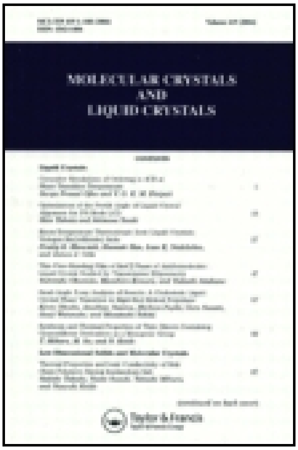

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The Role of Water in Phase Transfer Catalysis

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THE ROLE OF WATER IN PHASE TRANSFER CATALYSIS

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Abstract Water is shown to be an essential component in anion exchange process between metal salts and quaternary onium salts in organic solvents. Hydration of ion pairs in organic phases, on the other hand, reduces the nucleophilicity of anions in displacement reactions. These and other effects of water in liquid-liquid and solid-liquid phase transfer catalyzed substitution reactions are combined into the complex role of water in phase transfer catalysis. The subject is discussed in view of some specific examples.

INTRODUCTION

When phase transfer catalysis (PTC) was introduced in the late sixties as a new synthetic concept, the most popular reagent applied in these systems for various chemical transformations was a 50% aqueous sodium hydroxide solution.[1]

Similarly, aqueous solutions of cyanide, halides, carboxylates and other anions were applied in a variety of two-phase substitution reactions.[2,3] It was later observed that though water does not participate in the stochiometry of most phase transfer reactions it has a very significant effect on the rate and selectivity of these processes.[4-6]

In this article we review the unique role of water in liquid-liquid and solid-liquid phase transfer systems. We shall limit our discussion to catalysis by quaternary ammonium salts which are by far the most popular catalysts used.[3] Some of the principles presented can, however, be applied to other catalytic systems, e.g. crown ethers, polyethers or cryptands.[3] We shall also ignore reactions where non-stochiometric extraction is taking place in the course of the catalytic cycle (e.g. metal catalyzed reactions,[7] oxidation by hypochlorite[8] or hydrogen peroxide[9]).

The general stochiometry of ammonium salts catalyzed phase transfer substituion reactions can be presented as follows: (eq. 1)[2.3]

$$(1) \qquad RX + Y^- \longrightarrow RY + X^-$$

The proposed reaction mechanism proceeds according to the following three elementary steps:

(a) Formation of an anion by acid-base equilibrium in the bulk of the aqueous phase or at the interphase:

$$(2)\quad HY(org) + OH^-(aq) \rightleftharpoons Y^-(interphase) + H_2O$$

(b) Extraction of the anion from aqueous phase or from the interphase to the organic phase via an anion exchange process:

$$(3)\quad Q^+X^- (org) + Y^-(aq) \rightleftharpoons Q^+Y^-(org) + X^-(aq)$$

(c) Substitution reaction in the organic phase:

$$(4)\quad Q^+Y^- + RX \longrightarrow Q^+X^- + RY$$

For compounds where stable salts of the anion Y^- are available it is preferred to apply a salt, MY, in aqueous solution or in the solid state.

We shall distinguish between the simple mechanism which includes steps (b) and (c) and the more complex one which involves step (a) as well. We shall refer to the former as mechanism 1 and to the latter as mechanism 2. Usually, when mass transport between the phases is fast enough, the rate determining step in mechanism 1 is (4) while in mechanism 2 it is (3)[10]. In addition some rare examples are known where the extraction of the hydroxide ion itself is a step in the catalytic cycle and the anion is formed in the bulk of the organic phase.[10]

It will be shown that although water participates stochiometrically only in step (2), where the base is a hydroxide ,and does not appear at all in mechanism 1,it has a rather dramatic influence on the catalytic reaction.

We define the selectivity coefficient K^{sel} as follows:[11]

$$(5) \qquad K^{sel} = \frac{[QY]_{org}\,[X^-]_{aq}}{[QX]_{org}\,[Y^-]_{aq}}$$

This magnitude reflects the relative affinity of the quaternary cation towards the attacking nucleophile and the leaving group.

According to mechanism 1 the steady state concentration of QY can be expressed as follows:

$$(6) \qquad [QY]_{org} = \frac{K^{sel}[Q]_0\,[Y^-]_{aq}/[X^-]_{aq}}{1 + K^{sel}\,[Y^-]_{aq}/[X^-]_{aq}}$$

(where $[Q]_0$ is the total concentration of catalyst in the system) and the overall rate: (eq 7)

$$(7) \qquad -\frac{d[RX]}{dt} = \frac{k\,K^{sel}[Q]_0\,[Y^-]_{aq}/[X^-]_{aq}}{1 + K^{sel}\,[Y^-]_{aq}/[X^-]_{aq}}$$

A key issue, which will be developed later, is that only dissolved or hydrated anions participate in the process. Salts in the solid state are inert and therefore do not appear in the rate equation.

This property gives us a strong tool to control the system by increasing the ratio of the aqueous concentrations $[Y^-]/[X^-]$.

For the case of mechanism 2 the development is far more complicated. The result can be presented in a simplified way as follows: (eq 8)

$$(8) \qquad -\frac{d\,[RX]}{dt} = \frac{k\,K\,K^{sel}\,[Q]_0\,[HY]\,[B]}{[X^-]_{aq} + K\,K^{sel}\,[HY]\,[B]}$$

Since K^{sel} for organic anions (relative to chloride or bromide) is usually very high, even weak acids like amides,nitriles, ketones, thiols etc. can be alkylated in the presence of aqueous sodium hydroxide under PTC conditions.[12] Substrates with $pKa<23$ react via mechanism 2 while substrates with $23<pKa<37$ require the actual extraction of the hydroxide anion to the organic phase.[10] For the case of mechanism 1 when the concentration of QY in the organic phase is kept constant throughout the reaction the rate equation simplifies to a pseudo first order equation:(eq 9)[13]

$$(9) \qquad \text{rate} = k\,[RX]$$

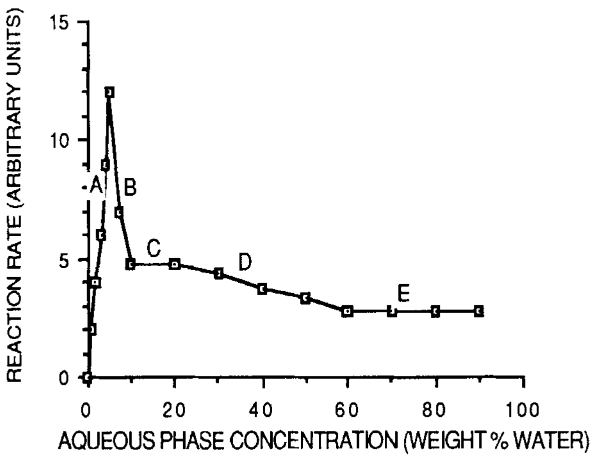
Eq 9 is also applicable to mechanism 2 provided that K is sufficiently large and that QY is again constant during the process.

In both mechanisms equation 9 is useful in *initial rate* measurements[14] where the amount of X^- is minor.

Water molecules affect each of the elements in equations 7&8 in a different way, resulting in a complex overall dependence of the rate on the concentration of water in the system. We have thoroughly studied the kinetic behaviour of reactions of type (1) with X= Cl, Br and Y= F[15], Cl, Br[16], HCO_2[17-19]and C_2H_5O[20] for R= different primary alkyl groups. These reactions in the presence of various quaternary ammonium catalysts have shown very similar behaviour with regard to the effect of water despite differences in specific rates.

A typical graph presenting the average rate of exchange reaction 1 (via mechanism 1) as function of the water content in the system is shown in figure 1.[21] The precise structure of the curve, particularly the exact location of the maximum, depends on the nature of the reactants, the catalyst,the solvent and the temperature.

FIGURE 1: EFFECT OF WATER ON PTC REACTIONS



We shall distinguish between five different regions in the diagram:

(a) Region A - (0 to 1-5% water based on the solid) Starting at zero reaction rate at complete dryness, sharp increase in rate upon gradual addition of water until a maximum is reached.

(b) Region B- (1-5 to app. 10%) Sharp decrease in rate.

(c) Region C- (app. 10% to 30-50%) Rate practically does not change upon further addition of water. Solids are still present in the system.

(d) Region D- (30-50% to 60-80%) The rate is slowly decreasing upon dilution. The system consists of two liquid phases with no solids.

(e) Region E-(60-80 to 100% water) Slow reaction rate but almost independent of change in the aqueous phase concentrations.

The three constants k,K and K^{sel}, as well as the concentrations (or rather the activities) $[X^-]_{aq}$ and $[Y^-]_{aq}$, are each strongly dependent on the amount of water present in each phase. The observed overall rate in the different regions is the result of these combined effects.

The following discussion will elaborate on the behaviour of the reacting systems in each of the above regions and will qualitatively present the changes in the magnitude of k,K, K^{sel} and the concentrations in eq. 8 and, consequently,of the overall rate as function of the water content in the reacting mixtures.

REGION A : RATE DETERMINING DISSOLUTION

It was quite early reported by Starks, and later by other authors that in the total absence of water PTC reactions with quaternary ammonium salts do not proceed at all. Despite the technical problems associated with complete drying of the various components in the system, particularly of the catalyst, we succeeded in demonstrating this phenomenon for reactions with X= Cl,Br and Y=Br[22],F[15] and HCOO.[18] Attempts to find the same effect in processes where caustic bases were applied failed, due to the difficulties in drying these reagents.

It was argued that quaternary ammonium salts cannot exchange anions directly with solid crystals and the presence of water is required to overcome the lattice energy by dissolution or hydrate formation. As expected, we were unable to exchange tetrabutylammonium bromide (TBAB) or aliquat 336® with solid potassium fluoride when water was not present.

Upon addition of trace amounts of water (as low as 100 ppm) anion exchange and the phase transfer process commenced.

When the total amount of water in the system is below 1-5% of the weight of the solid salt, the mechanism is different from the scheme described above since the rate determining step becomes the transport of ions from the solid crystal to the aqueous film. We have termed this phenomenon "Thin Layer Phase Transfer Catalysis".[19] Some interesting observations were made in this region in the reaction of 1-chlorodecane in o-dichlorobenzene with potassium formate catalyzed by aliquat 336®:

(a) Rate equation : As could be expected the rate in this region did not depend on the concentration of the catalyst nor on the concentration of the organic substrate or on the amount of the salt. It followed a clear zero order rate equation with a very low activation energy.

(b) Distribution of water: While in the absence of the catalyst the water preferred to stay with the formate salt, upon addition of the quaternary ammonium catalyst redistribution took place and up to 90% of the water was transported to the organic phase via hydration of the catalyst. This effect resulted in a very unusual phenonenon of deactivation by excess of catalyst. Addition of larger amounts of catalyst caused drying of the thin water film and totally impaired the exchange process.

(c) Effect of mixing: The mass transport process in this region could be improved by effective stirring but only up to 600 rpm. Above this speed the rate remained unchanged. Further increase in rate could only be obtained upon application of ultrasonic radiation.

(d) Decomposition of the catalyst: In reactions where highly basic anions, e.g. hydroxide or fluoride, are present, water molecules have an additional function: the protection of the quaternary cation against Hofmann degradation. In the absence of hydration water the naked hydroxide or fluoride attacks the cation paired with it, converting it to various catalytically inactive degradation products.[15] The extreme instability of quaternary ammonium fluorides and hydroxides in anhydrous conditions was demonstrated by several authors.[23]

As shown in figure 1 the reaction rate in region A increases with the addition of water. None of the elements in eq. 8 is affected by water in this region and the change in rate is attributed to the enhanced mass transport with the increasing surface area of the water film on the surface of the salt crystals.

Interestingly it was shown by Bram[21],and also by Lattes[24],that one can use a polar solvent other than water (e.g. DMF) to form the thin film on the surface of the solid and so to allow the anion exchange process to occur.

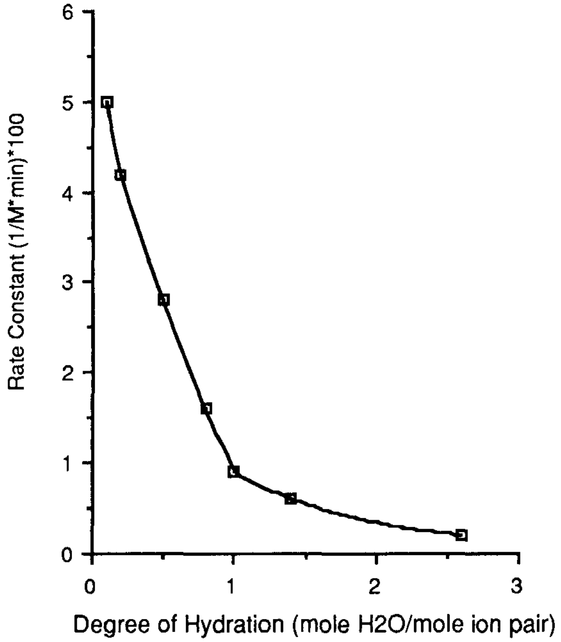
REGION B :HYDRATION

Upon addition of water to the solid-liquid system,a thin film of water is built on the surface of the solid, thus improving the mass transport of anions across the interphase. Simultaneously water is distributed to the organic phase increasing the degree of hydration of the nucleophile thus lowering its activity.[25] These contradictory effects are the reason for the maximum observed in figure 1 between regions A and B.

We have examined the rate of the second order reaction of tricaprylmethylammonium formate with 1-chlorodecane in o-dichlorobenzene at 75º as function of the ion pair hydration. The results are shown in figure 2 where the the rate constants are plotted vs. the degree of hydration.[19]

The dependence shown in figure 2,similar to observations made by other authors,clearly suggests that the nucleophilicity of the ion pair in the organic phase, and consequently the magnitude of k, sharply decreases with the level of hydration until saturation is attained. When the organic phase is saturated with hydration water, k is at its lower level and is invariant with further addition of water.

FIGURE 2 :NUCLEOPHILICITY OF FORMATE ION PAIR AS FUNCTION OF HYDRATION LEVEL



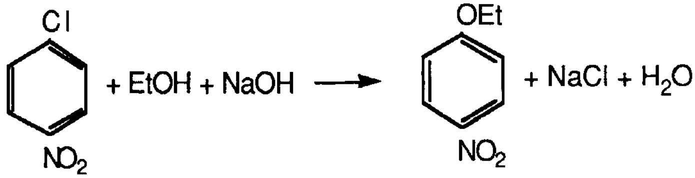
It was demonstrated by Landini and his coauthors that upon dehydration of the organic phase (e.g. upon addition of concentrated caustic solution) one can approach the reactivity of a "naked anion" in the gas phase.[26] The relative nucleophilicity of some typical anions was also found to depend on the level of hydration of the ion pairs.

The same authors reported the dramatic increase in the *basicity* of extracted hydroxide anion upon dehydration.[26] This enhanced basicity is of great interest for synthetic applications[10].

REGION C : PRECIPITATION OF A SOLID SALT

When more than one solid salt is present in the system, the small amount of water will distribute preferentially to the more *hydrophilic* salt thus allowing selective extraction of this anion. Since hydrophilic anions usually suffer from very low selectivity coefficients relative to lypophilic anions,which is the cause of the poisoning phenomenon described later, application of minute quantities of water will assist in overcoming this limitation of phase transfer catalysis.[17] We have applied this principle for substitution reactions of formate, fluoride and ethoxide. Thus, for example, in reaction 9[20], in order to achive 97% conversion at 78º using 5 mole% TBAB catalyst,one has to use 15 moles of 20% w/w sodium hydroxide solution or 4 moles of 50% solution or only 1.7 moles of solid sodium hydroxide.

(9)

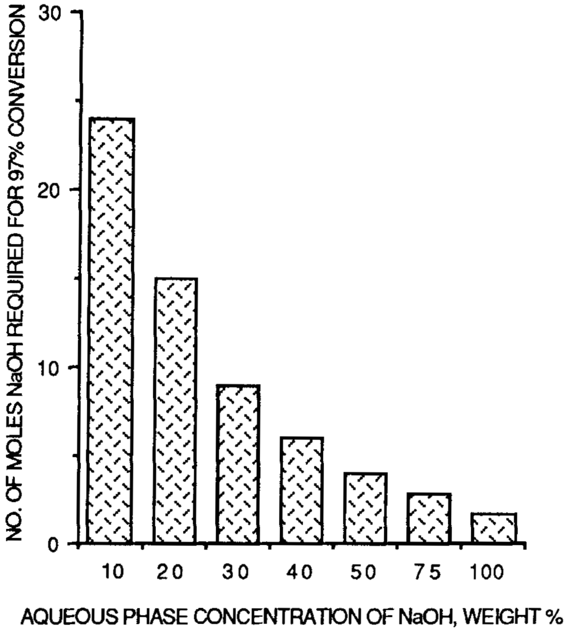


Results of these experiments are shown in figure 3.

For most salts it is the metal cation that contributes more to the total free energy of hydration which determines the affinity of the salt to water and ,consequently, its solubility and extractability by the quaternary ammonium salt residing in a separate phase. The best source of information for that matter is the ternary phase diagram MX-MY-H_2O for mechanism 1 and MOH-MX-H_2O for mechanism 2.

From careful examination of the ternary phase diagram NaOH-NaCl-H_2O, the results presented in figure 3 were expected.

FIGURE 3: EFFECT OF NaOH CONCENTRATION ON CONVERSION IN REACTION 9



If the complete phase diagram is not available, one can use as a rule of thumb, the solubility ratio of the two salts at the reaction temperature or, at least, at any other temperature.

We have studied the exchange process (10) at 25º using aliquat 336® in chlorobenzene as anion exchanger:[15]

(10) $QCl + KF \longrightarrow QF + KCl$

It was determined that if the system is totally dry no, exchange takes place at all. Only a minor exchange is found, on the other hand, if sufficient water is present to completely dissolve both salts throughout the reaction. Best conversion (up to 28%)and exchange rate are obtained when the potassium fluoride contained approximately 1% of water. Under these conditions the potassium fluoride is hydrated more effectively than the potassium chloride and can be extracted. Interestingly when potassium fluoride was replaced by sodium fluoride no exchange was measured at all in the presence of a small amount of water. After verifying that the reverse reaction ($QF+NaCl \longrightarrow QCl+NaF$) does not take place at all we concluded that the observed phenomenon can be attributed[27] to the enormous difference in the solubility ratio between KF/KCl (2.7 at 25º) and NaF/NaCl (0.12 at 25º). In the case of the sodium salts, the fluoride is rejected from the aqueous film, and so deactivated for extraction, upon the formation of trace amounts of chloride.

A similiar phenomenon was observed when we reacted various formate salts with 1-chlorodecane in presence of aliquat 336® and

1% water .Both the rate and the maximum conversion corresponded to the solubility ratio of $MHCO_2/MCl$ and resulted in decreasing activity in the order K>Na>Li>Ca[17].

We have applied the same principle to select the best metal bromide salt for the bromination of alkyl chlorides via halogen exchange. Here the activity decreased in the order Li> Ca > Na>K.[16]

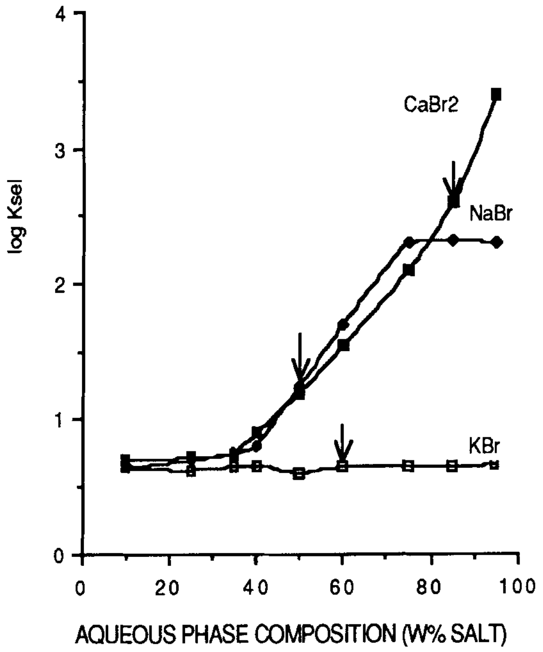
In another example, one which apparently proceeds according to mechanism 2, we have alkylated 2-pyrrolydone by benzyl chloride in presence of carbonate salts and a phase transfer catalyst.[28]While for potassium carbonate the rate dependence on the amount of water behaved according to the general characteristics of figure 1 with the maximum at 10% of water, sodium carbonate functioned in an entirely different manner. No reaction was observed at all with solid and slurried sodium carbonate. Only with saturated aqueous solutions of sodium carbonate a slow alkylation process took place. The inactivity of sodium carbonate in the region of low water content is the result of the solubility ratio $Na_2CO_3/NaCl$ (0.8 at 25º) vs. K_2CO_3/KCl (3.0 at 25º).

To summarize, the overall rate in region C is constant because the added water is consumed for the hydration of MY alone while MX remains anhydrous and therefore non extractable and the organic phase is already saturated with water.The two liquid phases are invariant in this region and so are the constants and concentrations in eq. 7 resulting in a constant rate.

REGION D : COMPLETE SOLUBILITY IN THE AQUEOUS PHASE

In region D the system consists of two liquid phases: an aqueous phase containing the salt or the base and an organic phase with the substrate in bulk or in a solvent. In this region the ion pairs in the organic phase are completely hydrated, resulting in a relatively smaller rate constant,k. Upon further addition water does not distribute to the saturated organic phase but rather accumulates with the brine. k therefore remains constant through this region. The slow decrease in the overall rate in this region is a result of changes in levels of hydration of the ions in the aqueous phase and consequently of K^{sel}. It was pointed out by Starks that if one of the anions (X^- and Y^-) is more strongly hydrated than the other then, on dilution, the anion which is more strongly hydrated is expected to become less extractable to the organic phase and K^{sel} will change in magnitude.[2] We have proposed the equilibrium position of the *reversible* exchange reaction of bromide salts with 1-chloroctane at 97º as a basis for calculation of K^{sel} for the couples KCl/KBr, NaCl/NaBr and $CaCl_2/CaBr_2$.[22] The results are given in figure 4 . The arrows mark the initial composition at which a solid phase is formed in the reaction mixture *during* the exchange processes with each of the salts. In the curve showing the behaviour of sodium bromide/sodium chloride we can clearly observe four different zones as follows:(1)10-40% salt-K^{sel} is constant (2)40-50% -increase in K^{sel} until a solid phase appears in the system. (3)50-75%-further increase in K^{sel}.(4)75-100%-no change in K^{sel}. The behaviour of the other two couples is different. For calcium there are three zones while for potassium K^{sel} is practically constant for any aqueous phase composition. One can clearly conclude that the selectivity "constant", when based on concentrations,is variable as a function of the aqueous phase composition, the nature of the metal cation and (in view of other experiments) the temperature.The specific behaviour of each of these systems was analyzed in view of the ternary phase diagram MCl-MBr-H_2O.

FIGURE 4: Ksel AS FUNCTION OF AQUEOUS PHASE COMPOSITION



Of particular interest to region D is the fact that K^{sel} is changing with composition even in zones where no solids are present and the aqueous phase is completely homogeneous. This suggests that in this region the hydration level of the two anions in the aqueous phase is changing upon further addition of water.Since the ratio $[Y^-]_{aq}/[X^-]_{aq}$ in this region is constant at different compositions,we concluded that the variation in the ratio of the activity coefficients of the two anions is responsible for the change in K^{sel} and consequently in the overall rate of reactions of type 1.

REGION E: COMPLETE SOLUBILITY WITH "FREE WATER"

In this region there is a sufficient amount of water not only for complete homogenity of the aqueous phase but also for total saturation of the hydration shell of the ions. K^{sel} is therefore constant in this region. However the magnitude of the selectivity coefficient significantly affects the system behaviour when the reaction is in progress. If K^{sel} is small, the leaving group X^- does not compete with Y^- for the catalyst, and the reaction proceeds according to the simplified rate equation (4) . On the other hand if K^{sel} is large, i.e. the catalyst has higher affinity for the leaving group X^- than for nucleophile Y^-, we observe the phenomenon of catalyst poisoning.[3]This phenomenon is very common in attempts to substitute alkyl iodides with nucleophiles like cyanide or acetate.[3]These reactions come to a total stop after a certain conversion is obtained. We have, for example, observed that the etherification process (9)[20] done at 78º in the presence of TBAB catalyst with one equivalent of 50% w/w aqueous solution of sodium hydroxide came to a total stop after a conversion of 48%. Higher conversion could be obtained only by applying a molar excess of sodium hydroxide solution as described above.

The complicated kinetic behaviour of the system (mechanism 1 only) under these conditions is described by the differential rate equation (7). It becomes extremely complicated upon integration.[2]

Another retarding effect taking place in this region is hydrolysis.The reversible step, 2,where the anion is formed is highly sensitive to the presence of water. Even in examples where the anion is introduced as a salt of a weak acid, traces of the free acid are always present. We have reported[29] that even very weak acids are extracted by the quaternary ammonium catalyst via hydrogen bond forming complexes of the type $QY(HX)_n$.[3] It was observed that Y^- is a much weaker nucleophile in this type of adduct then in the non solvated ion pair. Esterification reactions with formate or acetate salts or etherification with phenolate salts proceed very slowly due to hydrolysis and extraction of acid. This can be solved either by working in the absence of water or by addition of a hydroxide bases which neutralize the free acid released by hydrolysis.

In addition the basicity of dissolved hydroxide bases was found to be inferior to that of the solids. Thus certain substrates were deprotonated by solid sodium hydroxide (step 2) but were totally inactive in presence of saturated aqueous caustic solutions.[10] The isomerization of allyl benzene[30] and the alkylation of phenylacetonitrile[31] under PTC conditions were found to be extremely sensitive to the presence of water and the reaction rate depended on NaOH concentration to the 5th power (!).

Another important role of water in this region is the variation of selectivity as function of aqueous phase concentration. We have , for example, reported that the ratio of O/C alkylation of deoxybenzoin by dimethylsulfate increased with higher concentrations of sodium hydroxide. The difference in selectivity was attributed to the decrease in hydration of the ion pair as a function of the amount of water in the system.[32]

A problem associated with the solubility of the catalyst in the aqueous phase is also important in this region. Water soluble quaternary salts tend to distribute to the aqueous phase when the salting out effect is not strong enough. This is easily solved in reactions where highly lipophilic catalysts are required but,since in some instances small and accessible quaternary salts are more active[33], one should be cautious with the amount of water present.

SUMMARY

We conclude that water has a strong influence on the rate and selectivity of phase transfer catalyzed substitution reactions. In this article we analyzed the effects of water molecules on each of the steps in the phase transfer process demonstrated for some specific reactions. We believe that our conclusions can serve as a general guideline for the application of phase transfer catalysis in synthesis.

REFERENCES

[1] M. Makosza and B. serafinowa, Rocz. Chem. 39,1223 (1965).

[2] C. M. Starks and C. L. Liotta, Phase Transfer Catalysis:Principles and Techniques, Academic Press NY (1978).

[3] E.V. Dehmlow and S.S. Dehmlow: Phase Transfer Catalysis, 2nd Ed. Verlag Chemie, Weinheim (1983).

[4] G.Bram, A.Loupy and J.Sansoulet, Isr. J. Chem. ,26, 291(1985).

[5] H.A. Yee, H.J. Palmer and S.H. Chen, Chem. Eng. Prog. ,83, 33 (1987).

[6] H.J. Jou, B. Delfort, P. Hassanaly, R. Gallo and J. Kister,Bull. Soc. Chem. Belg., 89, 421 (1980).

[7] H. Alper, ACS Symp. Ser.(Phase Transfer Catalysis), 326, 8 (1987).

[8] S. Abramovici, R. Neumann and Y. Sasson, J. Mol. Catal., 29, 291 (1985).

[9] E.V. Dehmlow and M. Slopianka, Chem. Ber., 112, 2768 (1979).

[10] M. Rabinovitz, Y. Cohen and M. Halpern, Angew. Chem. Int. Ed. 25, 960 (1986).

[11] J.E. Gordon and R.E. Kutina, J. Am. Chem. Soc. 99,3903 (1977).

[12] A. Brandstrom, J. Mol. Catal., 20, 93 (1983).

[13] C.M. Starks J. Am. Chem. Soc. ,93, 195 (1971).

[14] R. Bar, J. de la Zerda and Y. Sasson, J.Chem. Soc. Perkin Trans. 2,1881 (1984).

[15] S. Dermeik and Y. Sasson, J. Org. Chem., 50, 879 (1985).

[16] Y. Sasson, M. Weiss, A. Loupy, G. Bram and C. Pardo, J. Chem. Soc. Chem. Comm. ,1250 (1986).

[17] Y. Sasson and H.A. Zahalka, J. Chem. Soc. Chem. Comm.,1347 (1983).

[18] H.A. Zahalka and Y. Sasson, J. Chem. Soc. Chem. Comm.,1652 (1984).

[19] O. Arrad and Y.Sasson, J. Am. Chem. Soc., in press.

[20] Y. Sasson and S. Zbeida, U.S. Patent, 4,479,015 (1984).

[21] See graphs of similar nature in: M. Delmas, Y. Le Bigot and A. Gaset, Tetrahedron Lett.,21,4831 (1981). G. Bram, A. Loupy and M. Pedoussaut, Tetrahedron Lett.,27,4171 (1986). R. Kelleman, R.F.Williams, G.Dimotsis, D.J. Gebri and J.C. Williams, ACS Symp. Ser.(Phase Transfer Catalysis), 326, 128 (1987) see also: M. Tanaka and M. Koyanagy, Synthesis, 973 (1981).

[22] M. Weiss and Y. Sasson Isr. J. Chem., 26, 243 (1985).

[23] D. Landini, A. Maia and Rampoldi, J. Org. Chem., 51, 3187 (1986).

[24] B.Escoula, I. Rico and A. Lattes, Tetrahedron Lett.,27,1499 (1986).
[25] D. Landini, A. Maia, F. Montanary and F. Pirisi, J. Chem. Soc.Perkin Trans. 2, 46 (1980).
[26] D. Landini, A. Maia and G. Podda, J. Org. Chem., 47, 2264 (1982). D. Landini, A. Maia and F. Montanary, Isr. J. Chem. ,26,263 (1985), D. Landini, A. Maia and Rampoldi, J. Org.Chem., 51, 5475 (1986).
[27] S. Dermeik and Y. Sasson,to be published.
[28] O. Arrad, Y.Sasson and N. Billman, to be published.
[29] H.A. Zahalka and Y. Sasson, J. Chem. Soc. Chem. Comm., 1581 (1984).
[30] M. Halpern, Y. Sasson and M. Rabinovitz, J. Org. Chem., 48, 1022 (198
[31] R. Solaro, S. D'Antone and E.Chiellini, J. Org. Chem., 45, 4179 (1980).
[32] M. Halpern, Y. Sasson, I. Willner and M. Rabinovitz,Tetrahedron Lett., 22,1719 (1981).
[33] M. Halpern, Y. Sasson and M. Rabinovitz, Tetrahedron, 38, 3183 (1982).