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PHASE TRANSFER CATALYSIS IN STRONGLY ALKALINE MEDIA : NOTES ON THE EXTRACTABILITY OF HYDROXYL IONS AND ON THE STABILITY OF CATALYSTS.

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Mechanism of phase transfer catalysis by quaternary ammonium salts in two-phase substitutions and oxidations is well established by now $^{1-6)}$. Similar catalysis for the many types of reactions performed in the presence of concentrated alkali metal hydroxides is less well understood: occurence of deprotonation in the organic phase, in a micellar or inverted micellar environment or at the interphase have been suggested. Lately evidence has been collected on alkylations$^{3,7)}$and on dihalocarbene generations$^{9)}$ that stresses the importance of the phase boundary.

We report here some findings which are fundamental to all mechanistic considerations:on the order of magnitude of extraction constants of ammonium hydroxides, on the relative extractability of hydroxide vs. other anions (e.g. halide),and on the location of the ammonium compounds in the two phases. Furthermore, the stability of the ammonium salts and their degradation is commented on.

There is some confusion in the literature as to the extent to which ammonium hydroxides can be extracted into relatively nonpolar solvents on several counts: (i) many water miscible solvents simulate too high titration values in the organic phase by bringing OH^- or the conjugated base of the solvent into the nonaqueous layer, even if only small amounts of this solvent (e.g.methanol) are left over from the preparation of the ammonium hydroxide.(ii) Impurities in the starting salt (e.g. $NR_3H^+X^-$) and (iii) decomposition of "pure" aqueous solutions of quaternary ammonium hydroxides give rise to amines again simulating too high titration values after stirring with organic solvent. (iv) Limits of solubility in either phase may be reached with many ammonium salts.(v) Equilibration of an organic $NR_4^+ X^-$ solution with concentrated NaOH will result in a complex system.

Extraction constants E_{QX} for systems $Q^+_{aq} + X^-_{aq} \rightleftarrows QX_{org}$ are defined by $E_{QX} = \frac{[QX]_{org}}{[Q^+]_{aq} \cdot [X^-]_{aq}}$. In a relative good approximation log E_{QX} values for symmetrical quaternary ammonium salts rise by 0.54 per added C-atom in the cation independent of anion and solvent, and many constants are known for inorganic and organic tetrabutylammonium salts[2,6,8].

We find that freshly prepared aqueous $NBu_4^+ OH^-$ can be extracted into CH_2Cl_2 to some extent. The titer of the solution decreases quickly, however, due to reaction with the solvent. Furthermore, an appreciable, but again decreasing amount of hydroxide is extracted into methylene chloride when this is stirred with $NBu_4^+ HSO_4^-$ / concentrated NaOH. In a similar experiment with $NBu_4^+ Cl^-$ only traces of alkalinity go into the organic layer. This is in conformity with the known extractabilities of the anions $SO_4^{2-} < OH^- < Cl^-$. We have taken advantage of these effects in investigating the phase transfer catalysed hydrolysis of CH_2Cl_2 as a model system. Table 1 shows that $NBu_4^+ HSO_4^-$ is a much better catalyst than $NBu_4^+ Cl^-$ up to the point where an equimolar amount of chloride has been liberated and pairs with the cation. We conclude then that with $NBu_4^+ HSO_4^-$ phase transfer catalysis can actually involve $NR_4^+ OH^-$ ion pairs in media like methylene chloride or chloroform, at least as long as more lipophilic anions are absent.

Table 1: Liberation of chloride by hydrolysis of 10 ml CH_2Cl_2 with 5 g NaOH in 5 ml H_2O at room temperature in the presence of 1 mmole catalyst.

Catalyst	time(min.)	mmole Cl^- liberated	Catalyst	time(min.)	mmole Cl^- liberated
none	10	0.00	NBu_4HSO_4	10	0.67
"	1000	0.01	"	15	0.89
NBu_4Cl	10	0.00	"	20	0.94
"	30	0.05	"	30	0.96
"	60	0.10	"	60	1.01
"	240	0.26	"	240	1.31

Extraction constants into an inert, even less polar solvent like benzene are a thousandfold smaller than those for methylene chloride[6]. Thus, the amount of

$N(n\text{-}C_5H_{11})_4^+OH^-$ or $N(n\text{-}C_6H_{11})_4^+ OH^-$ extracted from water into benzene is so small that E_{QOH} cannot be calculated with any precision. Increasing the size of the cation, we equilibrated aqueous 0.1 M tetra-n-heptylammonium hydroxide with an equal volume of benzene, obtaining $E_{NHep_4OH} = 1.2$ (benzene/water). The corresponding E_{NHep_4Cl} (benzene/water) again could not be determined exactly because the solubility of the salt in water is very low. It was possible, however, to establish $E_{NHex_4Cl} = 102$ (benzene/water). Using the rule mentioned ($\Delta \log E_{QX}$ 0.54 per C-atom) one extrapolates $E_{NHep_4Cl} \approx 14700$ (benzene/water). This means that the extraction constant of hydroxide is about 10^4 times smaller than that of chloride, a result that should be valid in a first approximation again for all water-unmixable solvents.

In actual phase transfer catalysis experiments the difference in extraction constants is partially offset by the use of a vast molar excess of sodium hydroxide in the aqueous phase relative to the small amount of chloride brought in with the catalyst. For instance, equilibrating 0.1 M $NHex_4^+ Cl^-$ in benzene with an equal volume of 50 % NaOH, one finds 99+ % of the ammonium ion in the organic phase, and 28 % of it is present as hydroxide. The same 28% OH-form is observed with $NHep_4^+ Cl^-$ under the same conditions, so this ratio seems to be the limiting value for very lipophilic cations. Working similarly with 0.014 M $NBu_4^+ Cl^-$ in benzene, just 52 % of the ammonium ion remains in the organic phase after stirring with NaOH; and with this more hydrophilic cation only 4,2 % of the catalyst in the organic layer is in the OH-form.

A word of caution about mechanistic speculations seems appropiate here, because a prerequisite for all considerations is a knowledge of distribution pattern plus solubility of the catalyst in both media. It should be noted for instance that E_{NBu_4Cl} (benzene/water) is very low ($\ll 0.1$), and it is only the "salting out" effect of the concentrated caustic soda that makes possible the use of this catalyst (or TEBA) with NaOH/benzene. On the other hand, the well known micelle forming cetyltrimethylammonium bromide is extremely sparingly soluble in benzene. Changing to CH_2Cl_2 (0.1 M solution) this same compound is retained to 98 or 82 % in the organic phase after stirring with an equal volume of concentrated sodium hydroxide or water, respectively.

These results indicate that hydroxyl ion can play a role in nonpolar media provided the catalyst cation is lipophilic enough. It must be remembered though that in the course of many phase transfer catalysed reactions anions more lipophilic than OH^- are formed and tend to tie up the catalyst more and more. Then reactions at the interphase undoubtedly become more important (cf.[3,7]).

Stability of the catalysts.

With strong alkali quaternary ammonium salts are subject to Hofmann degradation and the following processes: $R_3\overset{+}{N}\text{-}R' + OH^- \rightarrow R_3N + R'OH$ and $R_3\overset{+}{N}\text{-}R' + \overset{-}{O}R' \rightarrow R_3N + R'\text{-}O\text{-}R'$ (R'= benzyl, CH_3). We find that the catalysts normally applied are stable over days at room temperature in the presence of concentrated NaOH. Elevated temperature leads to decomposition: NBu_4^+ gave 52 and 92 % tributylamine after 7 hours at 60° or 100°C. A phosphonium salt ($C_{16}H_{33}PBu_3^+\ Br^-$) was unchanged after 16 hours at 100°. - Decomposition of TEBA ($PhCH_2NEt_3^+\ Cl^-$) gave a high yield of $PhCH_2NEt_2$; benzyltrimethylammonium chloride, however, yielded equal amounts of dibenzylether and $PhCH_2NMe_2$. Degradation products of $C_{16}H_{33}\overset{+}{N}Me_2CH_2Ph\ Br^-$ were: $C_{16}H_{33}NMe_2$, $C_{14}H_{29}CH{=}CH_2$, $PhCH_2OCH_2Ph$, and $PhCH_2NMe_2$.

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