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Micellar Effects on the Reaction between an Arenediazonium Salt and 6-*O*-Octanoyl-L-ascorbic Acid. Kinetics and Mechanism of the Reaction

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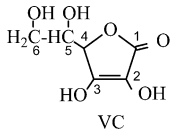
The effects of 6-*O*-octanoyl-L-ascorbic acid, VC8, on the reaction with 3-methylbenzenediazonium, 3MBD, tetrafluoroborate were investigated in the absence and in the presence of sodium dodecyl sulfate, SDS, cetyltrimethylammonium bromide, CTAB, and tetradecyltrimethylammonium bromide, TTAB, micelles at different pHs by employing a combination of UV−vis spectroscopy, high-performance liquid chromatography, HPLC, and differential pulse polarography techniques. VC8 behaves as a typical surfactant in aqueous solution giving rise to micellar aggregates at VC8 concentrations above its critical micelle concentration (cmc). This behavior is reflected in the variation of the observed rate constant, k_{obs}, with [VC8]; k_{obs} values increase smoothly upon increasing [VC8] up to a breakpoint at [VC8] $\approx 8 \times 10^{-3}$ M after which further addition of VC8 makes k_{obs} values increase sharply. Polarographic titration of VC8 with 3MBD shows that the reaction between 3MBD and VC8 takes place through an inner sphere mechanism leading to the formation of an unstable *Z*-diazo ether intermediate. All evidence is consistent with a competitive reaction mechanism, that is, the thermal $D_N + A_N$ dediazoniation and a rate-limiting decomposition of the *Z*-diazo ether "complex" formed from reaction between 3MBD and $VC8^-$ ions in a rapid pre-equilibrium step. In presence of SDS, CTAB, or TTAB, at fixed pH and [VC8] ≪ cmc, k_{obs} values increase upon increasing [VC8] up to a maximum after which further addition of surfactant leads to a sharp (SDS) or smooth (CTAB, TTAB) decrease in k_{obs} values. Results are consistent with the predictions of the pseudophase model and are rationalized in terms of micellar-induced concentration-dilution effects (SDS) and reactant and coion (3MBD) incorporation into the micellar Stern layer of CTAB and TTAB micelles. HPLC analyses of the reaction mixtures in the presence of added surfactants show a significant micellar effect on product distribution.

Introduction

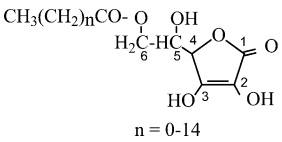
L-Ascorbic acid, VC, and some of its derivatives are widely employed as antioxidants to protect fats, vitamins, and other biological materials from radical reactions, which are believed to be responsible for a number of human diseases and for the development of rancidity and bad odors and flavors in food systems.[1−3] The ascorbic acid molecule, Chart 1A, behaves in aqueous solution as a weak acid with pK_a values of 4.2 and 11.6 for the hydroxyl groups in the 3 and 2 positions, respectively. Because of its high hydrophilicity, it cannot be used as a protective agent against peroxidations in the hydrophobic phases of micelles, food emulsions, and vesicles, and to overcome this problem, a number of hydrophobic VC derivatives were synthesized, as ethers or esters, by addition of hydrocarbon chains of different lengths in the 2, 3, 5, or 6 positions of the ascorbic acid ring, resulting in the formation of hydrophobic compounds which may eventually self-aggregate in aqueous systems leading to micelle-type supramolecular structures with the ascorbic moiety located in their interface.[4−8] Chart 1B shows some of the VC ethers substituted in the 6 position that can be readily prepared by reaction of ascorbic acid with the corresponding carboxylic acid (see Experimental Section).

Chart 1. Chemical Structures of L-Ascorbic Acid and Those of Its Derivatives Substituted in the 6 Position[a]



A

VC



B

n = 0-14

[a] The compound with $n = 6$ is the 6-*O*-octanoyl-L-ascorbic acid derivative employed in this work.

A number of reports indicate that the antioxidant activity of these hydrophobic VC derivatives is very similar to that of the parent VC, and this ability makes VC derivatives important for a number of applications in the food industry.[5,6,9] On the other hand, VCs may also act as dangerous pro-oxidant agents giving rise to the formation

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of radical molecules.[10−14] This is the case, for example, when metal ions or arenediazonium ions are present in solution. Metal ions react with VC yielding activated oxygen species, which favor lipid peroxidation.[10,12,15,16] Alternatively, VC is able to directly reduce arenediazonium, ArN_2^+, ions via one-electron-transfer processes[17−21] and there is good evidence that the aryl radicals produced in the course of these dediazoniations may be responsible for the mutagenic and carcinogenic properties of ArN_2^+ ions.[22−24]

Recently we explored the reaction of a number of ArN_2^+ ions with VC in aqueous solution at different pHs and proposed a mechanism for the reaction.[20] We have also investigated the effects of sodium dodecyl sulfate, SDS, micelles on the reaction between a number of ArN_2^+ ions with VC and with the hydrophobic 6-*O*-palmitoyl-L-ascorbic acid, VC16, at different pHs.[21] In this work, we report a study of the reaction of 3-methylbenzenediazonium, 3MBD, tetrafluoroborate with 6-*O*-octanoyl-ascorbic acid (VC8), whose structure is shown in Chart 1B ($n = 6$), in the absence and presence of anionic and cationic micelles. 3MBD was chosen because the kinetics and mechanism of its reaction in aqueous and micellar solutions, in either the presence or absence of VC, are known showing a higher reactivity toward VC than the other methyl derivatives.[20,21] VC8 may self-micellize, providing an opportunity to explore a system where the micelle is reactive and to compare the results with those obtained when employing micelles such as SDS, cetyltrimethylammonium bromide (CTAB), or tetradecyltrimethylammonium bromide (TTAB), which are relegated to passive roles.

The aim of the manuscript is twofold: first, to check if the reaction proceeds through the same mechanism as that proposed for VC, which would eventually allow confirmation of the results obtained in a previous work,[21] and second, to analyze the effects of micellar systems on the reaction and to expand our knowledge on these reactions. The results should allow bridging the gap between the chemical and biological antioxidant activity by exploring the effects of the microenvironment in which the antioxidant is located by means of employing membrane mimetic systems.[5,13,25,26]

For the sake of clarity, the work is divided in two parts: the first one deals with the reaction with VC8 in the absence of added surfactants, and the second one is focused on the micellar effects on the reaction.

Experimental Section

Instrumentation. UV−vis spectra and some kinetic experiments were followed on Beckman model DU-640 or HP Agilent model 8453 UV−vis spectrophotometers both equipped with a thermostated cell carrier attached to a computer for data storage. Product analysis was carried out on a Waters high-performance liquid chromatography (HPLC) system including a 560 pump, a 717 automatic injector, a 486 VIS−UV detector, and a computer for data storage. Instrumental details are the same as in previous work.[21] Differential pulse polarographic (DPP) measurements were obtained with a Ecochemie model Autolab PGSTAT 12, in conjunction with a Metrohm VA-Stand model 663 (set in the SME mode) equipped with a water-jacketed voltammetric cell. The three-electrode system was completed as indicated elsewhere.[21] All potentials given hereafter will be relative to the Ag/AgCl electrode.

pH was measured by using a previously calibrated Metrohm 713 pH-meter equipped with a temperature sensor. ^{1}H NMR spectra were obtained on a Brucker ARX 400 spectrometer.

Materials. Reagents were of maximum purity available and were used as received. The surfactants SDS, CTAB, and TTAB, the reagents used in the preparation of the 3MBD diazonium salt (as tetrafluoroborate), and the VC8 derivative were purchased from Aldrich or Fluka. Other materials were from Riedel de Häen. All solutions were prepared by using Milli-Q grade water.

3MBD was prepared under nonaqueous conditions as previously reported[27] and was stored in the dark at low temperature to minimize its decomposition. VC8 was prepared by reaction of the corresponding carboxylic acid with L-ascorbic acid in a concentrated sulfuric acid solution according to a literature procedure.[28] The ^{1}H NMR spectra of VC8 in DMSO is consistent with that described in the literature, confirming the purity of the compound.[28] To minimize VC8 degradation, stock solutions were prepared each day by dissolving solid VC8 in aqueous solutions containing HCl or the universal Britton−Robinson (BR) buffer and citric acid. Additional details can be found elsewhere.[20]

The pK_a of VC8 in the absence and in the presence of SDS, CTAB, and TTAB micelles was obtained by measuring the changes in absorbance at $\lambda = 244$ nm with pH at $T = 35$ °C (results not shown), and the experimental data were fitted to eq 1,

$$pK_a = pH + \log \frac{A_N - A}{A - A_I} \quad (1)$$

where A_N is the absorbance of the neutral form of VC8, A_I is the absorbance of the ionized form, and A is the absorbance at any pH. In the absence of added surfactants, that is, in pure aqueous solution, a pK_a value of 4.15 ± 0.07 was obtained, very similar to that reported in the literature for the parent VC,[20,29] showing that the addition of the C_8 hydrocarbon tail has an insignificant effect on the ionization constant. Micelles may shift the pK_a values of bound weak acids such as VC8 because of the transfer of the substrate (in both acidic and protonated form) and H_3O^+ (or OH^-) from the large bulk volume of water into the much smaller volume of the micellar interface and because of medium effects.[30−32] Addition of SDS shifts the pK_a up to a constant value of 5.4 at [SDS] > 0.15 M; meanwhile cationic micelles show a negligible effect (average value 4.25 ± 0.15).

Methods. Kinetic data were obtained spectrophotometrically by monitoring the disappearance of ArN_2^+ at $\lambda = 314$ nm as

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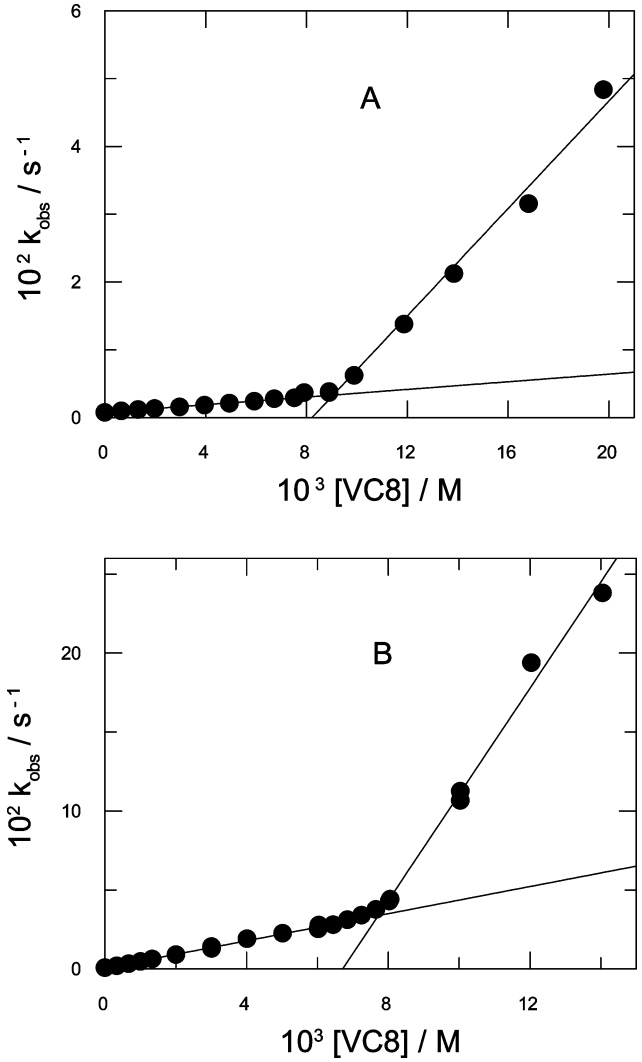

Figure 1. Effects of [VC8] on k_{obs} for dediazoniation of 3MBD at pH = 2 (A) and pH = 3 (B). [3MBD] ~ 2×10^{-4} M, $T = 35$ °C. Solid lines were obtained by fitting the experimental data to a linear equation (see Discussion).

previously described.[20,33] Observed rate constants were obtained by fitting the absorbance−time data to the integrated first order eq 2 using a nonlinear least-squares method provided by a commercial computer program:

$$\ln\frac{(A - A_\infty)}{(A_0 - A_\infty)} = -k_{obs}t \qquad (2)$$

where A is the absorbance at any time t, A_0 and A_∞ represent the absorbance at zero and infinite time, respectively, and k_{obs} is the measured rate constant. All runs were done at $T = 35 \pm 0.1$ °C, except where otherwise indicated, with 3MBD as the limiting reagent. The good agreement between the optimized and experimental A_∞ values confirmed that reactions are first order with respect to VC8. Identification and quantification of reaction products was done by HPLC analyses of the reaction mixtures once the reaction was completed, that is, at infinite time, by following the procedure described elsewhere.[20,21]

Results

(1) Reaction in the Absence of Added Anionic or Cationic Surfactants. *(a) Effects of [VC8] on the Observed Rate Constant, k_{obs}, for the Reaction with 3MBD.* Figure 1 shows the biphasic profile observed for the

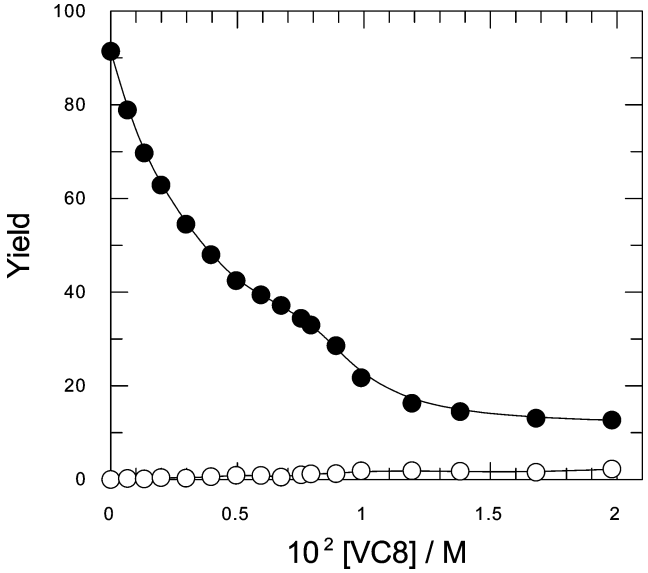

Figure 2. Effects of [VC8] on product distribution. ●, 3-cresol; ○, toluene. Samples were analyzed after 20−24 h at $T = 35$ °C, pH = 2 (BR buffer), [3MBD] ~ 2×10^{-4} M. Solid lines were fitted to aid the eye.

variation of k_{obs} upon increasing VC8 at pH 2 and 3. k_{obs} values increase modestly up to a breakpoint at [VC8] ≈ 8×10^{-3} M; further addition of VC8 results in a rapid increase in k_{obs}. Higher VC8 concentrations could not be employed because reactions become very fast. In the absence of VC8, a $k_{obs} = 10 \times 10^{-4}\ s^{-1}$ value was obtained, very similar to those previously reported for the spontaneous dediazoniation of 3MBD under similar conditions.[33,34]

VC8 behaves as a typical surfactant in aqueous solution; hence the rapid increase in k_{obs} may be attributed to the concentration effect arising from the formation of VC8 micelles and the cross point of the two straight lines in Figure 1 defines the kinetically determined critical micelle concentration (cmc) of VC8, cmc ≈ 8×10^{-3} M, a value very close to that determined by surface tension measurements at $T = 30$ °C.[8] Results in Figure 1 also show that pH exerts an effect on k_{obs} values, which are about 10 times higher at pH = 3 than at pH = 2 in agreement with previous observations.[20,21]

(b) Effects of [VC8] on Product Distribution. The effects of VC8 on product distribution were determined by HPLC analyses of a number of reaction mixtures after 20−24 h. Chromatograms in the presence of VC8 showed, in addition to the front peak, two well-resolved peaks with retention times, t_R, of 6.5 and 14.5 min, associated with 3-cresol and toluene, respectively, and a number of minor ones. The variation in the percentage of formation of products upon increasing [VC8] is shown in Figure 2. When no VC8 is added, the percentage of conversion to 3-cresol is quantitative and only traces (<2%) of toluene were detected. Upon increasing [VC8], yields of 3-cresol decrease up to a saturation limit of ~10% when [VC8] = 2×10^{-2} M; meanwhile yields of toluene increase smoothly, but in all cases its yield is lower than 7%.

Nonquantitative conversion to products was previously observed for the reaction of 3MBD with VC in aqueous acid solution and in the presence of SDS micelles and attributed to the formation of a thermodynamically stable *E*-diazo ether derivative of the type Ar−N=N−O−R which elutes with the front peak.[20,21] Evidence for the formation

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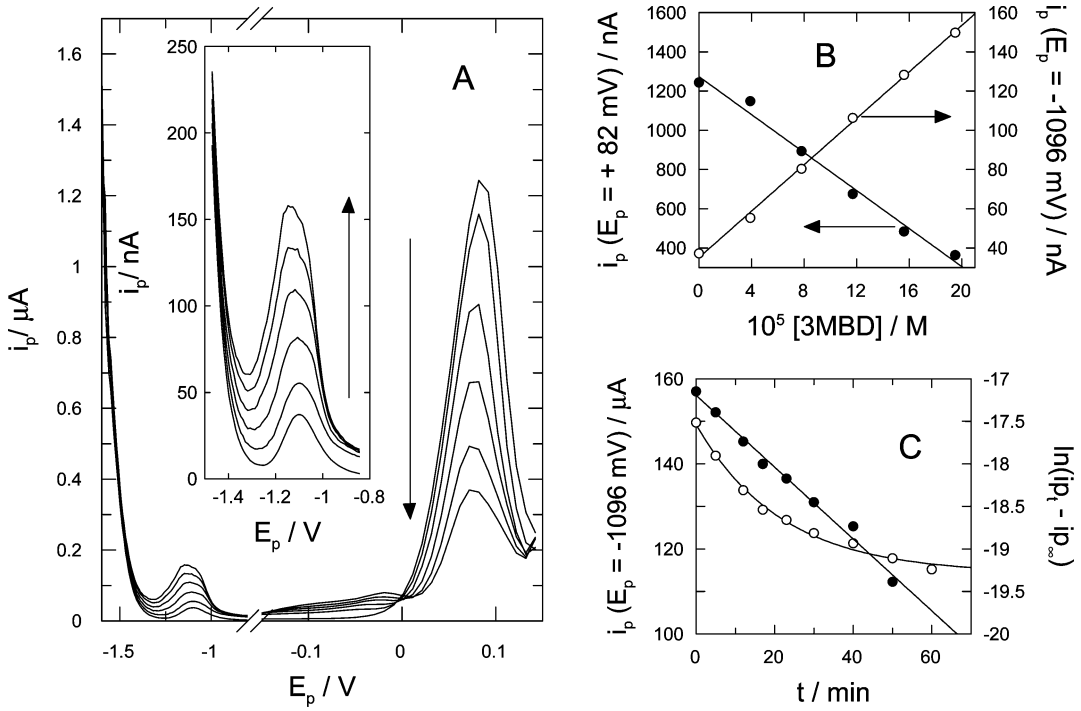

Figure 3. (A) Titration of VC8 ([VC8] = 2.00×10^{-4} M) with 10 μL equivalent aliquots of 3MBD (final concentration = 2×10^{-4} M) at pH = 4 obtained at room temperature. Note that the polarographic peaks of 3MBD (at ~50 and ~450 mV) are not observed. (B) Variation in the peak current of the polarographic peak detected at $E_p = -1096$ mV (○), which is attributed to the transient diazo ether formed between 3MBD and $VC8^-$, and the decrease in the peak current of the polarographic reduction peak of VC8 at $E_p = +82$ mV (●) upon titration. (C) Variation in the peak current of the transient diazo ether with time at room temperature (○) and first-order plot (●).

of such transient intermediates was obtained primarily by UV−vis spectroscopy in some dediazoniations.[35] However, under our experimental conditions, the absorption band of VC8 or that of $VC8^-$ masks those of reactives and products, especially at high [VC8], and thus no new absorption bands beyond those attributable to the reactives were detected. Formation of diazo ether intermediates in reactions between arenediazonium ions and VC in aqueous solution was demonstrated experimentally by employing electrochemical methods,[20] although the method did not work in SDS micellar systems because the polarographic peak of SDS shows up in the same potential region as that for the expected polarographic peak of the transient diazo ether.[21] Given that no surfactant other than VC8 is present in the system, the DPP electrochemical technique was employed to look for evidence of the formation of such intermediates in the reaction with VC8, which would eventually confirm that the mechanism of the reaction is the same as that with the parent VC and, at the same time, would explain the low yields obtained, Figure 2.

(c) Experimental Evidence for the Formation of a Transient Intermediate in the Reaction between 3MBD and VC8. Figure 3A shows the differential pulse, DP, polarogram of a solution containing a fixed amount of VC8 in aqueous buffered solution (pH = 4) at room temperature and the polarograms obtained after addition of aliquots of a 3MBD solution.[36] The inset in Figure 3A details the $E_p = -0.8$ to -1.5 V potential region. A main reduction peak associated with VC8 can be observed at a peak potential of $E_p = +82$ mV and a much smaller one at $E_p = -1096$ mV (vs Ag/AgCl). Polarographic titration of ascorbic acid with aliquots of 3MBD, Figure 3B, shows a linear decrease in the intensity of the VC8 peak at $E_p = +82$ mV with a concomitant increase in the intensity of the peak located at $E_p = -1096$ mV.

The peak at $E_p = -1096$ mV may be associated with the presumed transient intermediate formed between 3MBD and VC8 because in previous electrochemical work on the reaction between 3MBD and VC, the polarographic peaks associated with the formation of the corresponding transient diazo ether were detected at $E_p = -1060$ mV and $E_p = 1200$ mV.[20] Further evidence for the formation of a transient intermediate is given by the fact that the polarographic peaks associated with the reduction of 3MBD ions, which should appear about −50 and − 450 mV, do not show up in the polarograms, Figure 3A. Furthermore, preliminary experiments, Figure 3C, indicate that the intensity of the new peak at $E_p = -1096$ mV is not constant with time in agreement with previous findings.[37,38] A first estimation for the observed rate constant for the disappearance of the diazo ether can be obtained by fitting the variation in the peak current at $E_p = -1096$ mV with time to the first-order rate equation, Figure 3C, $k_{diss} \approx 7 \times 10^{-4}$ s^{-1} (data obtained at room temperature).[36]

(2) Micellar Effects on the Reaction between VC8 and 3MBD. (*a) Anionic and Cationic Micellar Effects on k_{obs} for the Reaction between VC8 and 3MBD.* As shown previously, the reaction between VC8 and 3MBD depends on pH and [VC8], so the effects of micellar systems on the reaction were determined by using buffered control pH and fixed [VC8]. Binding constants, K_{VC8}, of VC8 to micellar

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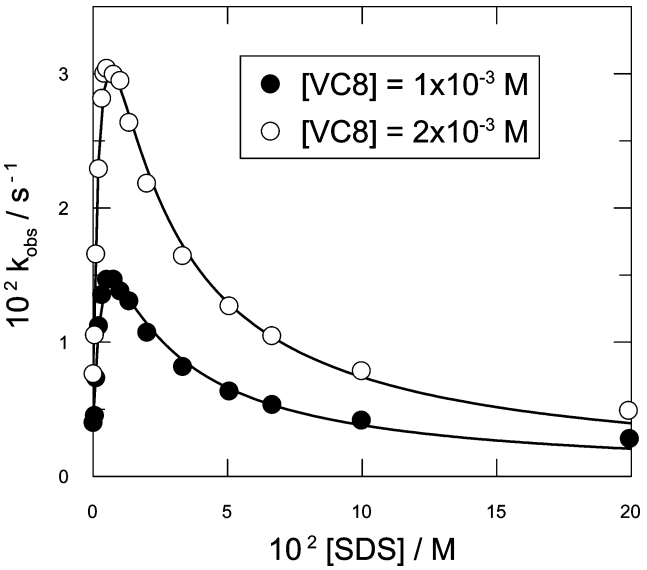

Figure 4. Effects of SDS on k_{obs} for the reaction between 3MBD and VC8. [3MBD] $\sim 1 \times 10^{-4}$ M. ○, [VC8] $= 2 \times 10^{-3}$ M; ●, [VC8] $= 1 \times 10^{-3}$ M. pH = 3 (BR buffer), $T = 35$ °C. Solid lines were obtained by fitting the experimental data to the typical rate constant equation for bimolecular reactions in the presence of surfactants.

systems are not currently known but can be estimated to be $K_{VC8} \sim 10^3$ M^{-1} based on the effect of the hydrocarbon chain length on the association constant of the substrates and micelles.[39] Hence VC8 should be totally bound to micelles even at low surfactant concentrations leading to the formation of mixed micelles. Figure 4 shows the effects of increasing [SDS] on k_{obs} at selected VC8 concentrations much lower than its cmc. In both cases investigated, k_{obs} values increase upon increasing [SDS] up to a maximum at [SDS] $\sim 1 \times 10^{-2}$ M after which further addition of SDS leads to a decrease in k_{obs} up to a value very close to that in the absence of SDS.

Panels A and B in Figure 5 show the effects of CTAB and TTAB micelles, respectively, on k_{obs} upon increasing surfactant concentration. k_{obs} values increase rapidly up to a maximum after which further addition of surfactant leads to a plateau (A) or a slight decrease (B) in k_{obs} values, in contrast with the abrupt decrease in k_{obs} observed for SDS, Figure 4. The maximum k_{obs} value is reached at [CTAB] ≈ [TTAB] ≈ 0.01 M, and similar k_{obs} values are obtained at any other given [CTAB] = [TTAB], indicating that both surfactants have a similar effect on the reaction.

(b) Micellar Effects on Product Distribution. Product distribution was obtained by HPLC analyses of the reaction mixtures after 20 h at different pHs. In all cases, no extraneous peaks other than the front peak and those for the 3-cresol and toluene derivatives were found.

Figure 6A shows the effects of SDS micelles on product distribution when employing a fixed [VC8] much lower than the kinetically estimated cmc. Yields of 3-cresol decrease sharply upon increasing [SDS] up to a minimum at [SDS] $\approx 4 \times 10^{-3}$ M after which an increase is observed. Yield of toluene increases sharply up to [SDS] $\approx 5 \times 10^{-3}$ and then more smoothly upon increasing [SDS], and when [SDS] ≈ 0.8 M yields of 3-cresol and toluene are the same. However, total yield is not quantitative; total yield is about 45% at [SDS] ≈ 0.8 M.

When cationic micelles are employed, the product distribution is somehow different than that with SDS,

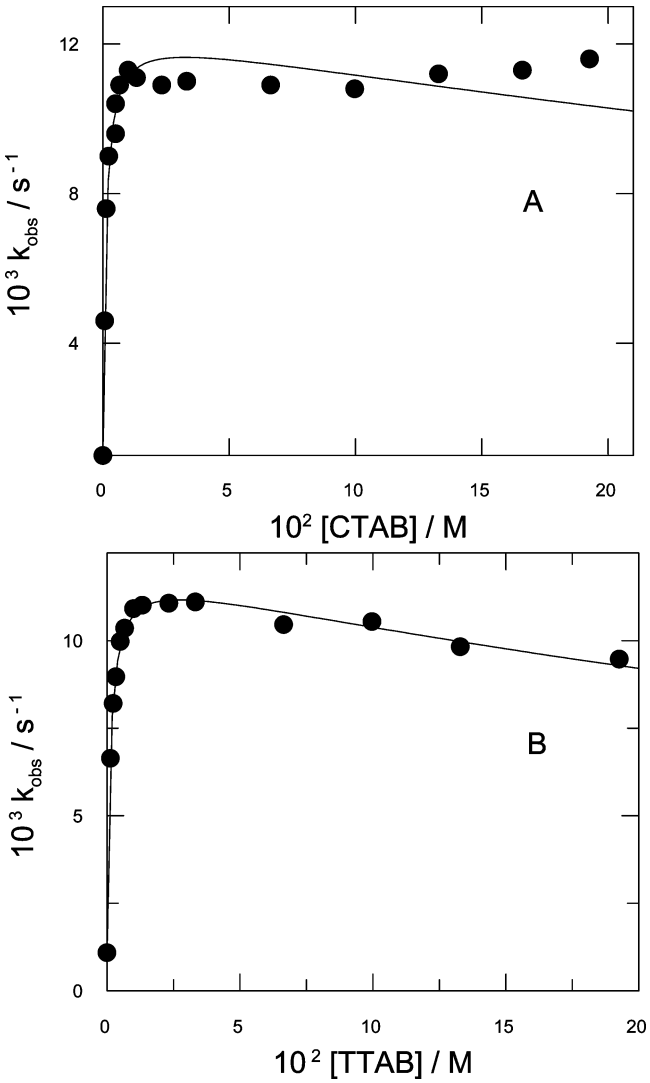

Figure 5. Effects of CTAB (A) and TTAB (B) on k_{obs} for the reaction between 3MBD and VC8. [3MBD] $\sim 1 \times 10^{-4}$ M, [VC8] $= 1 \times 10^{-3}$ M, pH = 2 (BR buffer), $T = 35$ °C. Solid lines were obtained as in Figure 4.

although again only the chromatographic peaks for 3-cresol and toluene and the front peak showed up in the chromatograms. Figure 6B, chosen as representative, shows the product distribution observed for CTAB. In the absence of CTAB, the yield of 3-cresol is about ~65% and only traces of toluene are detected. Upon increasing CTAB, the yield of 3-cresol decreases sharply up to [CTAB] $\approx 1 \times 10^{-3}$ M and then much more smoothly with a concomitant increase in the yield of toluene, and at [CTAB] $\geq 5 \times 10^{-3}$ M both yields are essentially equal to each other. Total yield is ~30% at any [CTAB] $> 2 \times 10^{-3}$ M and remains essentially constant upon increasing [CTAB].

Discussion

Arenediazonium ions may function as one-electron oxidizing agents, and therefore free radicals are generated in reactions with suitable electron donors.[18−20,35,40] Two particular mechanisms, outer and inner sphere, have been proposed for these reactions.[40,41] The outer-sphere mechanism assumes a direct electron transfer from a reducing

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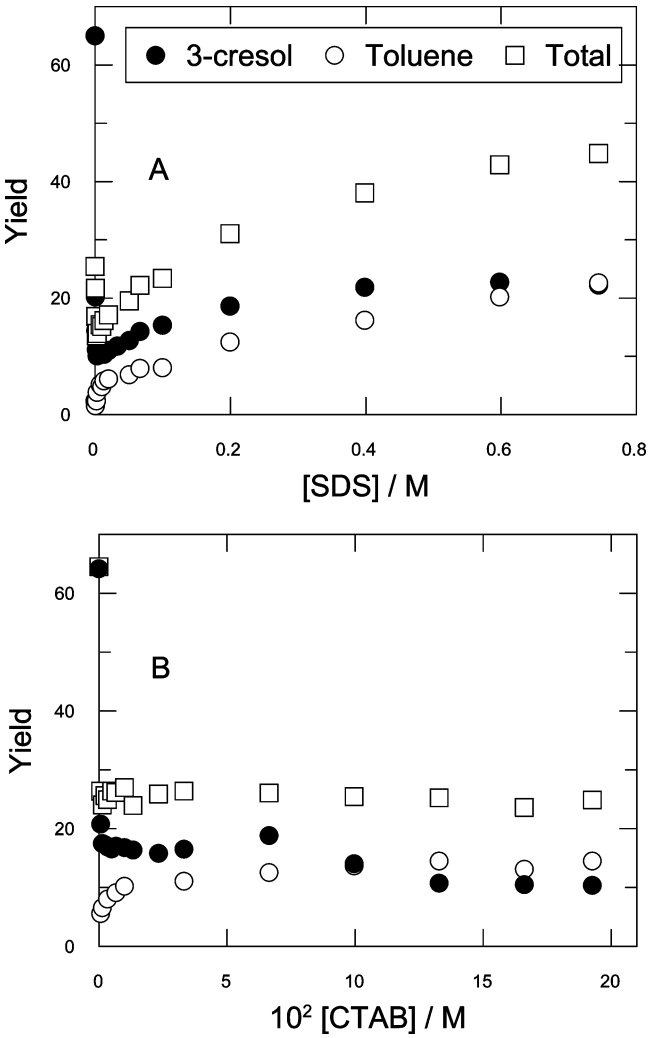


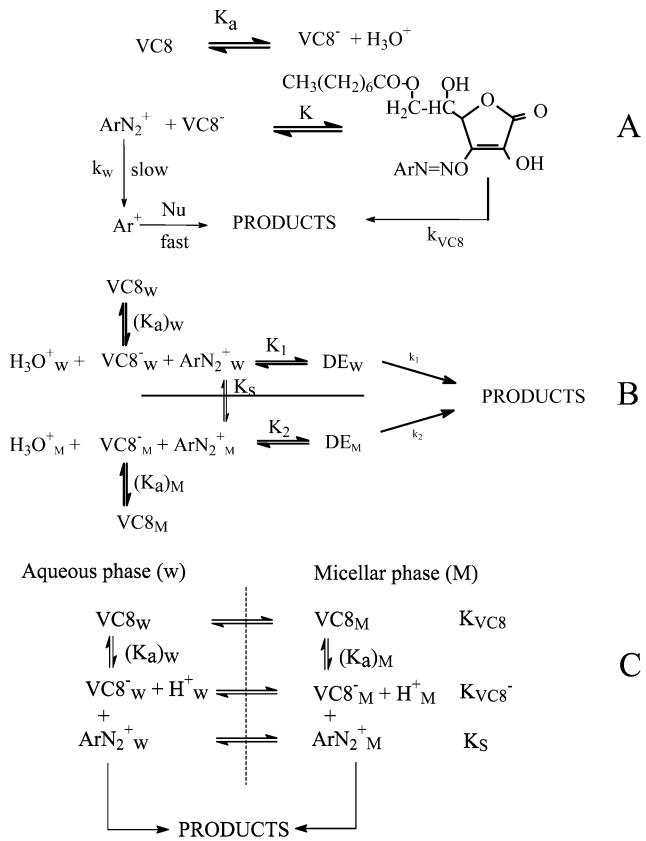
Figure 6. Effects of SDS (A) and CTAB (B) on the product distribution for the reaction between 3MBD and VC8. Samples were analyzed after 20−24 h at $T = 35$ °C. pH = 2 (BR buffer), $[mMBD]_o \approx 2 \times 10^{-4}$ M, $[VC8] = 1.08 \times 10^{-3}$ M. ●, 3-cresol; ○, toluene; □, total.

agent to ArN_2^+ ions, yielding a radical from the reducing agent and an aryl diazenyl radical, $ArN_2^{\bullet}$, which subsequently decompose spontaneously in aqueous solution yielding N_2 and the corresponding aryl radicals. In the alternative inner-sphere mechanism, reduction of the arenediazonium ion is preceded by the formation of a complex, namely, Ar−N═N−O−R,[42] generated by reaction of ArN_2^+ with RO^- in a rapid pre-equilibrium step.[20]

If the outer-sphere mechanism operates, the diazenyl radical, $ArN_2^{\bullet}$, should be detected in the +50 to −20 mV range,[38] which is not the case, Figure 3. Furthermore, the titration experiments in Figure 3A show a polarographic peak at potentials clearly different from those of $ArN_2^{\bullet}$ and very close to those previously detected for the unstable diazo ether formed in the course of the reaction between a number of ArN_2^+ ions and VC,[20] indicative of an inner-sphere mechanism controlling the reaction of 3MBD with VC8. In addition, the peak current of such a peak increases upon increasing [3MBD] with a coupled decrease in the peak current of the peak associated with VC8, Figure 3B, and preliminary experiments indicate that the intensity of those new peaks is not constant with time, Figure 3C.

Hence, all electrochemical evidence is consistent with an inner-sphere mechanism similar to that proposed for the reaction of 3MBD with VC,[20] that is, the overall reaction taking place through two competitive reaction pathways, Scheme 1A. The first one is the thermal $D_N + A_N$ dediazoniation mechanism, which is predominant in the absence of VC8, and a rate-limiting decomposition of a diazoether complex that is formed in a rapid pre-equilibrium step from the reaction between the arenediazonium ions and the monobasic form of VC8. Since VC8 behaves as a weak acid with a pK_a value of ∼4.2 for the C_2 hydroxyl group, the most probable structure of such a diazo ether complex is that shown in Scheme 1A, in keeping with literature reports.[20,43] The assumption of a rate-limiting decomposition of the diazo ether is consistent

Scheme 1. Reaction Mechanisms[a]



[a] (A) Proposed competitive reaction mechanism for the reaction between 3MBD and VC8 at VC8 concentrations lower than its cmc, showing the thermal $D_N + A_N$ mechanism and the unimolecular decomposition of the transient diazo ether (DE) formed in a rapid pre-equilibrium step. (B) Reaction mechanism when VC8 micelles are present (i.e., [VC8] > cmc). (C) Reaction mechanism for the reaction between 3MBD and VC8 in the presence of anionic SDS micelles. K_a stands for the ionization constant of VC8; k_w and k_{VC8} are the rate constant in the absence of VC8 and that for the unimolecular decomposition of the DE, respectively. K represents the equilibrium constant for the diazo ether formation. K_S, K_{VC8}, and K_{VC8^-} stand for the association constants of ArN_2^+ ions, VC8 monomers, and $VC8^-$ ions to SDS micelles, respectively. The subscripts w and M refer to the aqueous (w) and micellar (M) pseudophases.

(42) Diazo ethers are rarely formed as stable products because they are sensitive to acids and bases, although in some instances they have been isolated and characterized. These O-coupling reactions are currently believed to take place through the very rapid formation of the kinetically controlled *Z*-diazo ether, and in a second step, some of the *Z*-diazo ether decomposes to yield reduction products (usually hydrodediazoniation) and the rest is converted into the thermodynamically stable *E*-diazo ether. See refs 20 and 21 for further details.

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with reported results for other O-coupling reactions[40,44−46] and was experimentally probed in reactions of arenediazonium ions where geometric restrictions apply.[47,48]

From Scheme 1A, taking into consideration the corresponding mass balances and the first ionization equilibrium for VC8 (K_a) and bearing in mind that we have worked under pseudo-first-order conditions, the observed rate constant given by eq 3 can be obtained.

$$k_{obs} = \frac{k_w + k_{VC8}B[VC8]_T}{1 + B[VC8]_T} \quad (3)$$

where B is given by eq 4:

$$B = \frac{K_a K}{K_a + [H_3O^+]} \quad (4)$$

Equation 3 predicts that for those cases where the spontaneous decomposition of ArN_2^+ is negligible compared to product formation via the complex, that is, $k_w \ll k_{VC8}B[VC8]_T$, k_{obs} should be independent of [VC8] at very high [VC8]. However, an increase in [VC8] leads to the formation of VC8 micelles, Figure 1, and hence the presumed saturation kinetic profile cannot be observed. Alternatively, one expects a linear increase in k_{obs} upon increasing $[VC8]_T$ when $B[VC8]_T \ll 1$. This condition is achieved either at very low [VC8] or when $[H_3O^+]$ is higher, by a power of ~2, than the acidity constant of VC8.[20] The assumption appears to be fulfilled even at pH = 3, Figure 1, because the pK_a of VC8 in pure water is 4.15 (see Experimental Section) and K values for 3MBD are about $\sim 10^3\ M^{-1}$;[21] thus $B \approx KK_A/[H_3O]^+ \leq 10$, and hence $B[VC8]_T \ll 1$ when [VC8] < 10^{-2} M. Under these conditions, eq 5 applies.

$$k_{obs} = k_w + k_{VC8}B[VC8]_T \quad (5)$$

which predicts a linear increase in k_{obs} upon increasing [VC8]. From the slope of the first linear part in Figure 1 (i.e., up to the breakpoint), values of $k_{VC8}B = (2.8 \pm 0.1) \times 10^{-1}$ (pH = 2) and 4.3 ± 0.1 (pH = 3) can be obtained, allowing one to estimate values of $k_{VC8} = 4 \times 10^{-2}\ s^{-1}$ (pH = 2) and $k_{VC8} = 6.5 \times 10^{-2}\ s^{-1}$ (pH = 3). The estimated k_{VC8} values are much higher than that estimated by monitoring diazo ether disappearance, Figure 3C, probably because of the different methods and the higher temperatures employed.

Once the cmc of VC8 is reached, Figure 1, VC8 micelles are formed and k_{obs} values increase rapidly because of the increase in the local concentration of reactives. Under this condition, Scheme 1B should apply[49] and the investigated system is a typical situation where functionalized micelles (VC8) are present. The final rate equation that can be derived from Scheme 1B will be a composite of expressions;[50] nevertheless, any quantitative treatment is unreliable at the present stage because of the number of variables that need to be determined. For instance, the equilibrium constants K_1 and K_2 for diazo ether formation in the aqueous and micellar pseudophases, respectively, need to be known and as indicated before, it is not possible to determine K_1 because of the formation of VC8 micelles. Even though a number of approximations can be done (for example, a gross simplification could be done by assuming that the equilibrium constants K_1 and K_2 are similar), the lack of k_{obs} values at very high [VC8], Figure 1, also precludes an estimation of K_2. In addition, changes in the micellar charge as a result of deprotonation of VC8 monomers should be taken into account.[50]

Experiments in the presence of intentionally added SDS, CTAB, and TTAB were performed by employing VC8 concentrations lower than its cmc; thus mixed SDS−VC8, CTAB−VC8, or TTAB−VC8 micelles are present. The positive charge of the 3MBD ions makes them fully associated to SDS micellar systems,[33,51] and the reaction between the anion of VC8 and 3MBD ions takes place almost exclusively in the interface region of the SDS micelles, where the reactants are brought together. Bearing in mind that both VC8 and ArN_2^+ are micellar bound, Scheme 1C is appropriate.[49] A complete quantitative treatment was not attempted because a number of approximations are needed, but a comprehensive set of equations for solving Scheme 1C (or similar reaction schemes)[30,31,50,52] and details and the basic assumptions of the PIE model can be found elsewhere.[53]

The reaction between 3MBD and VC8 is second-order overall even though it has been carried out under pseudo-first-order conditions by making [3MBD] ≪ [VC8]. Thus, the bell-type kinetic profile shown in Figure 4 can be interpreted in terms of 3MBD and VC8 ions reacting at the micellar interface; k_{obs} values increase rapidly because of the concentration of reactants at the micellar Stern layer up to a maximum followed by a sharp decrease in k_{obs} values due to the dilution of the reactants within the micellar pseudophase upon increasing micelle concentration in solution.

In the presence of cationic micelles, 3MBD ions are expected to be mainly located in the aqueous pseudophase because of their positive charge, and VC8 should be totally bound to micelles because of its hydrocarbon tail. Hence one would expect an inhibition of the reaction between VC8 and 3MBD because of the micellar-induced separation of the reactants and the kinetic profiles shown in Figure 5 are unexpected. Results in Figure 5 can be interpreted by assuming that 3MBD ions behave as co-ions of CTA^+ monomers, being partially incorporated into the micellar Stern layer. The increase in k_{obs} upon increasing surfactant concentration may be then interpreted in terms of concentration of reactants in the Stern layer, and the subsequent decrease in k_{obs} represents the dilution of the reactants within the micellar pseudophase upon increasing micelle concentration in solution. A similar situation was found when investigating the effects of SDS micelles on the reaction between 3MBD and VC, where evidence

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(49) Scheme 1B,C illustrates the relevant equilibria involved when VC8, $VC8^-$, and 3MBD ions are present in the system. We did not include that for exchange between Na^+ and H^+ intentionally in Scheme 1C for the sake of clarity and because it was not studied directly in the present work, e.g., by addition of NaCl. Hence, the data in the paper provide no evidence in support of or against ion exchange. The primary effects of increasing surfactant concentration on k_{obs} are caused by concentration-dilution of the reactants in the micellar pseudophase (vide infra) and not by ion exchange.
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for incorporation of VC^- ions into the SDS micellar Stern layer was found.[21] The assumption of 3MBD ions having access to the Stern layer of the CTAB or TTAB micelles is consistent with a number of reports that conclude that cationic micelles inhibit but do not completely suppress reactions between bound substrates and co-ions[50,53−55] and is consistent with dediazoniation experiments showing the presence of X^- ions in the interfacial region of SDS micelles[56,57] but apparently contrasts with previous work on some dediazoniations.[58,59]

Product yields, Figure 6, were obtained by HPLC analyses of the reaction mixtures after 20−24 h. No extraneous peaks other than that for the front peak and those for 3-cresol and toluene were detected. As shown in Figure 6, nonquantitative yields were obtained in all cases investigated and it is apparent that micelles present a significant effect on product distribution as pointed out in a previous report.[21] As noted before, the nonquantitative yields are attributed to the formation of the thermodynamically stable *E*-diazo ether, which elutes in the front peak. The bond-rotating mechanism to transform the *Z*-isomer into the much more stable *E*-derivative has been described in aqueous solution,[60] but nothing is known about the micellar effects on the reactivity and stability of such diazo ethers.

In conclusion, we have been able to show that reaction of arenediazonium ions with the hydrophobic VC8 takes place through the same competitive mechanism as that proposed for the reaction with VC, Scheme 1, that is, the thermal $D_N + A_N$ mechanism and a rate-limiting decomposition of a transient diazo ether intermediate which is formed in a rapid pre-equilibrium step via an inner-sphere mechanism. The formed diazo ether is unstable and decomposes to give the thermodynamically stable *E* isomer and homolytic products, that is, toluene. A significant change in the variation of observed rate constant upon increasing [VC8] is detected because of VC8 self-micellization. The results confirm the mechanism for the reaction between a number of ArN_2^+ ions and VC16 in the presence of SDS micelles, which was proposed in a previous work.[21]

In the absence of anionic or cationic surfactants, k_{obs} values increase smoothly, in a linear fashion upon increasing VC8 up to the formation of VC8 micelles, that is, its cmc. Further addition of VC8 results in a sharper increase in k_{obs} because reactants are brought together at the interface of the VC8 micelles. When the reaction is carried out in the presence of cationic or anionic surfactants, all evidence is consistent with 3MBD and $VC8^-$ reacting at the micellar interface and with the observed variation in k_{obs} with surfactant concentration following a bell-type curve due to the concentration-dilution effects exerted by the micelles, as found for a number of bimolecular reactions.

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