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STUDIES ON CATIONIC MICELLE INHIBITED TRANSIMINATION REACTIONS OF BARBITURYL-AZINE-INDANDIONE AND AZINE-BIS-INDANDIONE WITH SEMICARBAZIDE

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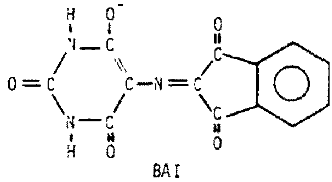
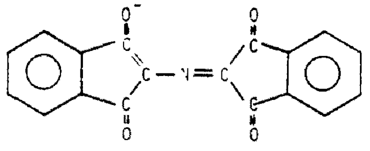
Abstract – The acid cataylsed transimination reactions of barbituryl-azine-indandione (BAI) and azine-bis-indandione (ABI) with semicarbazide are inhibited by n-alkyl trimethylammonium bromides. At a given detergent concentration, the efficiency of inhibition increases with increasing alkyl chain-length of the detergent. Addition of counterions and alcohols increased the cetyltrimethylammonium bromide (CTAB) inhibited rate. Extent of micellar inhibition is reduced by the addition of counterions in the order NO_3 > Br > Cl > SO_4 and by the addition of alcohols in the order n-butanol > n-propanol > ethanol > methanol. Activation parameters for the reactions in the presence of CTAB have been evaluated and compared with those obtained in the absence of detergent.

In an earlier communication[1] we have reported the micellar effects on the acid catalysed transimination reactions of azine-bis-barbiturate (murexide) and related Schiff bases with semicarbazide. While the reactions of azine-bis-barbiturate and its tetramethyl derivative were only slightly inhibited by cetyltrimethylammonium bromide (CTAB), the reactions of relatively more hydrophobic barbituryl-azine-indandione (BAI) and azine-bis-indandione (ABI) were inhibited by factors of 14 and 113 respectively. The anionic and nonionic micelles had negligible effect on these reactions.


BAI


ABI

We now report the effect of increasing alkyl chain-length of cationic micelle forming surfactants and the effect of counterions (to surfactant), alcohols and temperature on the CTAB inhibited reactions of BAI and ABI with semicarbazide.

EXPERIMENTAL

Materials. Barbituryl-azine-indandione and azine-bis-indandione were prepared following the method of Ruheman[2] and were purified by the method of Davidson.[3] Semicarbazide hydrochloride was recrystallized from aqueous EtOH. Analytical grade CTAB was purified by following the standard method.[4] Other surfactants nonyl-, decyl-, dodecyl-, and tetradecyltrimethylammonium bromides were obtained from Eastman Kodak Co (U.S.A.) Analytical grade alcohols were further purified prior to use. All the other chemicals used were analytical grade reagents.

Method. Reactions were followed spectrophotometrically by noting the decrease in absorbance as a function of time at the absorption maximum of the respective compounds. Temperature of the cell compartment was maintained by an externally connected thermostat to a precision of ±0.1°. Appropriate pH (6.0 and 4.8 for BAI and ABI reactions respectively) was selected for the study such that the rate of hydrolysis was negligible compared to the rate of reaction with semicarbazide. Slopes of the pseudo first order plots were obtained by least square analysis.

RESULTS AND DISCUSSION

Effect of n-alkyl chain-length of the surfactant. Effect of a series of cationic surfactants like nonyl-, decyl-, dodecyl-, tetradecyl-, and hexadecyltrimethylammonium bromides on the reactions of BAI and ABI with semicarbazide has been examined. All the surfactants are found to be inhibitory. The results for the reaction of BAI are given in Fig. 1. Similar trend is observed for the reaction of ABI. Inhibition by nonyl and decyl surfactants takes place at higher concentrations than those shown in Fig. 1. Azine anion binds to the cationic micelles and is thereby shielded from protonation. The nonavailability of the protonated substrate for the rate determining attack by semicarbazide leads to the observed inhibition. It may be seen from Fig. 1 that the surfactant having a longer alkyl chain is a better inhibitor at any given concentration (in the range studied). This difference persists even at concentrations well above the reported cmc's[5] of all the surfactants. The extent of inhibition in terms of k_{rel} values at 1×10^{-2} M surfactant concentration for the

Table 1. Extent of inhibition at 0.01 M n-alkyl trimethylammonium bromides for the reactions of BAI and ABI with semicarbazide at 25

n-alkyl trimethyl-ammonium bromide	k_w / k_ψ for BAI	k_w / k_ψ for ABI
Nonyl	1.04	1.19
Decyl	1.06	1.21
Dodecyl	3.80	26.30
Tetradecyl	9.54	80.40
Hexadecyl	14.26	113.10

Table 2. Binding constants between n-alkyl trimethylammonium bromide micelles and anions of BAI and ABI obtained from the quantitative treatment of the kinetic data

n-alkyl trimethyl-ammonium bromide	N	BAI		ABI	
		$K / N, M^{-1}$	correlation coefficient	$K / N, M^{-1}$	correlation coefficient
Nonyl	30	8.34×10^1	0.9969	3.47×10^2	0.9973
Decyl	48	1.44×10^2	0.9934	7.04×10^2	0.9970
Dodecyl	50	4.07×10^2	0.9950	5.41×10^3	0.9981
Tetradecyl	75	9.92×10^2	0.9950	1.29×10^4	0.9980
Hexadecyl	61	1.68×10^3	0.9995	3.65×10^4	0.9998

Table 3. Activation parameters for the reactions of BAI and ABI with semicarbazide in the presence and absence of CTAB

Thermodynamic quantity	BAI		ABI	
	In absence of CTAB	In presence of 0.01 M CTAB	In absence of CTAB	In presence of 0.005M CTAB
$E^{\neq}$, kcal mole^{-1}	6.98	11.24	7.62	11.35
$\Delta G^{\neq}$, kcal mole^{-1}	19.22	20.71	19.10	21.26
$\Delta S^{\neq}$, cal mole^{-1} deg^{-1}	-43.02	-33.74	-40.48	-35.21
$\Delta H^{\neq}$, kcal mole^{-1}	6.40	10.66	7.03	10.77

reactions of both BAI and ABI are listed in Table 1. Each of the surfactant at a selected concentration is a better inhibitor for the reaction of ABI than for the reaction of BAI. This result is in agreement with the finding that the inhibitory effect increases with increasing substrate hydrophobicity.

To understand these effects quantitatively in terms of binding, the data have been analysed by a standard model[6] described in our earlier paper.[1] According to this model if k_m (the rate constant in micellar phase) is taken to be zero, the following equation is obtained.

$$(k_w/k_\psi - 1) = K/N(C_D - \text{cmc}) \qquad (1)$$

where k_w and k_ψ are the rate constants in the absence and presence of micelles respectively, K is binding constant, N is aggregation number, C_D is the concentration of the surfactant and cmc is the critical micelle concentration. The approximation that k_m is equal to zero for highly inhibited reactions has been successfully used in earlier cases.[7,8]

As required by eqn (1) plots of $(k_w/k_\psi - 1)$ against C_D are found to be linear with very high correlation coefficients (Table 2). Values of K/N obtained from slopes are listed in Table 2. It is of interest to note that K/N which is a relative measure of binding between substrate and micelle increases as surfactant alkyl chain-length increases in the order nonyl < decyl < dodecyl < tetradecyl < hexadecyl. This order of binding ability remains unchanged even if we account for the differences in aggregation numbers[9,10] thereby indicating that the increased binding of azine anion to the micelle of longer chain surfactant is solely due to

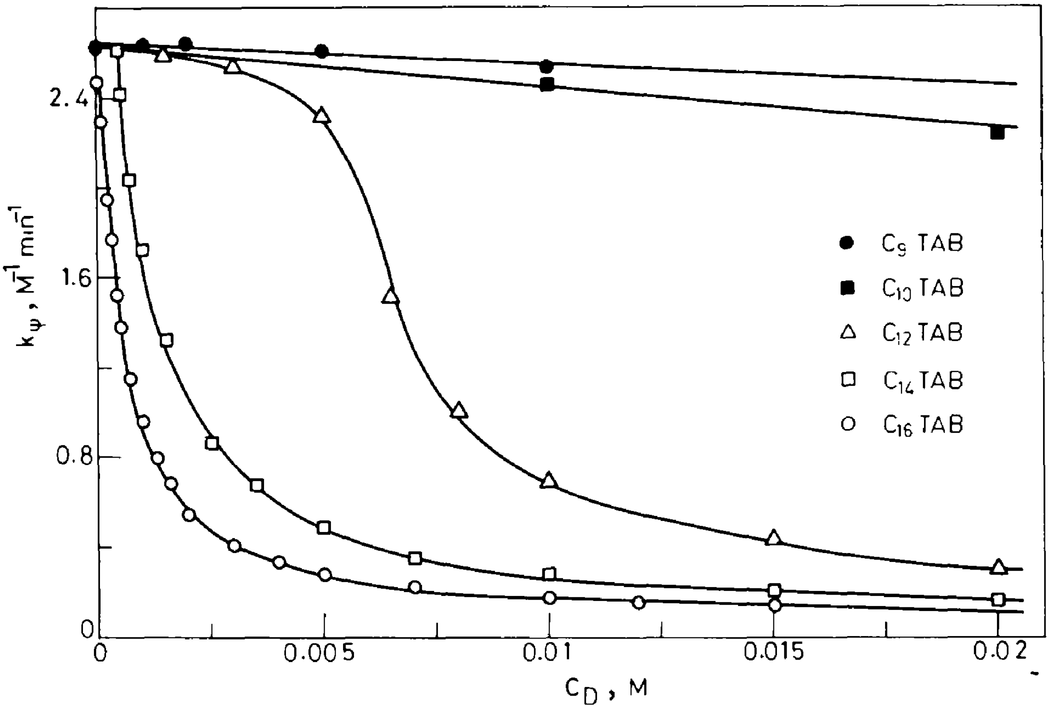


Fig. 1 Effect of n-alkyl trimethylammonium bromides on the reaction of BAI with semicarbazide at 25 C [BAI] = 4.5×10^{-5} M. (●) nonyl, (■) decyl: (△) dodecyl: (□) tetradecyl: (○) hexadecyl.

the increased surfactant hydrophobicity. Consequently, these binding constants explain the better inhibitory efficiency of a longer alkyl chain surfactant at a given concentration.

Effect of added counterions. Effect of added counterions on the reactions of BAI and ABI with semicarbazide has been studied in the presence of 5×10^{-3} M CTAB by varying the concentration of NaX (X = NO_3^-, Br^-, Cl^-, or SO_4^-) in the range 0 to 0.4 M. It is observed that as the concentration of counterion increases the CTAB inhibited rate increases i.e. the overall inhibition by CTAB decreases (Fig. 2). The effectiveness of counterions in reducing the inhibitory efficiency of micelles for both the reactions follows the order: $NO_3^- > Br^- > Cl^- > SO_4^-$. This order of anion efficiency is explicable in terms of larger affinity of low charge density anions towards cationic micelles. Effect of these counterions can be the consequence of various factors like changes in micellar structure, alteration in the concentration of micelles due to changes in cmc and increased neutralization of the micellar charge. Under the present experimental conditions, the latter factor seems to be contributing most to the observed effect by reducing the electrostatic interactions between the azine anion and cationic micelle, which is partially responsible for the inhibition of these reactions by CTAB micelles.

Effect of alcohols. In contrast to the effect of solvents on the reactions of BAI and ABI with semicarbazide in the absence of micelles, where they show negligible effect,[11] the rate of CTAB inhibited reactions increases as the concentration of alcohol increases. It may be noted from Fig. 3 that for the reaction of ABI with semicarbazide, the decrease in the inhibitory efficiency of CTAB micelles at a given alcohol concentration follows the increasing order of alcohol hydrophobicity, i.e. n-BuOH > n-PrOH > EtOH > MeOH. Similar results have been obtained for the reaction of BAI also. Apart from possible contribution from changes in the micellar structure and properties by the addition of alcohols, the observed effects appear to be largely due to the displacement of part of the substrate from the micellar phase by alcohol molecules, thereby decreasing the concentration of micelle-bound substrate. This evidently shows up as increase in overall rate of the reaction in presence of micelles.

This proposition is supported by the observation that the absorption maximum of ABI (570 nm) which is red shifted to 580 nm in presence of 0.01 M CTAB, tends to shift back to the original value in the absence of CTAB with increasing alcohol concentration. This tendency is probably indicative of the weakening interaction between the substrate and micelle in presence of alcohols. Further the reports of studies on exchange of alcohol molecules between micelles and surrounding solution by relaxation methods tend to substantiate this interpretation.[12,13] The order in which alcohols diminish the micellar effects is also in agreement with the finding that the longer chain alcohol molecule interacts more strongly with the micelles than the short chain one.[12]

Effect of temperature. Dependence of CTAB micelle inhibited rate on the temperature has been studied with a view to interpret the micellar effects in terms of activation parameters. Rate increases with increasing temperature and plots of log k_ψ against 1/T are found to be linear (Fig. 4). The energy of activation in presence

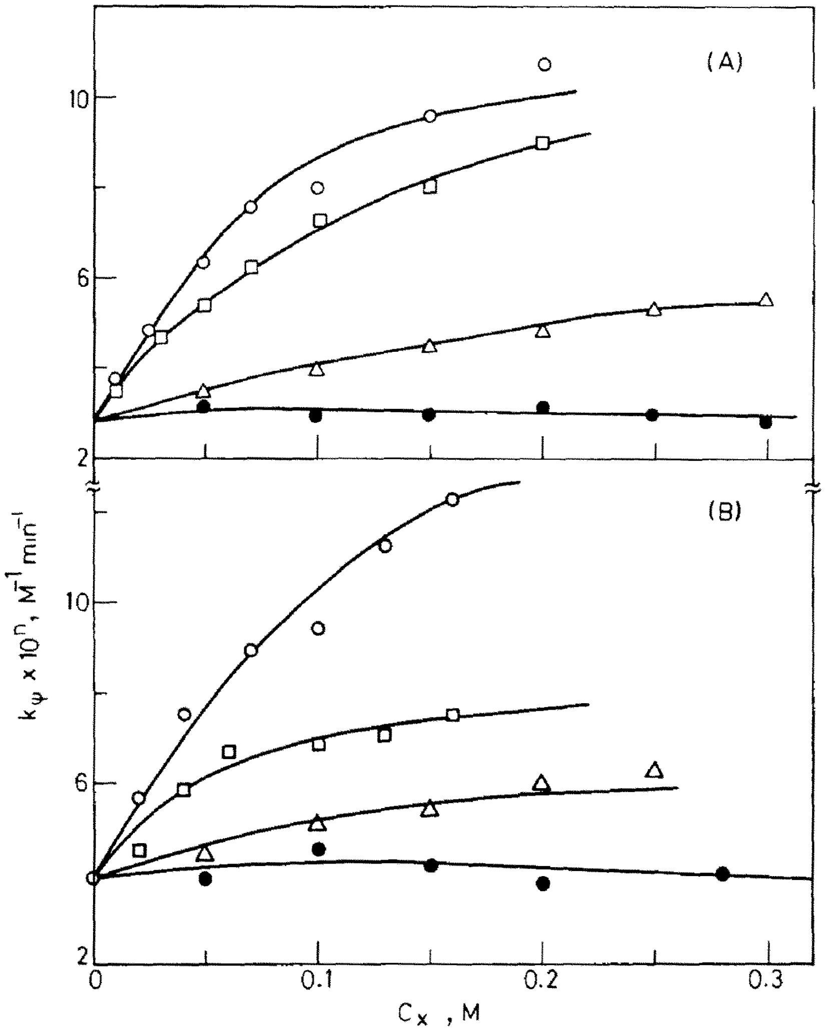


Fig. 2. Effect of added counterions on the CTAB (0.005 M) inhibited reactions of ABI (A, n = 2, [ABI] = 2.36×10^{-5} M) and BAI (B, n = 1, [BAI] = 2.7×10^{-5} M) with semicarbazide at 25°C. (○) NO_3^-; (□) Br^-; (△) Cl^-; (●) $SO_4^=$.

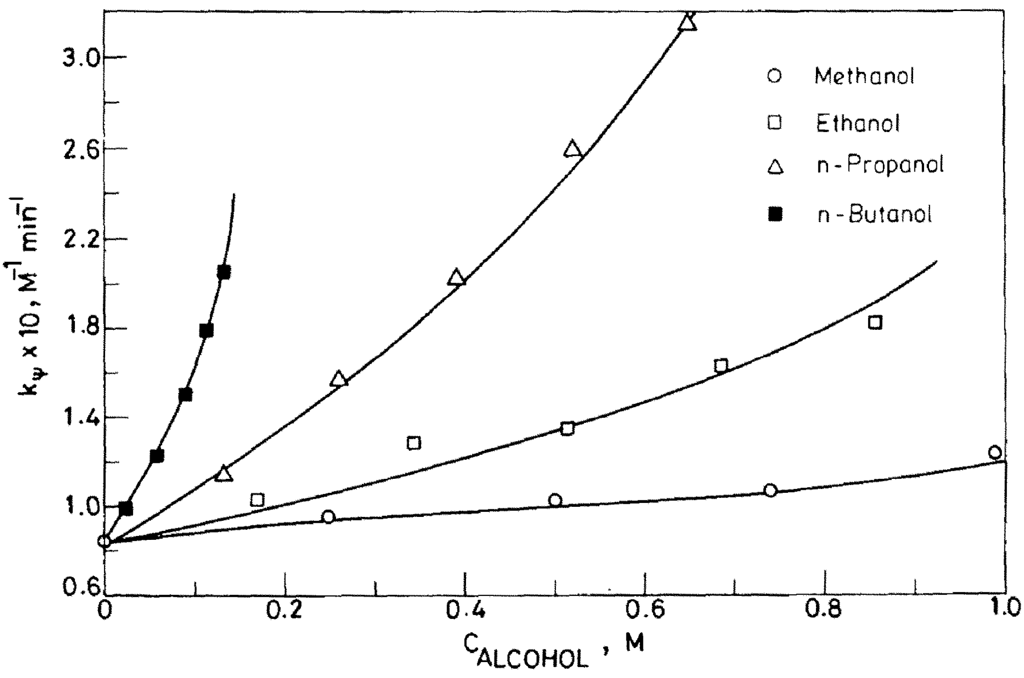


Fig. 3. Effect of alcohols on the reaction of ABI with semicarbazide in presence of 0.005 M CTAB at 25°C. [ABI] = 2.5×10^{-5} M. (○) methanol; (□) ethanol, (△) n-propanol; (■) n-butanol.

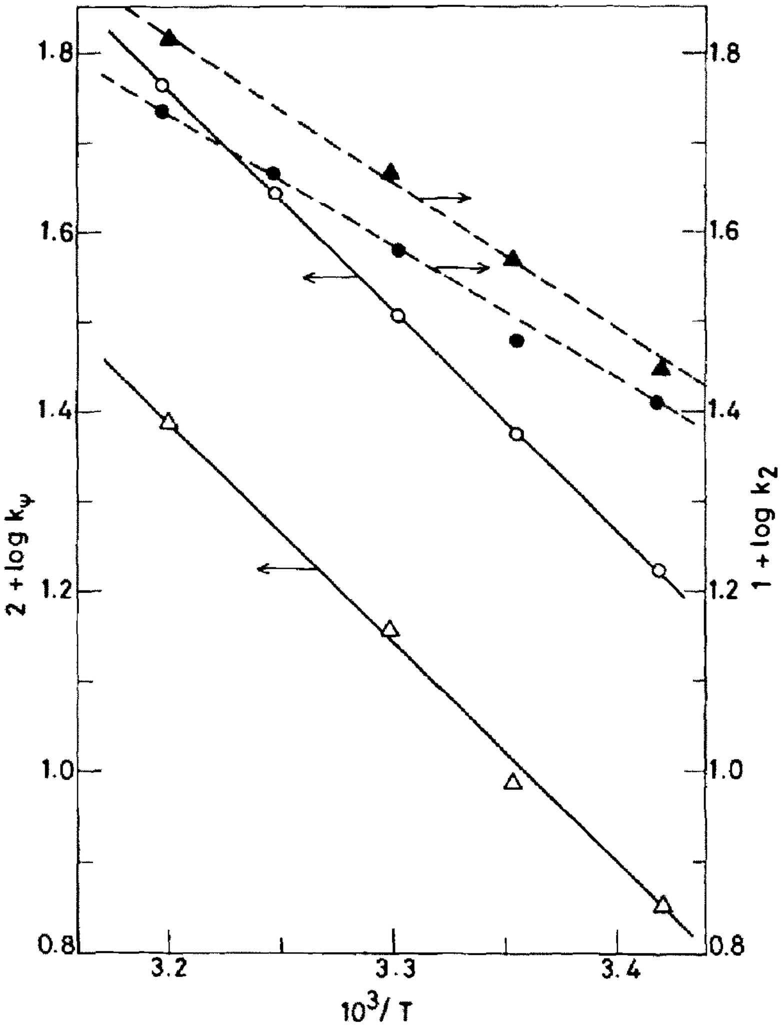


Fig. 4. Arrhenius plots for the reaction of BAI (○) and ABI (△) with semicarbazide in presence of 0.01 M and 0.005 M CTAB respectively. Dotted lines are for the corresponding reactions in the absence of CTAB. $[\mathrm{BAI}] = 4.8 \times 10^{-5}$ M; $[\mathrm{ABI}] = 2.32 \times 10^{-5}$ M.

of CTAB is found to be about 4 kcal/mole higher than that obtained in the absence of CTAB for both BAI and ABI reactions (Table 3). Other thermodynamic parameters ($\Delta G^{\neq}$, $\Delta S^{\neq}$, $\Delta H^{\neq}$) calculated in the presence and absence of CTAB are given in Table 3. The observed inhibition of BAI and ABI reactions with semicarbazide by CTAB is understandable in terms of about 4 kcal/mole increase in activation enthalpy, in spite of slightly favorable entropy of activation in presence of CTAB, as compared to the values in absence of CTAB.

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