de Rossi *et al.*[4] allowed reaction to occur for 90 min after mixing before measuring the absorbance, we measured the absorbance immediately after mixing since the initial reaction with DNFB occurs very rapidly. During the 90 min allowed by de Rossi *et al.*[4] a significant amount of the trapped ether could be consumed in the second phase of reaction, thus leading to a lower percentage trapping. This problem is more serious at 10 mM than at 1 mM NaOH since the amount of trapped material lost is greater at the higher NaOH concentration. Thus

at 1 mM NaOH where the phase 2 reaction is slow we obtained the same result as de Rossi *et al.*,[4] but at 10 mM NaOH we detected more trapping than did de Rossi *et al.*[4]

Using the rate constants for DNFB in Table 2 and the data on the percentage trapping in Figure 1, individual rate constants for direct hydrolysis (k_{dir}) and for trapping (k_{trap}) can be calculated, and the results are given in Table 4.

A similar treatment for reaction of DNCB is more difficult because the rates of phase 1 and phase 2 reactions are comparable. Consequently, after allowing five half-lives of the first phase, which corresponds to the loss of 96·5–97% DNCB, the amount of trapped aryl ether determined spectrophotometrically is low because of a substantial amount of subsequent hydrolysis (phase 2).

An analysis of the kinetics of the first-order reaction system (or for reactions carried out under pseudo-first-order conditions):



yields

$$[ArX] = A_0 \exp(-k_1 t)$$

where A_0 is [ArX] at $t = 0$ and $k_1 = k_D + k_{MO}$. Thus

$$[ArOM] = A_0\left(\frac{k_{MO}}{k_2 - k_1}\right)[\exp(-k_1 t) - \exp(-k_2 t)]$$

Writing γ for the fraction of the reaction that proceeds via the ArOM intermediate:

$$\gamma = \frac{k_{MO}}{k_{MO} + k_D} = \frac{k_{MO}}{k_1}; \qquad k_{MO} = \gamma k_1$$

Table 4. First-order rate constants (k_{trap}[a] and k_{direct}/s^{-1}) for the first phase of the hydrolysis of DNFB (6×10^{-5} M) at 30 °C

	2-OHCTAB		CHPDAB		CHEDAB		CDOH	
[Surfactant]/mM	$10^3 k_{trap}$	$10^3 k_{direct}$	$10^3 k_{trap}$	$10^3 k_{direct}$	$10^3 k_{trap}$	$10^3 k_{direct}$	$10^3 k_{trap}$	$10^3 k_{direct}$
1·0	—	—	—	—	—	—	1·35	2·07
2·0	—	—	—	—	—	—	2·53	2·14
3·0	76	64	681	106	6371	399	3·19	2·05
6·0	124	99	998	132	9554	316	5·71	2·06
10·0	176	130	1183	157	11963	307	8·68	2·32
15·0	202	134	1230	160	12425	75	11·95	2·55
20·0	206	138	1185	145	13020	—	16·32	2·88
25·0	210	135	1145	144	12480	—	16·82	3·08
30·0	211	135	1134	116	12140	—	19·62	2·88
35·0	207	129	1116	124	11080	—	19·31	3·20
40·0	206	129	1157	103	10490	—	22·8	3·38

[a] Calculated from the total rate of loss of DNFB (Table 2) using the percentage trapping in Figure 1. All reactions followed at 323 nm, the isosbestic point for the second phase of reaction; 0·01 M NaOH in all reactions.

and δ for the ratio k_2/k_1:

$$[\text{ArOM}] = A_0\gamma[\exp(-k_1t) - \exp(-\delta k_1t)]/(\delta - 1)$$

If the reaction is followed for five half-lives, then after this time

$$\exp(-k_1t) = 1/32, \qquad [\text{ArX}] = A_0/32 \text{ and}$$
$$[\text{ArOM}]_5 = A_0\gamma[\tfrac{1}{32} - \exp(-5\delta \ln 2)]/(\delta - 1)$$

From which

$$\gamma = \left(\frac{[\text{ArOM}]_5}{A_0}\right)\left[\frac{\delta - 1}{1/32 - \exp(-5\delta \ln 2)}\right]$$

can readily be determined.

This mathematical correction was partially successful for reactions in CHEDAB and CHPDAB (Figure 2), but for reaction in 2-OHCTAB the model leads to an over-correction when determining the amount of aryl micellar or cyclodextryl ether that has decomposed, giving results in excess of 100% trapping. Hence the simple model above used in the correction is not appropriate for reaction in 2-OHCTAB and for some concentrations of CHEDAB (1–2 mM). The reason for the failure of this simple model is unknown, but it may indicate the occurrence of some additional process within the micelle before the second phase of reaction (i.e. ArOM → ArO^-) occurs. This may involve conformational changes of the ether within the micelle and we are currently looking for independent evidence of such an additional process.

In CHPDAB and CHEDAB a similar percentage of trapping was observed for both DNFB and DNCB (it was assumed that the results for DNFB and DNCB would also be similar in 2-OHCTAB). Thus the value of the percentage trapping for DNFB in 2-OHCTAB was used to calculate the dissected rates (i.e. k_{trap} and k_{direct}) for DNCB (Table 5). For reactions in CHEDAB and CHPDAB the percentage trapping determined for DNCB after application of the mathematical correction were used to determine the dissected rates in Table 5.

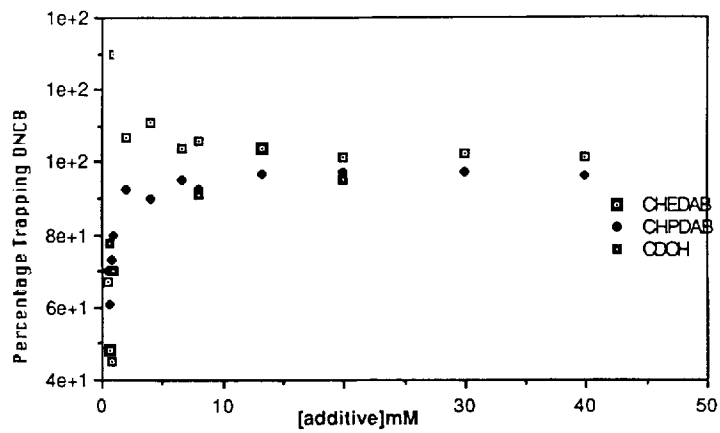


Figure 2. Percentage trapping (formation of aryl micellar or cyclodextryl ether) as a function of surfactant concentration for DNCB (6×10^{-5} M) at 30·4 °C in the presence of 5 mM NaOH (CHEDAB), 0·05 M NaOH (CHPDAB) and 0·1 M NaOH (CDOH).

Table 5. First-order rate constants (k_{trap}[a] and k_{direct}/s^{-1}) for the first phase of the hydrolysis DNCB (6×10^{-5} M) at 30 °C

[Surfactant] mM	2-OHCTAB[b,c]		CHPDAB[d]		CHEDAB[e]		CDOH[e]	
	10^3k_{trap}	10^3k_{direct}	10^3k_{trap}	10^3k_{direct}	10^3k_{trap}	10^3k_{direct}	10^3k_{trap}	10^3k_{direct}
0·4	—	—	0·62	0·26	0·59	0·29	—	—
0·6	—	—	0·94	0·60	1·21	1·31	0·026	0·007
0·8	—	—	1·62	0·60	1·91	2·34	—	—
1	0·086	0·089	2·23	0·56	5·65	—	0·027	0·011
2	0·855	0·755	4·84	0·40	11·1	—	—	—
4	—	—	7·33	0·81	14·3	—	—	—
8	—	—	10·2	0·85	16·6	—	0·116	0·011
13·3	—	—	10·9	0·38	17·1	—	—	—
20	2·29	1·53	11·3	0·35	12·7	—	0·191	0·010
30	2·41	1·54	9·9	0·31	9·9	—	—	—
40	2·41	1·47	8·35	0·35	7·7	—	—	—

[a] Calculated from the total rate of loss of DNCB (Table 1) using the percentage trapping in Figure 2 for all systems except 2-OHCTAB.
[b] Calculated from the total rate of loss of DNCB (Table 1) but using the percentage trapping for DNFB (Figure 1).
[c] 0·1 M NaOH.
[d] 0·05 M NaOH.
[e] 0·005 M NaOH.

Effect of additive concentration

The total rates for the first phase of the hydrolysis of DNCB (Table 1) and DNFB (Table 2) show typical rate–surfactant profiles for second-order reactions. The rate increased to a maximum corresponding to complete solubilization of the aryl halide into the micelle (10–30 mM) (depending on the substrate and on the micelle) and then decreased. However, in the presence of CDOH the observed rate increased with increasing CDOH concentration up to 40 mM (the solubility of CDOH in water) without reaching a maximum or limiting rate (Table 2). The trapping percentage does, however, reach a limit of about 80% with increasing concentration (Figure 1). Similar behaviour was observed with the dissected rates for DNFB (Table 4). For the second phase of hydrolysis the maximum rate was observed at a very low micelle concentration (Table 7) (1–2 mM), consistent with a very hydrophobic substrate effectively bound to the micelle. For the cyclodextrin, however, the rate was almost independent of CDOH concentration.

For DNFB the percentage trapping increased with both increasing micelle concentration and with increasing CDOH concentration. The increase in percentage trapping as the micelle or CDOH concentration was increased was the result of a greater dependence on micelle or CDOH concentration for the rate of trapping than for the rate of direct hydrolysis (Table 4). The catalytic effect of the micelles or cyclodextrin was arbitrarily determined from a comparison of the optimum rate and the rate with 3 mM additive. This method was chosen in preference to using the rate in water as a reference point because in water only direct hydrolysis (no trapping) is possible.

A 2–3-fold increase in the observed rate for both reactions was seen with 2-OHCTAB and CHPDAB and for the rate of trapping in CHEDAB. The rate of direct reaction in CHEDAB actually decreased as the detergent concentration was increased but, since there is such a low percentage (< 1%) of direct reaction in CHEDAB, tis decrease is possibly not significant. In

CDOH, however, greater catalysis was observed for the rate of trapping (7-fold increase at 40 mM compared with the rate at 3 mM).

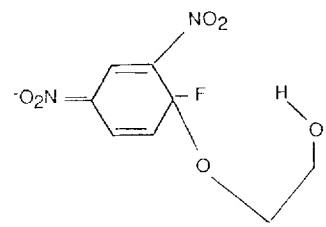
At all detergent and CDOH concentrations used the rate of both trapping and direct hydrolysis of DNFB was much slower in CDOH than in any of the micelles (10–2000-fold). For the micelles the efficiency of trapping was CHEDAB ≫ CHPDAB > 2-OHCTAB. The rate of direct hydrolysis was similar in both CHPDAB and 2-OHCTAB but faster in CHEDAB when significant direct reaction was observed (≤ 10 mM CHEDAB). The much slower rates of reaction in CDOH compared with the micelles may be a result of the presence of a charged surface in the micelle but not in CDOH.

For DNFB the percentage trapping (formation of ArO···CD) in the presence of CDOH was similar to that in 2-OHCTAB at low concentrations (1–4 mM) and to that in CHPDAB at higher concentrations (6–40 mM). At all the concentrations the percentage trapping in CDOH was much less than in CHEDAB. This lends support to the proposal[4] that binding of the aryl halides to the CDOH occurs at the secondary hydroxy groups on C-2 or C-3 rather than to the primary hydroxy groups on C-6.

The percentage trapping of DNFB in all of the micelles was effectively independent of [OH^-] but in the presence of CDOH the percentage trapping was greater at 1 mM [OH^-] than at 10–100 mM [OH^-] (Table 3).

At 1 mM NaOH (pH 11), CDOH is reported[5] to be only partially ionized. Several examples of multiple general acid–base catalysis by cyclodextrins in an appropriate pH range are known.[5,6] It has also been reported that in solvents of low polarity the loss of fluoride from DNFB is subject to acid catalysis[9b]

The cyclodextrin provides a region of lower polarity[3,4] than water and hence it is possible that the increased trapping at pH 11 is due to multiple catalysis by the cyclodextrin, with the ionized O^- acting at a nucleophile and the adjacent non-ionized OH acting as a general acid (see structure **4**).



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Since the attack of O^- and C—F bond breaking occur in different steps, strictly it is incorrect to describe this as multiple catalysis in this case. Rather, it is an example of single catalysis on each of the two steps.

Such catalysis is not observed in the hydroxy-functionalized micelles because since each surfactant molecule contains only one hydroxy group the possibility of the presence of both an ionized and a non-ionized group at the reaction centre is less than for a cyclodextrin. However, when reaction was performed in D_2O as solvent the percentage trapping was similar to that obtained in H_2O. Since the OH groups of the cyclodextrin should have exchanged with the D_2O, this result is inconsistent with the explanation of increased trapping due to intramolecular general acid catalysis because an isotope effect would have been expected, leading to reduced trapping in D_2O compared with H_2O. Hence the reason for increased trapping in CDOH at low hydroxide concentrations is unknown.

A comparison of results for the two micelles containing secondary hydroxy groups shows firstly that for DNFB more trapping occurs in CHPDAB than in 2-OHCTAB (Figure 1). Dissection of the rates for the first phase of the hydrolysis reveals that the rates of direct hydrolysis of DNFB are similar in the two micelles (Table 4), but that the rates of trapping in CHPDAB are considerably faster than in 2-OHCTAB.

We may conclude that the rate of production of the micellar ether in 2-OHCTAB is slower than in CHPDAB because the resulting micellar ether is more deeply buried inside the micelle in the former case. However, if the micellar ether from 2-OHCTAB is more deeply buried inside the micelle than that for CHPDAB, it is surprising that the rates of decomposition of these micellar ethers (Table 7) are so similar. As proposed above, this may indicate a conformational rearrangement of the micellar ether within the micellar pseudo-phase before the second-phase reaction occurs.

Phase 2 (breakdown of the aryl micellar/cyclodextryl ether)

Rate constants for the second phase of the hydrolysis of DNFB as a function of hydroxide concentration and as a function of detergent and CDOH concentration are given in Tables 6 and 7, respectively. As expected, the rate of the second phase of hydrolysis increased with increasing $[OH^-]$ in all systems (Table 6).

Table 6. Rate constants ($10^5 k_1/s^{-1}$) for the second phase of the hydrolysis of DNFB (6×10^{-5} M) in the presence of micelles or cyclodextrin as a function of hydroxide concentration

	[NaOH]/mM				
Additive[a]	1	5	10	50	100
CHEDAB	6·60	125	205	600	885
CHPDAB	—	6·6	8·7	47·5	70
2-OHCTAB	—	—	13	50	69·5
CDOH	—	—	1·02	2·98	4·98

[a] 8 mM detergent or CDOH at 30·4 °C. Reaction followed at 358 mm.

Table 7. Rate constants ($10^5 k_1/s^{-1}$) for the second phase of the hydrolysis of DNFB (6×10^{-5}M) in the presence of micelles or cyclodextrin as a function of detergent or cyclodextrin concentration[a]

[detergent or cyclodextrin]	CHEDAB	CHPDAB	2-OHCTAB	CDOH
0·4	—	—	69	—
0·6	1025	86	89	4·28
0·8	1100	90·5	97	4·67
1·0	1140	89·5	98	4·77
2·0	1170	88	96·5	4·74
4·0	1040	77	86·5	5·06
6·7	920	68·5	78	—
8·0	880	70	69·5	4·98
13·3	750	58·5	62·5	4·58
20·0	590	45	51·5	4·49

[a] In the presence of 0·1 M NaOH at 30·4 °C. Reaction followed at 358 nm.

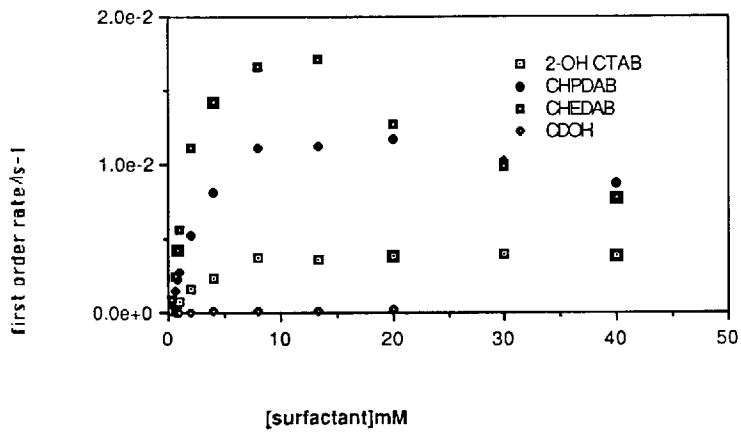


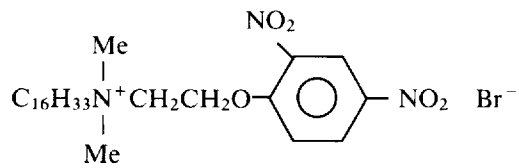
Figure 3. First-order rate constants (s^{-1}) for the first phase of hydrolysis of DNCB (6×10^{-5} M) at 30·4 °C in the presence of 0·1 M NaOH (2-OHCTAB and CDOH), 0·05 M NaOH (CHPDAB) and 0·005 M NaOH (CHEDAB).

EXPERIMENTAL

Materials

DNCB, DNFB, 2,4-dinitrophenol and β-cyclodextrin were commercially available. The hydroxy-functionalized micelles were prepared as previously reported.[10]

The CHEDAB micellar ether (**5**), m.p. 135–137 °C, was prepared in 57% yield from 1-(2′-bromoethoxy)-2,4-dinitrobenzene (1 g) by reaction with hexadecyldimethylamine (0·9 g) in ethanol (25 ml) at reflux for 16 h. The mixture was concentrated *in vacuo* and then cooled in ice. Addition of diethyl ether resulted in crystallization of the product, which was filtered off, air dried and recrystallized (EtOH–Et_2O). Found, C 55·5, H 8·2, N 7·8, Br 13·9; $C_{26}H_{46}BrN_3O_5$ requires C55·7, H 8·2, N 7·5, Br 14·3%.



5

1-(2′-Bromoethoxy)-2,4-dinitrobenzene was prepared from the reaction of 2-bromoethanol (0·082 mol) with DNFB (0·011 mol) in the presence of 2,4,6-collidine. The reaction mixture was diluted with dichloromethane (75 ml), washed with water (3 × 50 ml), 1 M HCl (50 ml) and 10% sodium carbonate (50 ml). The CH_2Cl_2 solution was then dried over $MgSO_4$ and the solvent removed on a rotary evaporator. The solidified residue was recrystallized (CH_2Cl_2) to give a pale yellow solid, m.p. 60–61 °C (lit.[11] m.p., 60·5–61 °C).

Stock solutions of DNCB and DNFB (0·01 M) were prepared in HPLC-grade acetonitrile (Mallinkrodt). Stock solutions of the hydroxy-functionalized micelles and CDOH (20 and 60 mM) were prepared in purified water. Sodium hydroxide (0·3 M) was also prepared in purified water and was standardized by titration against hydrochloric acid solution. Bromocresol green indicator was used. Distilled water was purified by using a Millipore system

to achieve a resistivity of at least 10 MΩ cm. Elemental analyses were performed by the Australian Microanalytical Service.

Kinetics

Micellar or CDOH solutions of the required concentration were equilibrated in the cuvette in the cell compartment of a Varian 635 UV–VIS or DMS-70 UV–VIS spectrophotometer. The substrate was then added (18 μl) by microsyringe and the reaction was initiated by addition of the required amount of sodium hydroxide solution which had been equilibrated in a water-bath. The solution was thoroughly mixed and the reaction was followed at either 232 nm (phase 1) or 358 nm (phase 2). The infinity value of each reaction was calculated by a computer program designed to give the best straight-line fit to data collected over at least two half-lives. Where possible, experimental infinity values were also obtained (e.g. phase 2 reactions) and good agreement was obtained between the calculated and experimental infinity values and rate constants. A National VP 6511A X–t recorder was used for kinetics and a Hewlett-Packard 7041-A X–Y recorded was used for repetetive scans of the reaction mixture.

The temperature within the cell was measured with a Jenco thermistor thermometer. The rate constants of fast reactions were determined by a stopped-flow technique using equipment as described by Grant and Magee[12] and the method described by Hardman and Scopes.[13] For DNFB, the percentage trapping was determined by measuring the absorbance at 300 and 358 nm immediately after mixing the solutions. The difference $(A_\infty - A_0)$ corresponds to the amount of either micellar or cyclodextryl aryl ether and the percentage of this material was calculated using the equation

$$\% \text{ trapping} = \frac{A_\infty - A_0}{A_\infty} \times 100 \tag{3}$$

The basis of this method is that reaction of DNFB is very fast and all the DNFB was consumed by the time the A_0 measurement was made. Since the reaction is so fast, no significant phase 2 decomposition of the trapped ether has occurred in this time. For DNCB, however, the substrate is consumed more slowly and a correction for subsequent hydrolysis of the micellar aryl ether was necessary.

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