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AOT-Based Microemulsions Accelerate the 1,3-Cycloaddition of Benzonitrile Oxide to *N*-Ethylmaleimide

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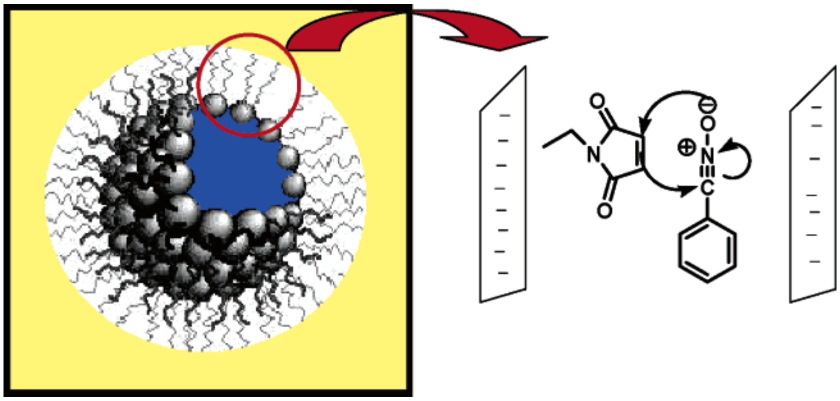

We studied the 1,3-dipolar cycloaddition of benzonitrile oxide to *N*-ethylmaleimide in AOT/isooctane/water microemulsions at 25.0 °C and found the reaction rate to be roughly 150 and 35 times greater than that in isooctane and pure water, respectively. The accelerating effect of the microemulsion is the combined result of an increase in the local concentrations of the reactants through incorporation into the interface and of the intrinsic rate of the process through electrostatic interactions with the headgroups in the surfactant.

Introduction

1,3-Dipolar cycloaddition reactions involve an unsaturated compound and a 1,3-dipole and result in the formation of a five-membered ring.[1] These reactions, which have been extensively studied both experimentally[2] and computationally,[3] share many of the characteristics of the well-known Diels−Alder reactions. One major difference between the two has to do with the effect of the reaction medium; thus, the rate constant of 1,3-dipolar cycloadditions increases or decreases with increasing polarity depending on the particular medium or is even completely independent of the medium composition in some cases.[4]

Microemulsions are thermodynamically stable dispersions of either water in oil (w/o) or oil in water (o/w). Their stability is a result of the presence of an appropriate surfactant. The solutes in microemulsions can partition between three different compartments, namely, (a) the internal aqueous core or water pool, (b) the micellar interface formed by a monolayer of surfactant molecules with their polar groups oriented toward the water pool, and (c) the external organic phase.[5] Microemulsions have grown substantially as reaction media in recent years. Among other applications, they have been used to prepare nanomaterials

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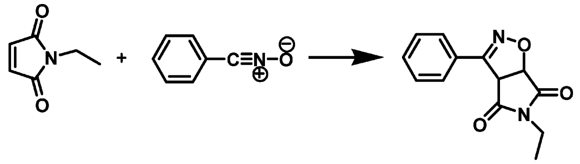
SCHEME 1



of controlled particle size adjusted via the microemulsion composition.[5] Also, because the microemulsion structure allows the accommodation of compounds of widely variable polarity, microemulsions can also be useful with a view to inducing regiospecificity in some organic reactions.[7] Finally, microemulsions have lately been used as an alternative to phase transfer catalysts.[8]

In previous work, we studied the effect of microemulsions on the Diels−Alder reaction between cyclopentadiene and *N*-ethylmaleimide and found its rate at the microemulsion interface to be smaller than that in the aqueous medium, but greater than that in isooctane. This was a result of the microemulsions exhibiting no enforced hydrophobic interactions due to the reduced water content of the interface[9] relative to the aqueous medium. In this work, we extended the previous study to the 1,3-dipolar cycloaddition of benzonitrile oxide to *N*-ethylmaleimide (Scheme 1) in AOT/isooctane/water microemulsions. The choice of this reaction, which had previously been extensively studied in water and micellar media,[10] was justified by the small dependence of its rate on the particular solvent, which distinguishes it from the Diels−Alder reaction.

Experimental Section

AOT was obtained from Aldrich and vacuum-dried in a desiccator for 2 days prior to use without further purification. *N*-Ethylmaleimide was purchased in the highest available purity from Fluka and used as received. On the other hand, benzonitrile oxide was prepared in situ by dissolving benzaldoxime (Aldrich) in a bleach/1-propanol mixture in a test tube with shaking for a few seconds.[10] The addition of sodium chloride caused the formation of two layers. A 0.5−1 μL aliquot of the organic layer was transferred to a quartz cuvette containing the reaction medium plus the other reactant (*N*-ethylmaleimide).

The rate constant, k_{obs}, for the process was determined from spectroscopic measurements made on a Varian Cary 50 UV−vis spectrophotometer. Thus, we monitored the decrease in the absorbance at 298 nm due to the disappearance of the dienophile from the reaction medium at 25.0 ± 0.1 °C. The benzonitrile oxide concentration used in all tests was markedly under-stoichiometric relative to that of *N*-ethylmaleimide.

Results

In the present study, we used widely different microemulsion compositions ranging from $W = 2$ to $W = 40$, where $W = [H_2O]/[AOT]$. This allowed us to modify not only the microdroplet size but also the physical properties of the entrapped water. Variable AOT concentrations ranging from 0.10 to 0.60 were used at each *W* value; in this way, the number of microdroplets increased with increasing surfactant concentration at constant *W*. The k_{obs} was determined for each microemulsion composition studied. To avoid errors arising from potential changes in the reactant concentrations, k_{obs} values were obtained at three different *N*-ethylmaleimide concentrations (5.60×10^{-4}, 7.00×10^{-4}, and 1.05×10^{-3} M). The observed rate constants always exhibited a linear correlation with the *N*-ethylmaleimide (*m*) concentration in the AOT-based microemulsions. The slopes of the corresponding plots were used to calculate the apparent bimolecular rate constant, k_{app}, which was a function of the microemulsion composition:

$$k_{obs} = k_{app}[m] \qquad (1)$$

Table 1 shows the k_{app} values obtained at variable surfactant concentrations and *W* values. A strong catalytic effect is apparent relative to the rate constant in pure hexane, $k_0 = 2.6 \times 10^{-3}$ M^{-1} s^{-1}. In fact, the reaction was roughly 140 times faster in the microemulsion, and the catalytic effect was virtually unaffected by its composition. Also, the reaction was about 35 times faster than that in pure water ($k_w = 8.5 \times 10^{-3}$ M^{-1} s^{-1}). The data in Table 1 can be used to examine the influence of the surfactant concentration on the apparent second-order rate constant, k_{app}, at different *W* values. As can be seen, raising the surfactant concentration in the microemulsion had virtually no effect on k_{app} (Figure 1). This is a result of the reaction taking place largely at the microemulsion interface, where it was much faster than that in an organic solvent, even at low surfactant concentrations. The slight decrease in k_{app} with an increase in [AOT] results from the increase of the interfacial volume and a decrease of the local reactant concentrations with increasing surfactant concentration.

Figure 2 shows the influence of *W* on k_{app} at a constant surfactant concentration. As can be seen, k_{app} is virtually independent of *W*.

Discussion

Interpretation of our experimental results in quantitative terms requires the determination the local reactant concentrations and the intrinsic rate constants in the different microemulsion pseudo-phases from the previously calculated apparent rate constants. Our research group has developed a kinetic model based on the pseudo-phase formalism that can be used to quantify the effects of microemulsion composition on chemical reactivity.[11] To apply the pseudo-phase formalism to the 1,3-dipolar cycloaddition of benzonitrile oxide to *N*-ethylmaleimide, we assumed that the microemulsion comprised three pseudo-phases depicted in Scheme 2, namely, an aqueous phase (*w*), a continuous medium consisting essentially of isooctane (*o*), and an interface formed mainly by the surfactant headgroups (*i*). On the basis of previous results[9,10] and on the solubility of our substrates in water and various organic solvents, we assumed *N*-ethylmaleimide to be present in the three microemulsion

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TABLE 1. Second-Order Apparent Rate Constant for the 1,3-Dipolar Cycloaddition of Benzonitrile Oxide to *N*-Ethylmaleimide in AOT/Isooctane/Water Microemulsions at 25.0 °C

	k_{app}/M^{-1} s^{-1}										
[AOT]/M	$W = 2$	$W = 5$	$W = 7$	$W = 10$	$W = 13$	$W = 17$	$W = 20$	$W = 25$	$W = 30$	$W = 35$	$W = 40$
0.103	0.3699	0.3923	0.4055	0.3701	0.5604	0.3700	0.4571	0.4401	0.3819	0.3530	0.3719
0.150	0.3652	0.3775	0.3489	0.3619	0.5429	0.4020	0.3487	0.4305	0.4137	0.4146	0.4255
0.206	0.3725	0.4148	0.4016	0.3420	0.4088	0.3690	0.3843	0.5085	0.3799	0.4182	0.4355
0.309	0.3544	0.5467	0.3220	0.3698	0.3137	0.3430	0.3704	0.4316	0.2172	0.3980	0.3766
0.411	0.3393	0.4450	0.3577	0.3214	0.4247	0.3290	0.3437	0.2440	0.2350	0.3763	0.2029
0.514	0.2837		0.4110	0.2198	0.4626	0.3020				0.1390	0.2923
0.617	0.2832	0.7025	0.3566			0.2930	0.3801			0.2470	

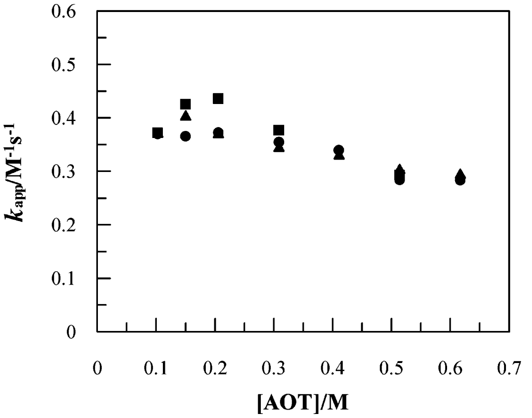


FIGURE 1. Influence of the AOT concentration on k_{app} for the 1,3-dipolar cycloaddition of benzonitrile oxide to *N*-ethylmaleimide at $T = 25.0$ °C and (●) $W = 2$, (▲) $W = 17$, and (■) $W = 40$.

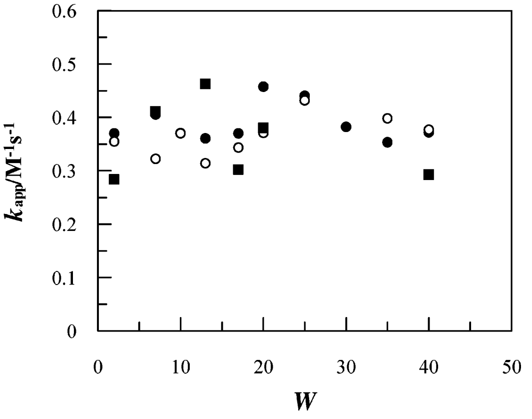


FIGURE 2. Influence of *W* on k_{app} for the 1,3-dipolar cycloaddition of benzonitrile oxide to *N*-ethylmaleimide at $T = 25.0$ °C and an [AOT] of (●) 0.103 M, (○) 0.309 M, and (■) 0.514 M.

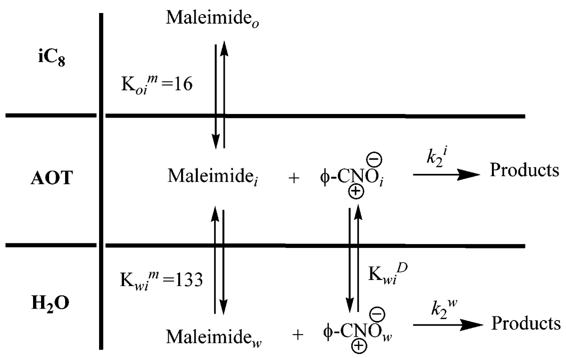
pseudo-phases and benzonitrile oxide at the interface and aqueous phase only.

The partitioning of *N*-ethylmaleimide between the microemulsion pseudo-phases can be defined in terms of its partition constant between the aqueous phase and the interface,[9] $K_{wi}^{m} = 133$, and that between the continuous medium and the interface,[9] $K_{oi}^{m} = 16$. On the other hand, benzonitrile oxide (D) will only partition between the aqueous phase and the interface, with K_{wi}^{D}. The previous partition constants are given by

$$K_{wi}^{m} = \frac{[m]_i}{[m]_w}W \quad K_{oi}^{m} = \frac{[m]_i}{[m]_o}Z \quad K_{wi}^{D} = \frac{[D]_i}{[D]_w}W \tag{2}$$

where parameter Z, by analogy with W, is the mole ratio between isooctane and AOT; Z = [isooctane]/[AOT], and $[m]_w$, $[m]_i$, and $[m]_o$ are the *N*-ethylmaleimide concentrations in the aqueous phase, interface, and continuous medium, respectively, as referred to the total microemulsion volume. The *N*-ethylmaleimide concentrations in the different microemulsion pseudophases can be estimated by assuming their total concentration to be the sum of the concentrations in the three phases.[9] Similarly, one can use the following expressions for the benzonitrile oxide concentrations at the interface and aqueous phase as referred to the total microemulsion volume:

SCHEME 2



$$[m]_w = \frac{K_{oi}^{m}W[m]_T}{K_{oi}^{m}K_{wi}^{m} + K_{wi}^{m}Z + K_{oi}^{m}W} \tag{3}$$

$$[m]_i = \frac{K_{oi}^{m}K_{wi}^{m}[m]_T}{K_{oi}^{m}K_{wi}^{m} + K_{wi}^{m}Z + K_{oi}^{m}W} \tag{4}$$

$$[m]_o = \frac{ZK_{wi}^{m}[m]_T}{K_{oi}^{m}K_{wi}^{m} + K_{wi}^{m}Z + K_{oi}^{m}W} \tag{5}$$

$$[D]_i = \frac{K_{wi}^{D}}{K_{wi}^{D} + W}[D]_T \quad [D]_w = \frac{W}{K_{wi}^{D} + W}[D]_T \tag{6}$$

On the basis of the distribution of the reactants in the microemulsion, the 1,3-dipolar cycloaddition can take place at the interface and in the aqueous phase. Therefore, the reaction rate for the process can be expressed as follows:

$$\text{rate} = k_i'[D]_i + k_w'[D]_w \tag{7}$$

where k_i' and k_w' are the pseudo-first-order rate constants at the interface and in the aqueous phase, respectively. To establish the rate law as a function of the first-order rate constants, one must use the *N*-ethylmaleimide concentration at the interface

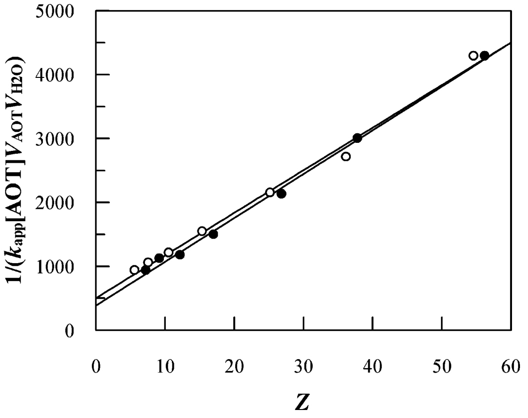


FIGURE 3. Fitting of eq 12 to the experimental results obtained in the 1,3-dipolar cycloaddition of *N*-ethylmaleimide to benzonitrile oxide in AOT/isooctane/water microemulsions at 25.0 °C; (●) $W = 2$, (○) $W = 17$.

as referred to the interface volume, $[m]_i{}^i$, and that in the aqueous phase as referred to its volume, $[m]_w{}^w$:

$$\text{rate} = k_{obs}[D]_T = k_2{}^i[m]_i{}^i[D]_i + k_2{}^w[m]_w{}^w[D]_w \qquad (8)$$

In this equation, $[m]_i{}^i$ and $[m]_w{}^w$ refer to the interface and aqueous phase volume, respectively. For easier manipulation, one must refer them to the total microemulsion volume:

$$[m]_i{}^i = \frac{1}{\bar{V}_{AOT}[AOT]}[m]_i \quad [m]_w{}^w = \frac{1}{\bar{V}_{H_2O}[H_2O]}[m]_w \qquad (9)$$

This allows the following expressions for the reaction rate to be derived:

$$\text{rate} = k_2{}^i\frac{1}{\bar{V}_{AOT}[AOT]}[m]_i\,[D]_i + k_2{}^w\frac{1}{\bar{V}_{H_2O}[H_2O]}[m]_w[D]_w \qquad (10)$$

By substituting eq 6 and the expressions for $[m]_w$ and $[m]_i$ into the rate equation, one obtains the following relation between the apparent rate constant and parameter Z:

$$k_{app} = \frac{k_2{}^i\dfrac{K_{oi}^mK_{wi}^mK_{wi}^D}{\bar{V}_{AOT}[AOT]} + k_2{}^W\dfrac{K_{oi}^mW}{\bar{V}_{H_2O}[AOT]}}{K_{oi}^mK_{wi}^m + K_{wi}^mZ + K_{oi}^mW}\,\frac{1}{(K_{wi}^D + W)} \qquad (11)$$

$$\frac{1}{k_{app}[AOT]\bar{V}_{H_2O}\bar{V}_{AOT}} = \frac{(K_{wi}^D + W)[K_{oi}^mK_{wi}^m + K_{oi}^mW]}{k_2{}^iK_{oi}^mK_{wi}^mK_{wi}^D\bar{V}_{H_2O} + k_2{}^wK_{oi}^m\bar{V}_{AOT}W} + \frac{(K_{wi}^D + W)K_{wi}^m}{k_2{}^iK_{oi}^mK_{wi}^mK_{wi}^D\bar{V}_{H_2O} + k_2{}^wK_{oi}^m\bar{V}_{AOT}W}Z \qquad (12)$$

Figure 3 is consistent with the linear correlation predicted by eq 12.

To determine the rate constant at the interface, k_i, we shall focus on the slopes of the fitting of eq 12 to the experimental results as these can be more accurately determined than the intercepts. The reciprocal slopes of Figure 3 can be expressed as

$$\frac{1}{\text{slope}} = \frac{k_2{}^iK_{oi}^m\bar{V}_{H_2O} + \dfrac{k_2{}^wK_{oi}^m\bar{V}_{AOT}}{K_{wi}^mK_{wi}^D}W}{1 + \dfrac{1}{K_{wi}^D}W} \qquad (13)$$

Figure 4 illustrates the influence of parameter W on the reciprocal slopes of Figure 3. As can be seen, they are all independent of the water content of the microemulsion.

This result can be explained in two different ways. First, the numerator and denominator on the right-hand side of eq 13 may fulfill the following inequalities: $k_2{}^iK_{oi}^m\bar{V}_{H_2O} \ll k_2{}^wK_{oi}^m\bar{V}_{AOT}/K_{wi}^mK_{wi}^DW$ and $1 \ll 1/K_{wi}^DW$. If these relations hold, then the expression can be simplified to

$$\frac{1}{\text{slope}} = \frac{k_2{}^wK_{oi}^m\bar{V}_{AOT}}{K_{wi}^m} = 0.0160 \qquad (14)$$

where the reciprocal slope is clearly independent of W, consistent with the experimental results. Equation 14 allows $k_2{}^w$ to be easily calculated since one knows $K_{oi}^m = 16$, $K_{wi}^m = 133$, and $\bar{V}_{AOT} = 0.34\ M^{-1}$. This leads to $k_2{}^w = 0.39\ M^{-1}\ s^{-1}$, which is rather disparate from the reported value in bulk water ($k_w = 8.5 \times 10^{-3}\ M^{-1}\ s^{-1}$).[10a] We can therefore rule out this possibility. The other is that the numerator and denominator on the right-hand side of eq 13 may fulfill these alternative inequalities: $k_2{}^iK_{oi}^m\bar{V}_{H_2O} \gg k_2{}^wK_{oi}^m\bar{V}_{AOT}/K_{wi}^mK_{wi}^DW$ and $1 \gg 1/K_{wi}^DW$. If so, then

$$\frac{1}{\text{slope}} = k_2{}^iK_{oi}^m\bar{V}_{H_2O} = 0.0160 \qquad (15)$$

Consistent with the experimental results, eq 15 predicts that the reciprocal slope is independent of W. If it holds, then one can determine the rate constant at the microemulsion interface ($k_2{}^i = 0.055\ M^{-1}\ s^{-1}$). The latter possibility is consistent with $K_{wi}^D \geq 400$, so the inequality must be fulfilled at any W value, including the highest ($W = 40$). The equilibrium constant for incorporation of benzonitrile oxide from the water microdroplets to the interface can be extrapolated from the results for aqueous micelles. Thus, SDS micelles have been found to fulfill the following expression: $K_s{}^D = V_mP_D = [D]_m/[D]_w[SDS]$, where P_D is the partition coefficient of D between the micelles and the aqueous medium, and V_m the surfactant molar volume. On the basis of previously reported values,[10b] $K_s{}^D = 24.5\ M^{-1}$. This value can be expressed in terms of the equilibrium constant for incorporation from the water microdroplets to the microemulsion interface, K_{wi}^D, simply by introducing the water concentration: $K_{wi}^D = K_s{}^D[H_2O] = [D]_m/[D]_w\ [H_2O]/[SDS]$. This yielded $K_{wi}^D = 1360$, which clearly obeys the inequality $1 \gg 1/K_{wi}^DW$. However, this value should be considered with caution as it was obtained on the assumption that the micelle association constants for SDS and AOT are similar. However, the extrapolated value of K_{wi}^D was large enough to rule out the first assumption, $1 \ll 1/K_{wi}^DW$, as it would require $K_{wi}^D \leq 0.2$, which is about 10^4 times lower than the value extrapolated from that for SDS micelles.

Table 2 shows the rate constants for the reaction into various solvents. As can be seen, the values are similar in all solvents except water, which reveals a slight accelerating effect. Note, however, that the rate constant at the microemulsion interface

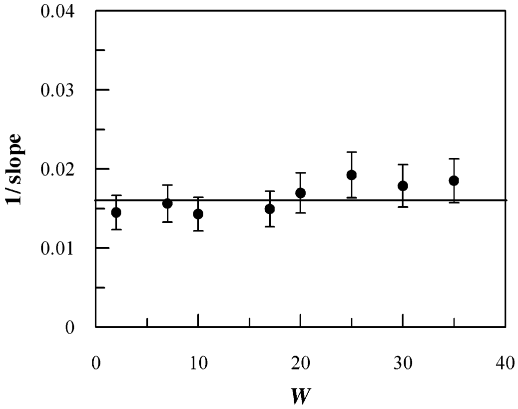


FIGURE 4. Fitting of eq 13 to the experimental results obtained in the 1,3-dipolar cycloaddition of benzonitrile oxide to *N*-ethylmaleimide in AOT/isooctane/water microemulsions at 25.0 °C.

TABLE 2. Rate Constant of the 1,3-Dipolar Cycloaddition of Benzonitrile Oxide to *N*-Ethylmaleimide at 25.0 °C

solvent	k/M^{-1} s^{-1}
hexane[a]	2.6×10^{-3}
1,4-dioxane[a]	1.7×10^{-3}
dichloromethane[a]	1.2×10^{-3}
DMSO[a]	2.7×10^{-3}
2,2,2-trifluoroethanol[a]	3.3×10^{-3}
ethanol[a]	2.3×10^{-3}
water[a]	8.5×10^{-3}
interface or AOT-based microemulsion[b]	5.5×10^{-2}

[a] From ref 10b. [b] In AOT/isooctane/water microemulsions.

is roughly 20 times higher than that in the organic solvents and approximately 5 times higher than that in water; this is rather surprising as the reaction is weakly sensitive to the polarity of the medium.

Experimental results for the 1,3-dipolar cycloaddition of benzonitrile oxide to *N*-ethylmaleimide[10a] were explained in terms of the frontier molecular orbital (FMO) theory, which has been used extensively to explain and predict reactivity in 1,3-dipolar cycloadditions.[12] This theory states that the Gibbs energy of activation is related to the energy gap between the interacting HOMO and LUMO. The energies of HOMO and LUMO can be experimentally assessed (ionization potential and electron affinity, respectively) or theoretically estimated. For a number of common reactants in 1,3-dipolar cycloadditions, Houk[13] has calculated the energy of the FMOs. For most 1,3-dipolar cycloadditions, a good correlation is observed between the Gibbs energy of activation and the ionization potential of the dipolarophile, in accordance with the FMO theory.[14] FMO theory also accounts for stereoselectivity and regioselectivity: reactions take place in the direction of maximum HOMO−LUMO overlap.[15] The relative levels of the HOMO and LUMO of both reactants determine whether the $\mathrm{HOMO_{(dipole)}}-\mathrm{LUMO_{(dipolarophile)}}$ interactions or the $\mathrm{LUMO_{(dipole)}}-\mathrm{HOMO_{(dipolarophile)}}$ interactions are dominant. Furthermore, one should take into consideration that the levels of the FMOs can be affected by (de)stabilizing factors. For example, electron-withdrawing substituents stabilize the FMOs, whereas electron-donating substituents raise the FMO energy. Similarly, complexation of Lewis acids leads to a drop in FMO energy.[16] Hydrogen bonding is another factor that can promote cycloadditions by reducing the energies of the FMOs.[17] Hydrogen-bond interactions can stabilize the FMOs of the reactants, and the magnitude depends on the susceptibility of the reactants toward such interactions. The preferred complexation of Lewis acids with nitrile oxides[18] indicates that nitrile oxides are good Lewis bases. Therefore, the FMOs of these dipoles are substantially stabilized in protic solvents. For the reaction of nitrile oxides with electron-poor dipolarophiles, the dominating interaction is that between the HOMO of the 1,3-dipole and the LUMO of the dipolarophile. The electron-poor dipolarophiles are relatively good hydrogen-bond acceptors, leading to a reduction of the levels of the FMOs in protic solvents. However, this interaction is less efficient than that between the nitrile oxide and protic solvents. This means that the Gibbs energy of activation is increased for this reaction, leading to a retardation of the cycloadditions of the nitrile oxide with electron-poor dipolarophiles in protic solvents.

Hydrogen bonding would provoke the reaction rate of benzonitrile oxide cycloaddition to *N*-ethylmaleimide to diminish on increasing the water content of the microemulsion. Previous studies in our laboratory have allowed us to obtain the values of the solvent ionizing power of the interface depending on the water content of AOT-based microemulsions.[19] The ionizing power and nucleophilicity of the interface of AOT-based microemulsions are influenced by the water content of the system. When *W* decreases so does the ionizing power because the strong interaction between the SO_3^- anionic headgroup of the surfactant and the water molecules decreases the electrophilic character of water. Nevertheless, the results obtained in the present work show that the reaction rate is *W*-independent and approximately 5 times higher than that in bulk water. Recent studies[20] on the cycloaddition of nitrones to nitriles have shown that the interaction of Lewis acids with the nitrile in the course of the reaction facilitates the cycloaddition by stabilizing transition states, intermediate, and product rather than by activating the nitrile. When the reaction takes place at the interface of AOT-based microemulsions, the possibility of interaction with Lewis acids must be discarded since the interface of the microemulsion presents an increase of the basic character in comparison with bulk water due to the interactions with the SO_3^- anionic headgroup of the surfactant and the water molecules.

To justify the behavior observed in AOT/isooctane/water microemulsions, one must consider the specific region of the

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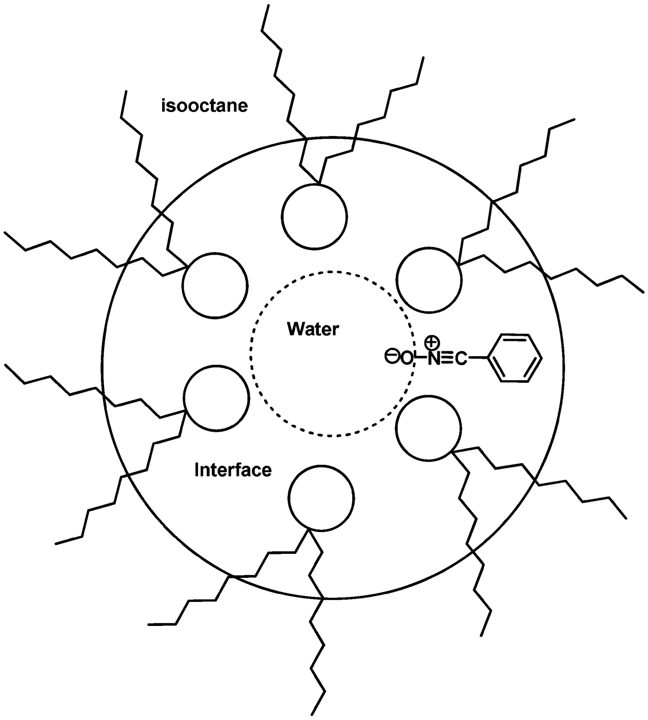
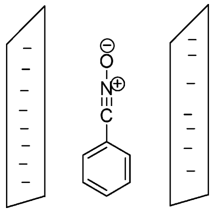
SCHEME 3



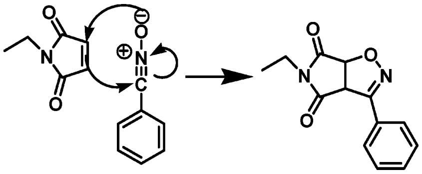
SCHEME 4



interface where the 1,3-dipolar cycloaddition takes place and also the reaction mechanism. Because of the dipolar nature of benzonitrile oxide, its 1,3-dipolar addition will take place in the innermost region of the microemulsion interface (Scheme 3), so that the oxide can be in direct contact with the polar headgroups in the surfactant and their solvating water molecules. The interface region where the reaction is to occur will possess some negative charge by virtue of the presence of the polar headgroups in the surfactant and will destabilize the negative charge of benzonitrile oxide (Scheme 4). No such instability will occur in water or an organic solvent. If the 1,3-dipolar cycloaddition took place in a positively charged environment, then the oxide will not be so markedly destabilized, and its positive charge would be efficiently stabilized by the resonance in the benzene ring.

1,3-Dipolar cycloaddition reactions proceed via a concerted mechanism (Scheme 5). If the reaction medium destabilizes the reactants, the process will be favored. In water or an organic solvent (Table 1), the stability of benzonitrile oxide is not affected; hence the absence of substantial differences in rate constant in these media. However, when the reaction takes place at the interface of an AOT/isooctane/water microemulsion, the negative charge in benzonitrile oxide is strongly destabilized by the presence of a negatively charged environment (Scheme 4); this destabilizes benzonitrile oxide, the initial state of the reaction, and favors the 1,3-dipolar addition. This is supposed to be the decisive factor accounting for the acceleration of the 1,3-dipolar addition reaction in AOT/isooctane/water microemulsions in relation to organic solvents and water.

SCHEME 5



This reaction has previously been studied in SDS and CTAB micellar media;[10b] the rate constants in both cases were lower than those obtained in pure water ($k_{SDS}/k_{water} = 0.23$ and $k_{CTAB}/k_{water} = 0.44$) as a result of the effect of the polar headgroups in the surfactant being smaller than those in the microemulsions and the micelles, therefore not influencing the stability of benzonitrile oxide. This different behavior of aqueous micelles and microemulsions has previously been observed for solvolytic reactions. Thus, the solvolysis of anisoyl chloride was found to always be faster in cationic microemulsions (TTABr/hexanol/isooctane/water), TTABr being tetradecyltrimethylammonium bromide, than in the case of anionic ones (SDS/hexanol/isooctane/water); also, the k_+/k_- ratio increased with decreasing water content in the microemulsion.[21] This effect can be ascribed to the release of the leaving group, Cl$^-$, being more favorable in the presence of cationic TTABr headgroups than in that of anionic SDS headgroups. By contrast, Bunton et al.[22] found the k_+/k_- ratio in aqueous micelles to be only 0.1. The difference between the behavior observed in w/o microemulsions and aqueous micelles may be the result of a difference in the relative ease of stabilization of the acylium ion and leaving group. In aqueous micelles, where abundant water is available, solvation of the chloride leaving group is fast and easy, so the reaction is faster with anionic surfactants than with cationic ones because the former help stabilize the acylium ion. Conversely, in w/o microemulsions, the contribution of the surfactant headgroups to solvation of the leaving group outweighs its contribution to stabilization of the acylium ion. This interpretation is consistent with the result that the k_+/k_- ratio increases with decreasing W. The decreased ability of the microemulsion to solvate the negative charge in the cycloaddition of benzonitrile oxide relative to SDS and CTAB micelles destabilizes the oxide and consequently increases its reactivity.

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