micelles, and these effects seem to be much more important with a bulky substrate such as a triaryl phosphate than with an aryl halide. These complications are important at detergent concentrations close to the cmc. Our kinetic salt effects also suggest that caution should be exercised in using buffers to control pH for acid- or base-catalyzed reactions in the presence of detergents, because of adventitious inhibition by anions of the buffer, and the pH in the micelle may be different from that in the bulk of the solution.[27]

A major problem in interpreting the kinetic effects of detergents is that reaction can occur in either the aqueous or micellar phase, and it is generally assumed that the part of the reaction which continues in the micellar phase is to a first approximation unaffected by the detergent. This crude approximation appears to be warranted in our present system where the over-all effects are much larger than expected in terms of simple solvent or electrolyte effects, but it may not be satisfactory in other systems.

**Registry No.**—*p*-Nitrophenyl diphenyl phosphate, 10359-36-1; hydroxide ion, 1428-30-9; fluoride ion, 16984-48-8.

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[27] G. S. Hartley and J. W. Roe, *Trans. Faraday Soc.*, **36**, 101 (1940); P. Mukerjee and K Banerjee, *J. Phys. Chem.*, **68**, 3567 (1964).

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# Electrolyte and Micellar Effects upon the Reaction of 2,4-Dinitrofluorobenzene with Hydroxide Ion[1]

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The electrolyte effects upon the rate of reaction between hydroxide ion and 2,4-dinitrofluorobenzene in water can be separated into effects upon the activity coefficient of the organic substrate and the relative activity coefficients of the hydroxide ion and the transition state; for example, large cations, *e.g.*, $(CH_3)_4N^+$, stabilize the transition state relative to the hydroxide ion. Cationic micelles of cetyltrimethylammonium bromide catalyze the reaction strongly but anionic micelles of sodium lauryl sulfate retard it, and nonionic micelles have almost no effect. With cationic micelles there is a rate maximum at a detergent concentration of *ca.* 0.025 *M*. The cationic micelle decreases the activation enthalpy.

The reaction between 2,4-dinitrofluorobenzene and nucleophiles has been studied very extensively, but largely in organic and aqueous organic solvents.[2,3] The reaction is a two-stage process involving nucleophilic addition followed by loss of the fluoride ion, and in some systems this second step can be slow, although it appears to be rapid in polar hydroxylic solvents. We have examined electrolyte and micellar effects upon the reaction between hydroxide ion and 2,4-dinitrochlorobenzene,[4] and we chose this reaction for initial study because loss of chloride ion from the tetrahedral intermediate is fast,[2] except in a few special cases.[5] Some electrolytes affect the rate of reaction between hydroxide ion and 2,4-dinitrochlorobenzene by changing the activity coefficient of the organic substrate, but ions of low charge density, *e.g.*, tetraalkylammonium or perchlorate, also change the ratio of the activity coefficients of the hydroxide ion and the transition state.[4]

The kinetic effects of micelles upon the reaction between hydroxide ion and 2,4-dinitrochlorobenzene are simple: a cationic micelle increases the rate sharply, an anionic micelle decreases it, and a nonionic micelle has little effect,[4] as expected on a simple electrostatic picture of incorporation of the organic substrate into the micelle changing the probability of attack upon it by hydroxide ion.[6–8]

The aim of the present work was to find out whether 2,4-dinitrofluorobenzene behaved similarly to the chloro compound with regard to effects of electrolytes and micelles, or whether these agents changed the nature of the rate-limiting step.

Richards and his coworkers have shown that micelles profoundly affect the rate of reaction between 2,4-dinitrofluorobenzene and amines,[9] and their interest in the use of this reagent for protein modification made it desirable to study its reactions in molecular aggregates.

## Experimental Section

**Materials.**—2,4-Dinitrofluorobenzene (Aldrich) was redistilled, bp 121.5–122° (3 mm) [lit.[10] bp 140–141° (5 mm)]. The detergents used in the present work were cetyltrimethylammonium

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[1] Support from the National Science Foundation is gratefully acknowledged.

[2] J. F. Bunnett, *Quart. Rev.* (London), **12**, 1 (1958); S. D. Ross, *Progr. Phys. Org. Chem.*, **1**, 31 (1963).

[3] J. F. Bunnett and R. H. Garst, *J. Amer. Chem. Soc.*, **87**, 3875, 3879 (1965).

[4] C. A. Bunton and L. Robinson, *ibid.*, **90**, 5965, 5972 (1968).

[5] R. L. Toranzo, R. V. Caneda, and J. Brieux, *ibid.*, **88**, 3651 (1966).

[6] (a) E. F. Duynstee and E. Grunwald, *ibid.*, **81**, 4540 4542 (1959); (b) *Tetrahedron*, **21**, 2401 (1965).

[7] M. T. A. Behme and E. H. Cordes, *J. Amer. Chem. Soc.*, **87**, 260 (1965); M. T. A. Behme, J. G. Fullington, R. Noel, and E. H. Cordes, *ibid.*, **87**, 266 (1965).

[8] F. M. Menger and C. E. Portnoy, *ibid.*, **89**, 4698 (1967).

[9] D. G. Herries, W. Bishop, and F. M. Richards, *J. Phys. Chem.*, **68**, 1842 (1964).

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bromide (CTA), sodium lauryl sulfate (NaLS), and Igepal, which is a dinonylphenol condensed with ethylene oxide and is designated as DNPE. The purification of the electrolytes and detergents has been described.[4]

**Kinetics.**—The reaction between 0.01 *M* sodium hydroxide and $10^{-5}$ *M* 2,4-dinitrofluorobenzene was followed spectrophotometrically at 3580 Å using a Gilford spectrophotometer.[4] Some of the reactions in the presence of CTA micelles had half-lives which were only just within the range of conventional kinetic methods, and for these reactions we mixed the reagents directly in the cell using a small rectangular Teflon stirrer which allowed rapid addition and mixing of the reagents.

**Distribution.**—The activity coefficients of 2,4-dinitrofluorobenzene in aqueous electrolyte solutions were determined by partitioning it between Spectrograde cyclohexane and the aqueous phase following the procedure used with 2,4-dinitrochlorobenzene[4] (*cf.* ref 11). Any 2,4-dinitrophenol which had been formed by hydrolysis in the aqueous layer was then determined spectrophotometrically and the aqueous layer was treated with NaOH to hydrolyze the 2,4-dinitrofluorobenzene, and the phenol was then determined spectrophotometrically at 3580 Å. We attempted to determine the solubility of 2,4-dinitrofluorobenzene in aqueous detergent solutions,[4] but because of the low melting point of the solute we had to use a low temperature; the results were unsatisfactory because NaLS is only sparingly soluble in water at 10° and below, and we obtained erratic results with the other detergents, probably because the DNPE solution was very viscous, and the reaction was too fast in CTA.

**Determination of Critical Micelle Concentration.**—The cmc of the ionic detergents was determined by the dye method,[12] using bromophenol blue for CTA and methylene blue for NaLS. At 25° with 0.01 *M* NaOH for CTA, cmc = $4.75 \times 10^{-4}$ *M* and for NaLS, cmc = $4.66 \times 10^{-3}$ *M*. The cmc values are not particularly sensitive to small amounts of added sodium hydroxide.[4,12,13]

## Results

**Electrolyte Effects on Reaction Rate.**—The kinetic salt effects upon the second-order rate constants, $k_2$, are very similar to those observed for reaction between hydroxide ion and 2,4-dinitrochlorobenzene. Figure 1 shows plots of log $k_s/k_0$ against ionic strength ($k_s$ and $k_0$ are the second-order rate constants in the presence and absence of salt). Salts which have cations of low or anions of high charge density generally assist reaction, and other electrolytes retard it. Plots of log $k_2$ against ionic strength are only approximately linear as is generally found at high electrolyte concentration.[14]

In the absence of added electrolytes or detergents the second-order rate constants, $k_2$, for reaction between sodium hydroxide and 2,4-dinitrofluorobenzene are $1.39 \times 10^{-2}$ at 3.4°, $5.16 \times 10^{-2}$ at 15.4°, and $12.0 \times 10^{-2}$ l. mol$^{-1}$ sec$^{-1}$ at 25.0°, in 0.01 *M* aqueous NaOH.

2,4-Dinitrofluorobenzene is approximately 1000 times as reactive as 2,4-dinitrochlorobenzene toward hydroxide ion. With methoxide ion in methanol the factor is 880, and for thiophenoxide ion it is 30.[15] This dependence of relative rates upon the reactivity of the nucleophile is quite general.

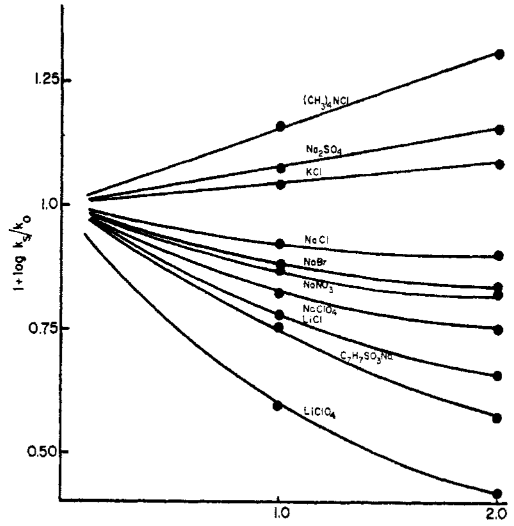

Figure 1.—Salt effects upon the reaction between 2,4-dinitrofluorobenzene and 0.01 *M* sodium hydroxide ion in water at 25.0°.

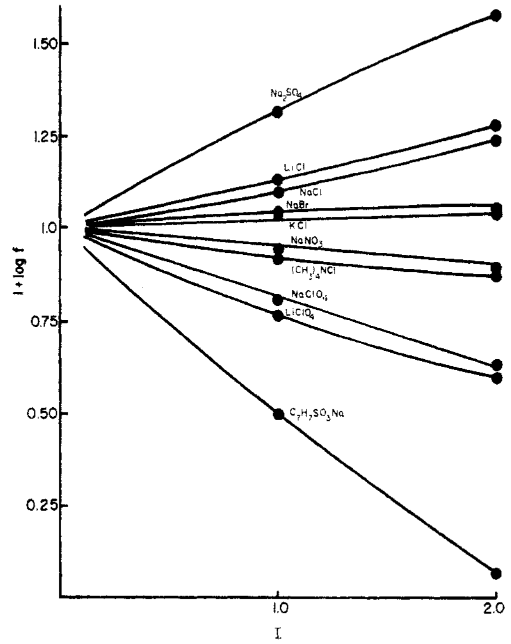

Figure 2.—Salt effects upon the activity coefficient of 2,4-dinitrofluorobenzene in water at 25.0°.

**Electrolyte Effects on Activity Coefficients.**—Anions of low charge density "salt-in" 2,4-dinitrofluorobenzene, and those of high charge density have the opposite effect (Figure 2). Similar, but less marked effects are observed with cations, and the salt order is very similar to those observed with 2,4-dinitrochlorobenzene and other polar nonelectrolytes.[4,16] Plots of log *f* against ionic strength approximately follow the Setchenhow equation.

**Kinetic Effects of Detergents.**—The micellar effects (Figures 3 and 4) are very similar to those observed for the reaction between 2,4-dinitrochlorobenzene and hydroxide ions.[4] Cetyltrimethylammonium bromide (CTA) sharply increases the reaction rate at concentrations above the cmc, sodium lauryl sulfate (NaLS) retards the reaction, and a nonionic detergent has almost no effect. (For CTA concentrations close to

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(11) R. L. Bergen and F. A. Long, *J. Phys. Chem.*, **60**, 1131 (1956).

(12) M. L. Corrin and W. D. Harkins, *J. Amer. Chem. Soc.*, **69**, 679, 683 (1947); P. Mukerjee and K. J. Mysels, *ibid.*, **77**, 2937 (1955).

(13) J. N. Phillips and K. J. Mysels, *J. Phys. Chem.*, **59**, 325 (1955).

(14) F. A. Long, W. F. McDevit, and F. B. Dunkle, *J. Phys. Colloid Chem.*, **55**, 813 (1951); D. McIntyre and F. A. Long, *J. Amer. Chem. Soc.*, **76**, 3240 (1954).

(15) J. F. Bunnett and W. D. Merritt, *ibid.*, **79**, 5967 (1957).

(16) F. A. Long and W. F. McDevit, *Chem. Rev.*, **51**, 119 (1952).

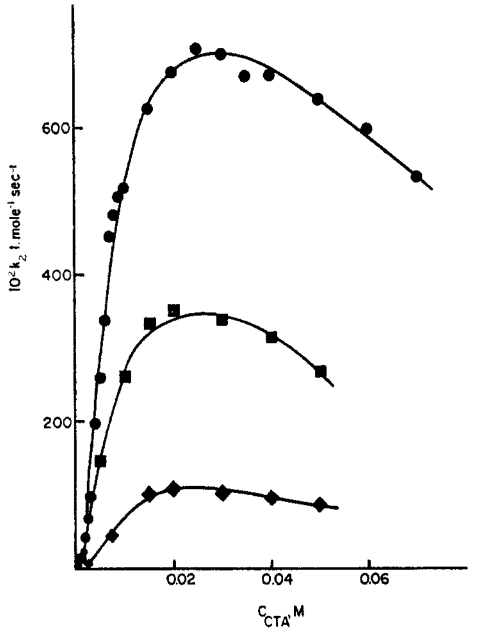


Figure 3.—Catalysis of the reaction between 2,4-dinitrofluorobenzene and 0.01 *M* sodium hydroxide by CTA: ●, at 25.0°; ■, at 15.4°; ◆, at 3.4°.

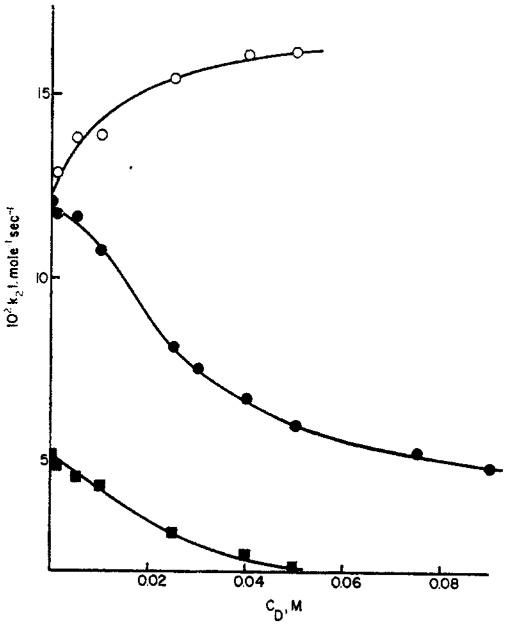


Figure 4.—Effects of NaLS and DNPE upon the reaction between 2,4-dinitrofluorobenzene and 0.01 *M* sodium hydroxide in water: ●, NaLS at 25.0°; ■, NaLS at 15.4°; ○, DNPE at 25.0°.

the cmc the following were the values of $10^2 k_2$ l. mol$^{-1}$ sec$^{-1}$ at 3.4, 15.4, and 25.0°, respectively: $C_{CTA}$ = 0.0005 *M*, ..., ..., 12.9; $C_{CTA}$ = 0.001 *M*, 1.61, 6.72, 14.1; $C_{CTA}$ = 0.0015 *M*, ..., ..., 19.8; $C_{CTA}$ = 0.002 *M*, ..., ..., 39.1.)

The second-order rate constants for reaction in the presence of CTA increase to a maximum at a detergent concentration of *ca.* 0.025 *M* and the kinetic form is very similar to that for the corresponding reaction of 2,4-dinitrochlorobenzene.[4]

Added salts inhibit the CTA-catalyzed reaction, but the effect depends very markedly upon the nature of the anion, as in other systems.[4]

## Discussion

**Electrolyte Effects.**—By analyzing the kinetic salt effect in terms of salt effects upon the activity coefficient of the substrate we can determine the ratio of the activity coefficients of the hydroxide ion and the transition state, *e.g.*, eq 1, where $k_s$ and $k_0$ are the

$$k_s f_s/k_0 = f_{OH^-}/f_{X^*} \qquad (1)$$

second-order rate constants in the presence and absence of added electrolyte for the reaction $S + OH^- \rightleftharpoons X^* \rightarrow$ products, and the standard state for all species is taken as that used for the determination of $k_0$. The values of $f_{OH^-}/f_{X^*}$ are given in Table I, and comparison between them and the kinetic data given in Figure 1 shows the same pattern as for the reaction between 2,4-dinitrochlorobenzene and hydroxide ion.[4] Sodium sulfate assists the reaction by destabilizing the substrate, and this effect overcomes the decrease in $f_{OH^-}/f_{X^*}$, but tetramethylammonium chloride behaves completely differently, in that it slightly stabilizes the substrate, but this rate-retarding effect is more than offset by an increase in $f_{OH^-}/f_{X^*}$. Sodium perchlorate and tosylate both retard reaction by stabilizing the substrate, and this effect is only partially offset by an increase in $f_{OH^-}/f_{X^*}$, and salts such as sodium nitrate and potassium chloride have small effects on both $f_s$ and $f_{OH^-}/f_{X^*}$.

Table I

Relation between Kinetic Salt Effect and Activity Coefficient of 2,4-Dinitrofluorobenzene[a]

| Salt | $f_{OH}/f_{X^*}$ | |
|---|---|---|
| | 1.0 | 2.0 |
| LiCl | 0.45 | 0.24 |
| NaCl | 0.68 | 0.47 |
| KCl | 1.03 | 1.13 |
| $(CH_3)_4NCl$ | 1.77 | 2.75 |
| NaBr | 0.67 | 0.61 |
| $LiClO_4$ | 0.68 | 0.66 |
| $NaClO_4$ | 1.05 | 1.34 |
| $NaNO_3$ | 0.87 | 0.87 |
| NaTos | 1.81 | 3.20 |
| $Na_2SO_4$ | 0.58 | 0.39 |

[a] In water at 25.0° with 0.01 *M* NaOH.

In general the effects of the individual ions are, for cations ($f_s$) $Li^+ > Na^+ > K^+ > (CH_3)_4N^+$, ($f_{OH^-}/f_{X^*}$) $(CH_3)_4N^+ > K^+ > Na^+ > Li^+$; for anions ($f_s$) $SO_4^{2-} > Cl^- > Br^- > NO_3^- > ClO_4^- > OTos^-$, ($f_{OH^-}/f_{X^*}$) $OTos^- > ClO_4^- > NO_3^- > Br^- \sim Cl^- > SO_4^{2-}$.

However, these effects are not completely independent of the nature of the counterion, and therefore we have not attempted to assign relative numerical parameters for the Setchenhow parameters for the individual ions.

It appears that for this reaction a cation of low charge density, *e.g.*, tetramethylammonium, will stabilize a bulky anion such as the transition state relative to its effects upon a small anion such as hydroxide ion, and a cation of high charge density such as lithium will have the opposite effect. Anions have similar, but less well-marked effects, *e.g.*, an anion of low charge density such as tosylate tends to stabilize the bulky transition state relative to the hydroxide ion. The effects could be exerted directly, *e.g.*, a tetraalkylammonium ion may associate transiently with the bulky transition state, or the effects may be indirect, and related to the effects of ions of high and low charge density upon the water structure.[6b,17] However, we concluded earlier that salt effects upon the reactions between anions and 2,4-dinitrochlorobenzene could not be determined wholly in terms of salt effects upon the water structure,[4] in part because changes in the nucleophile form $OH^-$ to $SPh^-$ did not markedly affect the salt order, and also because the same salt order was found in water as in aqueous ethanol where the solvent structure should have been destroyed.[18]

Very recently Miller and Hildebrand have shown that the solubility of inert gases in water can be explained in terms of a model in which all the water molecules are bonded together by flexible hydrogen bonds,[19] and they put forward this model as an alternative to the generally accepted model of water as a mixture of structured aggregates.[20] Effects of electrolytes which could be discussed in terms of changes in the structure of water could alternatively be discussed in terms of changes in the total number of hydrogen bonds.

Kinetic salt effects of the type which we have observed here seem to be quite general for anion–molecule reactions in polar hydroxylic solvents,[21–23] although in nonpolar solvents ion pairing and other association phenomena become very important.[21,24] However, it is clear that these salt effects upon anion–molecule reactions in hydroxylic solvents cannot be interpreted by using qualitative extensions of the Debye–Hückel theory which consider only ionic atmosphere effects (*cf.* ref 25 for an analysis of specific salt effects upon S<sub>N</sub>1 reactions in water).

The similarity between the salt (and detergent) effects upon the reactions of both 2,4-dinitrofluoro- and -chlorobenzene suggests that the rate-limiting step is the same for both reactions. This conclusion agrees with the other kinetic evidence relating to reaction in polar hydroxylic solvents.[2,3]

**Micellar Effects.**—The general pattern of micellar effects is very similar to those observed for other anion–molecule reactions where a cationic micelle assists reaction, an anionic micelle hinders it, and a nonionic micelle has little effect.[4,6–8]

**Anticatalysis.**—The retardation of the reaction between 2,4-dinitrofluorobenzene and hydroxide ion by NaLS (Figure 4) can be explained quite simply in terms of incorporation of the substrate into the anionic micelle where it is shielded electrostatically from attack by an anionic nucleophile. The anionic detergent, NaLS, increases the activation enthalpy and this rate-reducing effect is only partially offset by an increase in the activation entropy. We were unable to dissolve appreciable amounts of NaLS in water at low temperatures, and therefore there is some uncertainty in the Arrhenius parameters for reaction in the presence of this detergent because of the small temperature range studied; nonetheless there seems to be a consistent trend in the values.

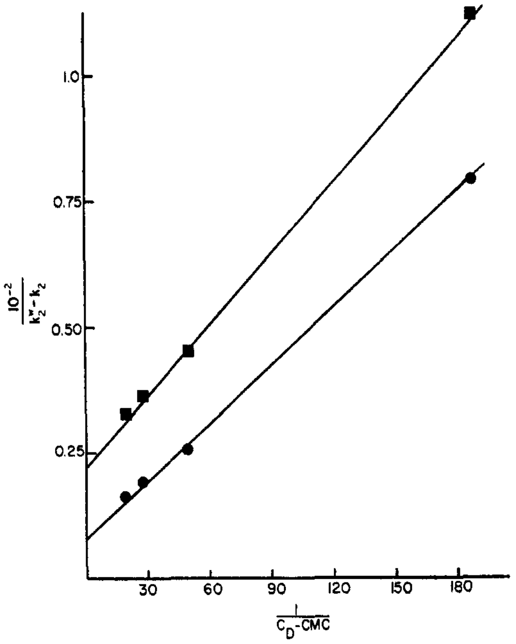
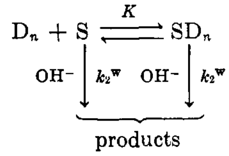


Figure 5.—Anticatalysis by NaLS: ●, at 25.0°; ■, at 15.4°.

We assume that reaction may occur in the aqueous or micellar phase ($D_n$) and following the usual approximations write[8]



$$1/(k_2^w - k_2) = 1/(k_2^w - k_2^m) + [1/(k_2^w - k_2^m)]\{N/[K(C_D - \text{cmc})]\} \quad (2)$$

where the concentration, $C_m$, of the micelles, $D_n$, is given by

$$C_m = (C_D - \text{cmc})/N \quad (3)$$

where $C_D$ is the total detergent concentration and $N$ the aggregation number. For NaLS in aqueous 0.01 *M* sodium hydroxide cmc = $4.66 \times 10^{-3}$ *M*.

Equation 2 fits the results reasonably well at both 15.4 and 25.0° (Figure 5). The intercept in this plot is close to the value calculated on the assumptions that $k_2^m$ is zero, and with 2,4-dinitrofluorobenzene as with 2,4-dinitrochlorobenzene there appears to be no reaction in the anionic micellar phase.[4] This result seems to be general for anion–molecule reactions.[4,6–8]

From the slopes of the plots in Figure 5 we can calculate values of the binding constant, *K*, provided that we know the aggregation number, *N*, for the micelle.

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TABLE II
VARIATION OF ACTIVATION PARAMETERS WITH MICELLAR CONCENTRATION[a]

| Detergent | $C_D$, $M$ | $\Delta H^*$, kcal mol$^{-1}$ | $\Delta S^*$, eu |
|---|---|---|---|
| | | 16.0 | −9 |
| CTA | 0.001 | 16.0 | −9 |
| CTA | 0.005 | 14.0 | −10 |
| CTA | 0.015 | 13.5 | −10 |
| CTA | 0.020 | 13.2 | −10 |
| CTA | 0.030 | 14.3 | −8 |
| CTA | 0.040 | 14.6 | −6 |
| CTA | 0.050 | 14.6 | −6 |
| NaLS | 0.005 | 16.0 | −7 |
| NaLS | 0.010 | 16.0 | −7 |
| NaLS | 0.025 | 17.0 | −3 |
| NaLS | 0.040 | 17.7 | −1.5 |
| NaLS | 0.050 | 17.9 | −1 |

[a] In water with 0.01 $M$ NaOH; calcd from data at 15.4 and 25.0° for NaLS, and 3.4, 15.4, and 25.0° for CTA.

For NaLS, $N \approx 62$ at 25.0° in water,[26] and therefore $K \approx 1400$ at 25.0° and 2500 at 15.4°, provided that we assume that $N$ will not be sensitive to relatively small changes in temperature or electrolyte concentration. For 2,4-dinitrochlorobenzene $K \approx 2700$, determined directly at 25.0° and 3600 estimated kinetically, using the treatment just described.[4] One would expect that a micelle would incorporate a chloride somewhat more strongly than the corresponding fluoride, and that the extent of incorporation would increase with decreasing temperature.

**Catalysis.**—The strong catalysis of the reaction between hydroxide ion and 2,4-dinitrofluorobenzene by CTA (Figure 3) is readily explicable on the assumption that the organic substrate when incorporated into the cationic micelle is in an electrostatically favorable environment for attack of hydroxide ion.[4,6-8] The rate maximum at *ca.* 0.025 $M$ CTA is very similar to that which we observed for the reaction between 2,4-dinitrochlorobenzene and hydroxide ion,[4] and seems to be general for anion–molecule reactions.[4,6-8] When the detergent concentration is such that virtually all of the organic substrate is incorporated into the cationic micelle addition of further detergent merely gives new micelles which attract, and therefore deactivate, the hydroxide ion.

TABLE III
INHIBITION OF MICELLAR CATALYSIS BY ADDED SALTS[a]

| $C_s$, $M$ | LiCl | NaF | NaCl | NaBr | $NaNO_3$ | $CH_3SO_3Na$ | $Na_2SO_4$ | KCl | $(CH_3)_4NCl$ |
|---|---|---|---|---|---|---|---|---|---|
| 0.005 | | | 5.66 | 5.15 | 4.91 | 5.70 | 4.66 | | |
| 0.010 | 5.72 | 6.00 | 5.51 | 4.61 | 3.69 | 5.26 | 3.68 | 5.18 | 5.66 |
| 0.015 | | | | | | | 3.57 | | |
| 0.020 | 4.58 | 5.40 | 4.21 | 3.78 | 2.42 | 4.53 | 3.15 | 3.97 | 4.70 |
| 0.030 | 3.61 | 5.14 | 3.75 | 2.51 | 1.87 | 3.72 | | 3.32 | 4.20 |
| 0.040 | 3.20 | 4.95 | 3.33 | 1.97 | 1.42 | 3.22 | | 2.76 | 3.68 |

[a] Values of $k_2$ at 25.0° with 0.01 $M$ NaOH and 0.025 $M$ CTA; in the absence of added salt $k_2 = 7.03$ l. mol$^{-1}$ sec$^{-1}$.

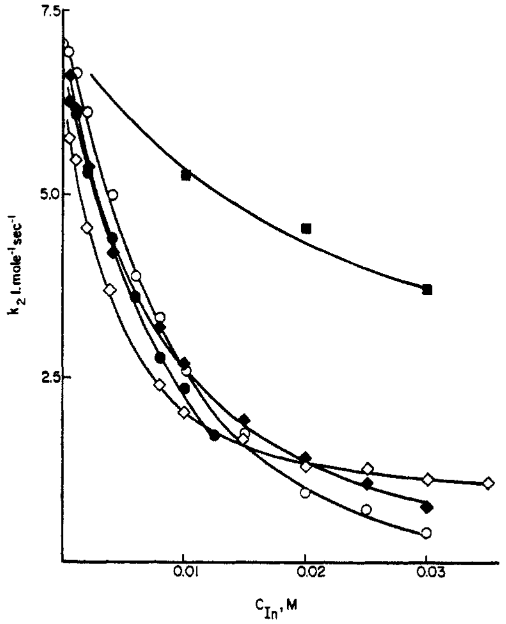

Figure 6.—Salt inhibition of the CTA-catalyzed reaction between 2,4-dinitrofluorobenzene and 0.01 $M$ sodium hydroxide in water at 25.0°: ■, $CH_3SO_3Na$; ○, $p$-$C_7H_7SO_3Na$; ●, 1-$C_{10}H_7SO_3Na$; ◆, $C_6H_5CO_2Na$; ◇, $o$-$C_6H_4(CO_2K)_2$.

As for the corresponding reaction of 2,4-dinitrochlorobenzene the effect of the cationic micelle is to lower the activation enthalpy (Table II), as expected in terms of simple electrostatic theory. When the detergent concentration is above that for the rate maximum the activation enthalpy increases slightly, because of deactivation of hydroxide ion by the cationic micelle.

**Inhibition of Micellar Catalysis.**—Added salts decrease the extent of catalysis by CTA (Figure 6 and Table III). The results for simple inorganic salts are given in Table III, and Figure 6 gives the results for the more effective inhibitors. Similar but less detailed observations were made on the reaction of hydroxide ion with 2,4-dinitrochlorobenzene.[4] The important point is that the extent of the inhibition depends upon the nature of the anion, and is least for anions of high charge density, and greatest for anions which contain bulky organic residues which can assist hydrophobic bonding.[20,27]

The role of a bulky organic residue can be seen by comparing for example the effect of an arenesulfonate ion with that of mesylate ion, and the efficiency of anions as inhibitors follows the sequence $F^- < Cl^- \sim CH_3SO_3^- \sim SO_4^{2-} < Br^- < NO_3^- < C_6H_5CO_2^- \sim o\text{-}C_6H_4(CO_2)^{2-} < C_7H_7SO_3^- < C_{10}H_7SO_3^-$.

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These salt effects arise because interactions between the anion and the cationic micelle make it more difficult for the hydroxide ion to attack the organic substrate which is incorporated into the micelle, and the stronger the interaction, *e.g.*, as with arenesulfonate ions, the greater the ability to exclude hydroxide ion.

The effect of the added salt upon the aggregation number of the cationic micelle also needs to be considered,[28] because some anions *e.g.*, $Br^-$ and $NO_3^-$, increase the aggregation number of micelles of the cetylpyridinium ion, and others, *e.g.*, $I^-$ and $ClO_4^-$, cause precipitation. An increase in the aggregation number should reduce the catalytic efficiency of the detergent, because of a reduction in the number of micelles, but our salt inhibitions were obtained at much lower concentrations of salt than that of 0.2 *m* used by Anacker and Ghose, suggesting that more than changes in micellar size and shape are involved in these salt effects.

The salt inhibition of the CTA-catalyzed hydrolysis of the dianions of 2,4- and 2,6-dinitrophenyl phosphate shows a similar dependence upon the charge density of the anions.[29]

**Registry No.**—2,4-Dinitrofluorobenzene, 70-34-8; hydroxide ion, 14280-30-9.

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# Kinetics of Reactions of 4-Substituted 2-Nitrofluorobenzenes with Piperidine in Methanol[1]

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Rates of reaction of six 4-substituted 2-nitrofluorobenzenes with piperidine in methanol are determined, in part by conventional methods and in part by a stopped-flow technique. The reactions are first order in substrate and first order in piperidine; thus they are not base catalyzed. A satisfactory linear free-energy correlation of log $k_A$ with $\sigma^-$ exists, and $\rho$ is +3.5. $\Delta S^\ddagger$ is substantially constant within this group of reactions.

The objectives of this research were twofold—to determine the effects of 4 substituents in 4-substituted 2-nitrofluorobenzenes on reactivity with piperidine in methanol and to ascertain whether reactions in this series are catalyzed by base.

A number of studies of substituent effects on aromatic nucleophilic substitution have been made in the last two decades. Many are summarized by Brieux, *et al.*,[4] and by Shein and Kozorez.[5] However, substituent effects have not previously been studied in the system of present interest.

Whether or not an aromatic substitution reaction involving an amine nucleophile is catalyzed by base is indicative of significant features of the energy profile of the reaction. In general, the absence of base catalysis (in hydroxylic solvents) indicates that the tetrahedral intermediate complex progresses to products faster than it reverts to reactants, while susceptibility to catalysis by base indicates the contrary.[6,7]

Reactions related to those studied in the present work differ in their susceptibility to catalysis by base. Those of piperidine with 2,4-dinitrochlorobenzene and 2,4-dinitroiodobenzene in aqueous dioxane are not catalyzed by base,[8] but the reactions of piperidine with 2,4-dinitrodiphenyl ether in aqueous dioxane[6] and with 2,4-dinitroanisole in aqueous dioxane[6b,9] or methanol[10] are accelerated by base. Reactions of 2,4-dinitrofluorobenzene with N-methylaniline in ethanol and aqueous dioxane are base catalyzed,[11] but those with *n*-butylamine and aniline are not.[12] The reaction of 2,4-dinitrofluorobenzene with piperidine in benzene solution is catalyzed by bases.[13,14] It was therefore of general interest as well as specific importance to our study of substituent effects to determine whether the present reactions are catalyzed by base.

The reactions studied are represented by eq 1. The 4-substituted 2-nitrophenylpiperidine products (II) are colored to the eye, having absorption maxima at *ca.* 375–440 m$\mu$, and reaction rates are conveniently followed photometrically.

All rate determinations were performed with piperidine in large excess over the aryl fluoride substrate. Good pseudo-first-order kinetic plots were obtained in

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