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Interactions Between Orange II and Selected Long Chain Quaternary Ammonium Salts

By GEORGE ZOGRAFI, PRAFUL R. PATEL*, and NORMAN D. WEINER

The interactions between the dye, sodium *p*-(2-hydroxy-1-naphthylazo)benzenesulfonate (orange II) and four long chain quaternary ammonium salts—1-hexadecylpyridinium chloride, dodecylquinolinium bromide, (2-phenoxyethyl)dodecylmethylammonium bromide, and (diisobutylphenoxyethoxyethyl)dimethylbenzylammonium chloride—have been investigated. The stoichiometry of these interactions has been determined to be 1:1 at pH values ranging from 0.73 to 12.91, except for the reaction involving the hexadecylpyridinium ion above pH 12.34, where the stoichiometry of dye to quaternary ammonium ion is 1:2. The solubility of the various solid compounds has been determined at 25, 30, 35, and 40°. From these data, the thermodynamic functions, ΔH° , ΔS° , and ΔF° have been calculated. Marked solubilization of these compounds has been observed in the presence of excess common quaternary ammonium ion at or near the critical micelle concentration of the particular long chain ion. The significance of these results is discussed.

IN RECENT YEARS the diverse properties of surface-active agents have led to an increased utilization of these substances in pharmaceutical preparations. Such uses include emulsification, wetting, solubilization, and disinfection. An important group of surface-active agents are the long chain quaternary ammonium compounds which have been shown to exhibit a high degree of activity against bacteria and fungi (1).

Because of the positive charge on the quaternary nitrogen, these compounds are extremely incompatible with substances such as soaps and anionic dyes, generally forming insoluble compounds. In view of this, many studies concerned with the introduction of quaternary ammonium

compounds into pharmaceuticals and the subsequent incompatibilities, have been reported (2-4). Lachman, *et al.* (5), studied the interaction of 1-hexadecylpyridinium chloride, dodecylmethyl(2-phenoxyethyl)ammonium bromide, and benzalkonium chloride with several anionic certified dyes. It was found that for equal quantities of the three quaternary ammonium salts, the amount of any dye which can be added without producing turbidity increases in the order: benzalkonium chloride, dodecylmethyl(2-phenoxyethyl)ammonium bromide, and hexadecylpyridinium chloride. They concluded that this order of reactivity can be assigned to the electropositive center and the steric configuration of the molecule.

It was the purpose of this investigation to gain more insight into the nature of these interactions by isolating the compounds formed from each dye-detergent¹ combination, measuring their

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* Present address: College of Pharmacy, University of Michigan, Ann Arbor.

¹ The general term, detergent, is used throughout this paper to refer to the quaternary ammonium salts; it should not necessarily be implied that they are useful as detergents.

solubility characteristics, and determining the thermodynamic quantities involved in the dissolution process.

EXPERIMENTAL

Materials.—The dye selected for this study was the sodium salt of *p*-(2-hydroxy-1-naphthylazo)-benzenesulfonic acid, commonly known as orange II. It was obtained, twice recrystallized from water, from Eastman Organic Chemicals and further purified by recrystallization from absolute alcohol. This dye is structurally similar to the commonly used certified dyes and has the advantage of being quite pure and free of isomers (6).

Four quaternary ammonium salts were selected: 1-hexadecylpyridinium chloride, commonly known as cetylpyridinium chloride (CPC); dodecylmethyl(2-phenoxyethyl)ammonium bromide, commonly known as domiphen bromide (PDDB); (diisobutylphenoxyethoxyethyl)dimethylbenzylammonium chloride, commonly known as hyamine 1622 (DDBC); and dodecylquinolinium bromide (DQB), which was synthesized according to the method of Few, *et al.* (7). All compounds, recrystallized, had melting points which agreed with reported values (7, 8). All other chemicals used were of reagent grade.

Spectral Properties of Orange II.—The concentration of orange II in solution was measured spectrophotometrically using a Beckman model DU spectrophotometer. Maximum absorption occurred at a wavelength of 488 $m\mu$ in distilled water. The molar absorptivity index was 2.097×10^4 . The wavelength of maximum absorbance and the absorptivity index were independent of ionic strength up to a value of 1.0.

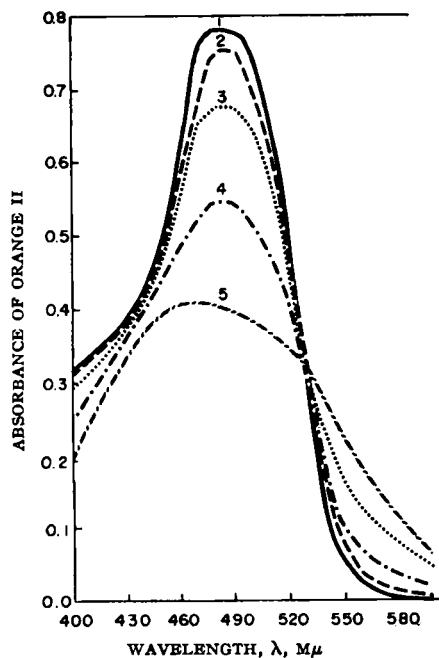


Fig. 1.—Plots of absorbance of orange II vs. wavelength in millimicrons at various pH values. Key: 1 —, pH 0.73 to 8.05; 2 — — —, pH 9.94; 3 ·····, pH 11.34; 4 — · — ·, pH 11.98; and 5 — — — —, pH 12.34 to 12.91.

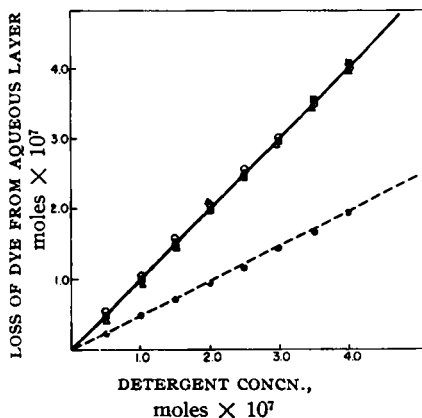


Fig. 2.—Dye loss from aqueous layer vs. detergent. Key: ■, CPC, pH 7.50; ●, CPC, pH 12.91; ○, PDDB, pH 7.50; △, PDDB, pH 12.91.

In view of the acidic properties of the dye it was of interest to determine the absorption spectrum over a wide range of pH values. Therefore, a series of dye solutions, varying in pH from 0.73 to 12.91, were prepared. The concentration of the dye was kept constant and the ionic strength of all solutions, except that at pH 0.73, was brought up to 0.15 with sodium chloride. All pH measurements were made with a Beckman model G pH meter. The absorption spectrum of this dye, as shown in Fig. 1, remains unchanged from a pH of 0.73 to 8.05. Above pH 8.05, a decrease in absorbance can be noted, until at pH 12.34 or higher, the absorbance reaches a minimum. The constancy of the spectrum from pH 0.73 to 8.05 indicates that the chromophore is essentially unaltered over this range of pH, the sulfonic acid group being completely dissociated and the phenolic group undissociated. Above this pH the chromophore is altered due to dissociation of the phenolic auxochrome. This is reflected by the decrease in absorbance and the shift in the absorption maximum at pH 12.34 from 488 $m\mu$ to about 460 $m\mu$.

Stoichiometry of Dye-Detergent Interactions.—It is generally expected that the stoichiometric relationship of a compound formed from monovalent ions of opposite charge will be 1:1. At high pH values (12.91), where the phenolic group of orange II is completely dissociated, the possibility of two detergent cations combining with one dye anion exists. Since for any consideration of the solubility characteristics of a slightly soluble salt, the number of ions involved must be known, it was decided to determine the stoichiometry of the various dye-detergent combinations.

The procedure used in this investigation was that of Few and Ottewill (9). It is based on the fact that a water-soluble dye is completely transferred to chloroform in the presence of an oppositely charged long-chain ion, due to the formation of a water-insoluble, chloroform-soluble "complex," while alone it is completely insoluble in chloroform. The method was modified in the following manner. Five milliliters of aqueous dye solution and 5 ml. of aqueous detergent solution were added to a 40-ml. glass-stoppered centrifuge tube. To this was added 10 ml. of chloroform. The tubes were then stoppered and shaken at least 50 times to insure complete

TABLE I.—ELEMENTAL ANALYSES^a AND MELTING POINTS OF DYE-DETERGENT SALTS

Dye-Detergent Salts	pH at which Obtained	C		Analyses %		H		N		M.p.
		Calcd.	Found	Calcd.	Found	Calcd.	Found	Calcd.	Found	
Dye-CPC-2 H ₂ O	7.50	68.40	68.26	8.00	7.93	6.46	6.72	14.0	14.1	140-141
Dye-2 CPC-4 H ₂ O	12.91	70.55	70.22	9.52	9.80	5.47	5.47	9.0	9.2	90-92
Dye-PDDB	7.50	69.02	68.85	7.75	7.78	6.35	6.69	11.8	11.9	118.5 to 119.5°
Dye-PDDB	12.91	69.02	69.39	7.75	8.23	6.35	6.75	11.8	11.9	118.5 to 119.5°
Dye-DDBC	7.50	69.90	69.43	7.23	7.39	5.69	5.31	12.1	12.2	121-122
Dye-DDBC	12.91	69.90	70.15	7.23	7.34	5.69	5.32	12.1	12.2	121-122
Dye-DQB	7.50	70.77	70.32	6.92	6.76	6.69	6.53	14.1	14.2	141-142
Dye-DQB	12.91	70.77	70.37	6.92	6.94	6.69	6.91	14.1	14.2	141-142

^a Analyses performed by Dr. G. Weiler and Dr. F. B. Strauss, Microanalytical Laboratory, Oxford, England.

extraction of the dye-detergent compound. The tubes were then centrifuged at 1500 r.p.m. for 10 minutes to obtain clear layers. Samples were removed from the aqueous layer and transferred directly to a 1-cm. spectrophotometric cell. Absorbance of the remaining dye was then measured at 488 m μ .

A solution containing a constant concentration of dye was equilibrated with one containing various concentrations of detergent, these concentrations all being less than the initial dye concentration. All solutions had an ionic strength of 0.15. The amount of dye-detergent complex transferred to chloroform in the presence of detergent was also determined at a pH of 12.91 (0.15 *M* NaOH), previously determined to be that pH where the dye is completely dissociated. Under these conditions, the pH of the aqueous layer, after extraction with chloroform, was adjusted with an equal quantity of 0.16 *M* HCl to allow the use of the molar absorptivity constant of the dye in distilled water.

To substantiate the stoichiometry of the various dye-detergent compounds, they were isolated in the following manner. Equal volumes of equimolar aqueous solutions of 0.1 *M* dye and detergent were mixed and allowed to stand for 12 hours. The same concentrations of dye and detergent, at a pH of 12.91, were also mixed and allowed to stand for the same length of time; an appropriate amount of NaOH was added to the dye solution before the addition of the detergent solutions. The combinations of dye and DDBC from distilled water and 0.15 *M* sodium hydroxide and dye-PDDB from 0.15 *M* sodium hydroxide yielded an oily layer which, when extracted with ethyl acetate, mixed with anhydrous sodium sulfate, filtered, and cooled, yielded a precipitate. These were recrystallized twice from ethyl acetate and dried under vacuum at room temperature. The combinations of dye plus PDDB, CPC, and DQB obtained from distilled water and DQB obtained from 0.15 *M* sodium hydroxide, yielded solids which were washed several times with distilled water and recrystallized twice from ethyl acetate. The CPC-dye combination obtained from 0.15 *M* sodium hydroxide required a water-acetone mixture (1:1) for recrystallization. All of these compounds were dried under vacuum at room temperature and submitted for elemental analysis.

Solubility of the Dye-Detergent Compounds.—Only the four salts obtained at neutral pH values were investigated, since the dye-CPC compound formed at high pH values is of little pharmaceutical interest. The general procedure for determining solubility was as follows. To about 30 ml. of distilled water in a 50-ml. container, 100 mg. of dye-

detergent compound was added. The containers were sealed and placed into a constant temperature water bath, equipped with a rotating wheel, for 8 hours. This was the time required to insure equilibrium. The containers were then removed from the rotating wheel and allowed to sit in the bath to facilitate settling of the solid. To prevent removal of solid particles, the supernatant liquid was removed through glass wool plugs. Comparison with known solutions of dye and detergent alone showed no loss of dye or detergent due to adsorption on the glass wool or container in the range of concentrations used. The samples were added directly to a Beckman spectrophotometer absorbance cell and measured at 488 m μ . The absorbance of the dye at this wavelength was unaffected by the presence of dissolved detergent. This procedure was followed at four temperatures—25, 30, 35, and 40° \pm 0.1°. To determine the effect of ionic strength, the solubility of the dye-DDBC compounds was measured at 25° in 0.01, 0.05, and 0.1 *M* sodium chloride.

Solubilization of Dye-Detergent Compounds in the Presence of Excess Detergent.—Precipitates formed from oppositely charged substances are known to be solubilized in the presence of surfactant micelles (10). Therefore, the solubility of each dye-detergent compound was measured in solutions containing excess detergent at concentrations below and above its critical micelle concentration (C.M.C.). The critical micelle concentrations of CPC, PDDB, and DDBC were measured by observing the characteristic break in the slope of a surface tension *versus* log concentration curve. Surface tension was measured using the Wilhelmy plate method (11); a thin roughened platinum plate was used to insure complete wetting of the plate. The critical micelle concentrations obtained are: CPC, 1.0×10^{-3} *M*; PDDB, 1.2×10^{-3} *M*; DDBC, 2.25×10^{-3} *M*. The value for CPC agrees with previously reported results (12), while the latter two values have not been previously reported. The critical micelle concentration of DQB is 4.8×10^{-3} *M*, determined by surface tension measurements (7). Following the procedure for measuring solubility, as outlined earlier, the appearance of dye in solution was measured at 488 m μ ; the wavelength of maximum absorbance in the presence of micelles remaining unchanged from that of the dye in water.

RESULTS

Stoichiometry.—The number of moles of orange II transferred to chloroform at low pH was equal, in all cases, to the number of moles of detergent present, indicating a 1:1 stoichiometry. This was

TABLE II.—SOLUBILITY PRODUCTS (K'_{sp}) AND STANDARD THERMODYNAMIC FUNCTIONS FOR THE DISSOLUTION OF DYE-DETERGENT SALTS AT VARIOUS TEMPERATURES

Temp. Absolute	$K'_{sp} \times 10^{10}$	ΔF° Kcal. mole ⁻¹	ΔH° Kcal. mole ⁻¹	ΔS° e. u.
Dye-CPC				
298
303	0.0713	15.32	38.4	76.0
308	0.213	15.04	38.5	
313	0.689	14.56	38.4	
Dye-PDDB				
298	0.582	13.96	11.8	
303	0.863	13.95	11.7	-7.3
308	1.15	14.01	11.8	
313	1.52	14.07	11.8	
Dye-DDBC				
298	1.07	13.56	10.3	
303	1.42	13.65	10.3	-11.1
308	1.96	13.68	10.3	
313	2.60	13.73	10.3	
Dye-DQB				
298	0.0548	15.35	18.0	
303	0.0906	15.31	18.0	9.0
308	0.146	15.27	18.0	
313	0.246	15.20	18.0	

also true over a pH range of 0.73 to 8.05 and at ionic strengths up to 1.0. At a pH of 12.91, 1 mole of orange II was transferred for every 2 moles of CPC, while a 1:1 relationship continued to exist for the other detergents. These results are graphically illustrated in Fig. 2. These observations are further substantiated by elemental analysis of the various dye-detergent compounds, as shown in Table I. Here it can be seen that, except for CPC, the same stoichiometry is obtained for each dye-detergent combination regardless of the pH.

Solubility.—The solubility of the various 1:1 compounds in distilled water, expressed as an apparent solubility product, K'_{sp} , is shown in Table II. The solubility product was obtained by using

$$K'_{sp} = (Q^+)(D^-) \quad (\text{Eq. 1})$$

where (Q^+) and (D^-) are the detergent and dye ion concentrations, respectively.

The effect of adding electrolytes can be seen in Table III. A significant increase in the apparent solubility product occurs as the ionic strength is increased. This may be explained on the basis of the following relationship for uni-univalent substances

$$K^\circ_{sp} = (Q^+)(D^-) \gamma_{\pm}^2 \quad (\text{Eq. 2})$$

where K°_{sp} is the thermodynamic solubility product, and γ_{\pm} is the mean activity coefficient. Since the activity coefficient becomes less than unity as the ionic strength is increased, one would expect the apparent solubility product to increase, as is observed.

To determine whether the apparent solubility products obtained in distilled water are actually the thermodynamic solubility products, it is necessary to extrapolate the solubility products obtained at various ionic strengths to zero ionic strength and compare the two values. This was conveniently done by combining Eqs. 1 and 2 which gives

$$K^\circ_{sp} = K'_{sp} \gamma_{\pm}^2 \quad (\text{Eq. 3})$$

Taking the logarithm of both sides of the equation and multiplying by -1 gives

$$pK^\circ_{sp} = pK'_{sp} - 2 \log \gamma_{\pm} \quad (\text{Eq. 4})$$

Using the extended form of the Debye-Hückel equation at 25° and rearranging Eq. 4

$$pK'_{sp} = pK^\circ_{sp} - \frac{1.02 \sqrt{\mu}}{1 + \sqrt{\mu}} \quad (\text{Eq. 5})$$

where μ is the ionic strength. A plot of pK'_{sp} versus $\sqrt{\mu}/(1 + \sqrt{\mu})$ should give a straight line with a slope equal to -1.02 and an intercept of pK°_{sp} . From the curves shown in Fig. 3, the thermodynamic solubility products at 25° are 0.601×10^{-10} for PDDB and 1.11×10^{-10} for DDBC, which is in good agreement with values obtained in distilled water, as shown in Table II. The slopes of these lines are -1.052 and -1.043 for PDDB and DDBC, respectively. Thus, it appears that the apparent solubility products determined in distilled water for these relatively insoluble compounds are the thermodynamic values.

The corresponding standard free energy, entropy, and enthalpy changes for the dissolution of the various compounds in distilled water are listed in Table II. The standard free energy change is obtained from

$$\Delta F^\circ = -RT \ln K^\circ_{sp} \quad (\text{Eq. 6})$$

where R is the gas constant in calories degree⁻¹ mole⁻¹, and T is the absolute temperature. The standard entropy change is obtained from

$$\left(\frac{\partial \Delta F^\circ}{\partial T} \right)_p = -\Delta S^\circ \quad (\text{Eq. 7})$$

The standard enthalpy change at each temperature was determined from the Gibbs-Helmholtz equation

$$\Delta H^\circ = \Delta F^\circ + T\Delta S^\circ \quad (\text{Eq. 8})$$

Solubilization in the Presence of Excess Detergent.—As seen in Figs. 4 and 5, the addition of a low concentration of detergent to a system containing the corresponding dye-detergent combination reduces solubility to zero. This may be attributed to the common ion effect for sparingly soluble substances. Further addition of detergent brings about a sudden increase in the solubility of the solid com-

TABLE III.—SOLUBILITY PRODUCTS (K'_{sp}) OF DYE-DETERGENT SALTS AT VARIOUS IONIC STRENGTHS (25°)

Ionic Strength	$K'_{sp} \times 10^{10}$	
	Dye-PDDB	Dye-DDBC
0.01	0.753	1.57
0.05	0.867	1.91
0.10	0.980	2.14

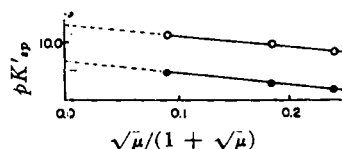


Fig. 3.—Plot of pK'_{sp} vs. $\sqrt{\mu}/(1 + \sqrt{\mu})$. Key: O, dye PDDB; ●, dye DDBC.

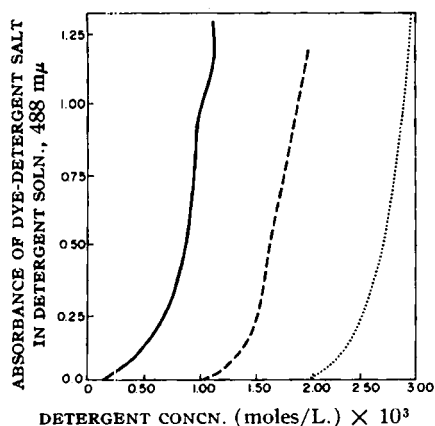


Fig. 4.—Plots of absorbance of dye-detergent salts in detergent solution at 488 $m\mu$ vs. detergent concentration. Key: —, dye-CPC; - - -, dye-PDDB; and . . . , dye-DDBC.

pound. For PDDB and DDBC, this redissolution occurs at the critical micelle concentration. For DQB, solubility commences just below the critical micelle concentration, while for CPC, solubilization occurs significantly below the critical micelle concentration. It is also interesting to note, as shown in Fig. 5, that much less dye appears in solution for a given change of DQB concentration, compared to the other systems.

DISCUSSION

Stoichiometry and Solubility.—The formation of the various 1:1 dye-detergent compounds is apparently due to electrostatic bonding between the negatively charged sulfonate group of orange II and the cationic nitrogen of the various detergents. However, differences in the solubility of these compounds, and particularly differences in the temperature coefficients for solubility, indicate a marked dependence on the electronic and steric configuration of the cationic species. Such differences as reflected in the heat of solution are $CPC \gg DQB > PDDB \approx DDBC$.

The heat of solution of a salt is dependent on the difference between the energy required to overcome the attraction between oppositely charged ions and the energy gain due to the solvation of the ions. The positive values for ΔH° obtained in all cases would indicate that the energy required to overcome the attractive forces is greater than the energy of hydration. Since the attractive energy increases with the reciprocal of the distance between the ions, those ions capable of close approach should exhibit greater heats of solution, all other factors being equal. The greater heats of solution of the dye-CPC and dye-DQB compounds, compared to the dye-PDDB and dye-DDBC compounds, are therefore probably because CPC and DQB contain a planar, aromatic structure capable of close approach to the likewise planar and aromatic dye. On the other hand, PDDB and DDBC contain a positive nitrogen atom surrounded by large alkyl and alkoxy groups in a tetrahedral arrangement. These systems, being bulky and sterically hindered, therefore, cannot approach the dye anion as close as the planar cations.

The large difference in the heat of solution of dye-

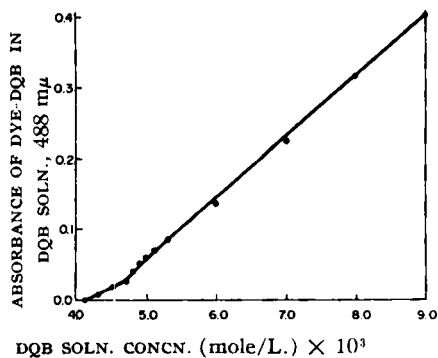


Fig. 5.—Plot of absorbance of dye-DQB in solution at 488 $m\mu$ vs. DQB concentration in solution.

CPC and dye-DQB appears to be due to more than steric considerations since both compounds are planar and aromatic. One would predict that ionic interactions should be stronger if the charge on each ion is localized to a greater extent. Both the pyridinium and quinolinium ring systems exhibit delocalization of their positive charge, the latter being capable of greater delocalization. On this basis, one would expect the pyridinium ion to be more tightly held to the anionic dye. Whether this difference can account for the observed differences in the heats of solution is difficult to say since the picture is further complicated by secondary attractive forces, energies of hydration, and steric hindrance. Whatever the major factors involved, they are probably also responsible for the fact that orange II can form a 1:2 salt with CPC when the naphthol group is ionized, while DQB and the other detergents cannot.

The large temperature coefficient for the solubility of dye-CPC indicates that the positive entropy changes associated with its dissolution are significant. This large increase of 76 entropy units may in part be accounted for on the basis of the two waters of crystallization, which are released upon dissolution of the salt. Since the standard entropy for water at 25° is 16.7 entropy units, the gain in entropy by this means should be about 33.4 entropy units. The small change in entropy exhibited by the other dye-detergent salts is generally in agreement with what is observed with most inorganic salts. For example, the standard entropy change for the dissolution of silver bromide, calculated from the solubility product data of Lewin (13), is about five entropy units. More accurate calorimetric data are necessary before the exact nature of the entropy changes can be understood, but it is apparent from these studies that entropy is a major factor in the interaction of orange II and CPC.

Solubilization in the Presence of Excess Detergent.—That detergent micelles are capable of solubilizing water-insoluble substances is well known and has been reviewed extensively by McBain (14) and Klevens (15). The solubilization of dye-detergent salts in excess detergent has been observed by Murkejee and Mysels (10). It was shown that for a number of dye-detergent combinations, solubilization occurred below the normal critical micelle concentration of the detergent. It was concluded that the presence of the insoluble dye-detergent salt induces the formation of mixed micelles consisting of the dye-detergent salt and the detergent. At

higher concentrations of detergent, they observed a transition from the dye-rich induced micelles to the more normal type of micelle, fewer dye ions per micelle being distributed uniformly among the great number of detergent micelles.

It can be seen in Figs. 4 and 5 that solubilization occurs very near or at the C.M.C. of all the detergents except CPC, although very slight solubilization below the C.M.C. of DQB may also be occurring. Thus, it would appear that dye-CPC, in particular, may be involved in a mixed micelle of the type shown by Mukejee and Mysels (10). It is also interesting to note the break in the slope of the solubilization curve (Fig. 4) for dye-CPC at $1.0 \times 10^{-3} M$, the critical micelle concentration of CPC. This may indicate a transition from induced to normal micelles as shown by Mukejee and Mysels.

The mechanism of micellization induced by a solubilize has been discussed by Ekwall (16), who showed that fatty alcohols are solubilized by soaps significantly below the C.M.C. of the soap. He attributes this phenomenon to a lowering of the free energy of formation of the soap micelles by the formation of a mixed micelle of alcohol and soap. If the alcohol orients between the ionized soap molecules, the repulsive forces of the like-charged soap ions will be reduced, thus facilitating micelle formation.

Likewise, the combination of an unionized long chain dye-detergent salt and an ionized detergent could also result in a mixed micelle which forms below the C.M.C. of the detergent. The importance of having the proper chemical structure and steric configuration so that mixed micelles can form has been shown by Schulman and Cockbain (17) in their work with emulsions. Using long chain alcohols and soaps, they showed that the length of both alkyl chains, the size and polarity of the head groups, and even the presence of double bonds in the alkyl chains are important factors which govern the formation of stable films. Therefore, it is not surprising that all dye-detergent systems do not exhibit marked shifts in the concentration of detergent required for solubilization. The dye-CPC salt apparently is able to form such mixed films with CPC, perhaps because of the planar nature of all the head groups, while the other detergents are too large and bulky to be capable of forming a stable mixed film. For instance, even though DQB is planar, it has a high C.M.C. ($4.8 \times 10^{-3} M$) and a small micellar weight (10,500) (18), which indicates an inability to pack many DQB molecules into a micelle due to the large size of the quinolinium head group. The presence of a 16 carbon chain CPC may also be important, since van der Waals attractions between the alkyl chains will contribute to the stability of a mixed film.

From a pharmaceutical point of view, the fact that these insoluble compounds can be solubilized by relatively low concentrations of surfactant should be useful in overcoming this common incompatibility. If systems capable of forming mixed micelles are used, even less detergent should be necessary. Of course, it must be kept in mind that the dye is now dissolved in a new phase, and that with some dyes a shift in the absorption spectrum of the chromophore may occur. Whether this is a prac-

tical problem will depend on the color desired in the final product; whether the antibacterial efficacy of the product is altered must also be considered.

SUMMARY AND CONCLUSIONS

1. The interactions between the dye, orange II, and quaternary ammonium compounds, 1-hexadecylpyridinium chloride (CPC), (2-phenoxyethyl)-dodecyltrimethyl ammonium bromide (PDDDB), (di-isobutylphenoxyethoxyethyl)dimethylbenzylammonium chloride (DDBC), and dodecylquinolinium bromide (DQB) have been investigated.

2. The stoichiometry of these interactions has been determined by measuring the distribution of the dye between water and chloroform as a function of pH and ionic strength, in the presence of various detergent ion concentrations. This has been substantiated by isolation and elemental analysis of the various dye-detergent compounds. Below pH 8.05, where the dye has one ionized group, all detergents give compounds with 1:1 stoichiometry. Above pH 12.34, shown to be that region where the dye contains two ionized groups, dye-CPC shows 1:2 stoichiometry, while the other dye-detergent salts continue to show 1:1 stoichiometry.

3. The solubility products of the various dye-detergent salts have been determined at 25, 30, 35, and 40°. Thermodynamic functions calculated for the dissolution of the salts indicate marked differences in the strength of these interactions, with CPC in particular exhibiting a very strong interaction with orange II.

4. Micellar solubilization of the various dye-detergent compounds occurs in the presence of the excess common detergent. Solubilization of dye-CPC, significantly below the C.M.C. of CPC, is believed to be due to the formation of mixed micelles consisting of the nonionic dye-detergent compound and CPC.

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