

CATALYSIS IN APROTIC SOLVENTS.
EFFECT OF THE POLARITY OF THE CATALYST.

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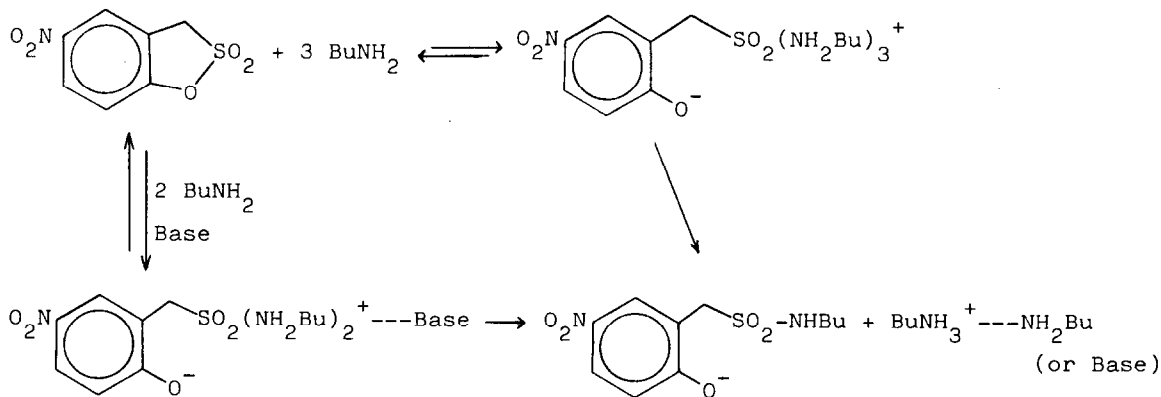
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Summary: The catalytic constants for the n-butylaminolysis of sultones in aprotic-apolar solvents are linearly correlated with a combination of the hydrogen-bonding parameter and the polarity parameter of the catalyst.

Aminolyses of carboxylic esters in aprotic solvents have been studied by Watson,¹ Menger,² and Taft.³ The reactions are catalyzed by general bases. The third order catalytic constants (first order with respect to each ester, amine, and catalyst) do not follow the Brønsted catalysis law. In the case of the n-butylaminolysis of p-nitrophenyl acetate in chlorobenzene,¹ the third-order catalytic constants are closely correlated with the hydrogen-bonding parameter, pK_{HB} ,⁴ while in other cases, e.g. the n-butylaminolysis of p-nitrophenyl trifluoroacetate in chlorobenzene or 1,2-dichloroethane,³ a satisfactory correlation was found with a combination of the hydrogen-bonding parameter and water basicity as shown in eq. 1.

$$\log k = a pK_{HB} + b pK_A + c \quad (1)$$

The n-butylaminolysis of 2-hydroxy-5-nitro- α -toluenesulphonic acid sultone in toluene is also catalyzed by general bases. The uncatalyzed reaction is fourth order overall (first order in substrate and third order in nucleophile). This and other kinetic features suggest the formation of an intermediate with three molecules of amine linked by hydrogen bonds (Scheme).⁵



SCHEME

In the catalyzed reaction, one of the three molecules of *n*-butylamine can be efficiently substituted by a general base generating a term in the kinetic expression which is first order in substrate, second order in *n*-butylamine and first order in catalyst. A plot of the logarithm of the catalytic constants versus the hydrogen-bonding parameter of the catalyst yields a poor correlation (Figure, left). Inclusion of water basicity in the correlation worsens the plot. On the other hand a good correlation can be found (Figure; right) with a combination of the hydrogen-bonding parameter, pK_{HB} ,⁴ and the polarity parameter, π^* ,⁶ according to eq. 2.

$$\log k_B = a pK_{HB} + p \pi^* + c \quad (2)$$

Least square treatment of the data yields $a = 0.9$, $p = 1.38$, and $c = -3.17$ with an excellent correlation coefficient, $r = 0.99$.

The correlation is so good that it can hardly be considered fortuitous. Thus, the transition state for the aminolysis of sulfonamides in toluene is stabilized not only via hydrogen-bond formation with the catalyst but also by its polarity. This is in contrast with the aminolysis of esters where the data can be accounted for by the hydrogen-bonding parameter and by the water basicity of the catalyst, the latter being a measure of proton transfer energetics.⁷

A dependence of the rate of reaction on π^* was found so far only in bulk solvents.⁸ The linear dependence of the catalytic constants with π^* indicates that this parameter can be used also to correlate rates in dilute conditions in apolar solvents. A similar observation was made by Kamlet and Taft for pK_{HB} and β parameters for hydrogen-bond formation, which were determined in dilute and pure base respectively and are linearly correlated.⁹

The effect of the polarity on the aminolysis of sultones in toluene is in accord with the suggested mechanism.⁵ It is in fact quite reasonable that a charged protic intermediate (or transition state) can be stabilized by a general base not only via hydrogen-bonding but also by its polarity and polarizability.

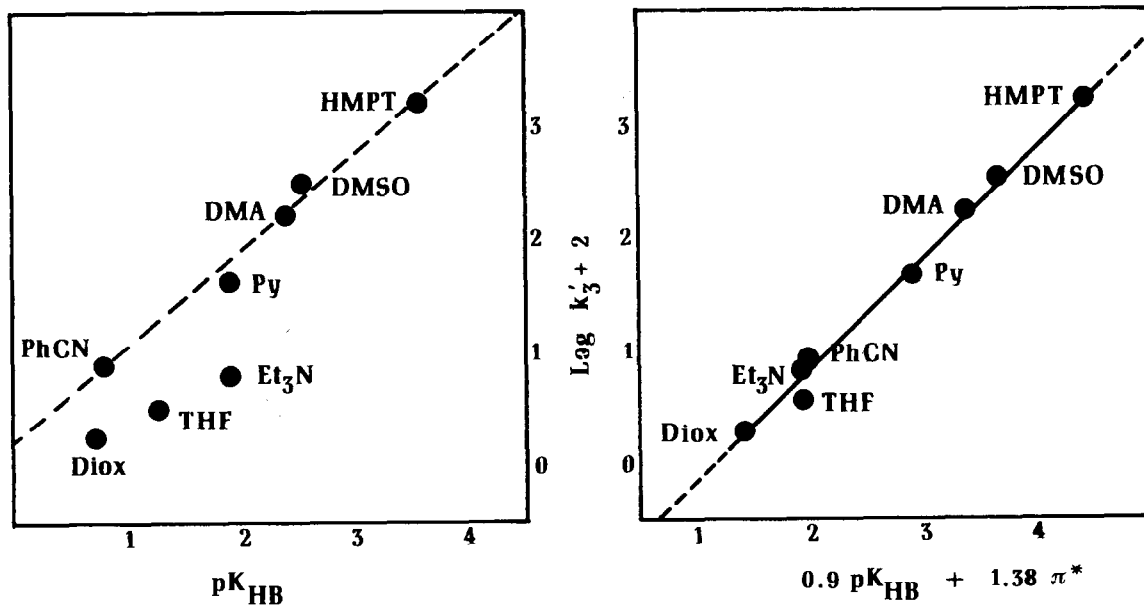
It will be interesting to find why the π^* parameter is not important in the aminolyses of esters where the catalytic constants are well correlated by eq. 1 which includes only parameters relative to either hydrogen-bond formation or proton transfer. In fact also for the aminolyses of esters the role of the catalyzing base is that of stabilizing a charged, protic intermediate even though the characteristics of the intermediate and of the product forming step are quite different.

The catalytic constant of n-butylamine is omitted from the plot since its polarity parameter is not known. We can on the other hand use the correlation (eq. 2) to calculate the π^* value for n-butylamine in the hypothesis that hydrogen-bond formation and polarity (and polarizability) are the only factors of importance in the catalysis. The calculated π^* value of n-butylamine is 0.0167; slightly lower than that of triethylamine (0.140) and close to that of

Base	$k_B/\text{sec}^{-1}\text{M}^{-3}$	$\log k_B$	ρK_{HB}^4	$\pi^{*,6,8}$
HMPT ^a	16.4	1.21	3.56	0.871
DMSO ^b	3.28	0.52	2.52	1.000
DMA ^c	1.74	0.24	2.38	0.882
Pyridine	0.447	-0.35	1.88	0.867
PhCN ^d	0.08	-1.10	0.79	0.904
THF ^e	0.035	-1.46	1.26	0.576
Et ₃ N	0.068	-1.17	1.91	0.140
Dioxane	0.019	-1.72	0.71	0.553
BuNH ₂	0.056	-1.25	2.11	(0.0167) ^f

^a Hexamethylphosphoramide; ^b Dimethylsulphoxide; ^c N,N-Dimethylacetamide;
^d Benzonitrile; ^e Tetrahydrofurane; ^f Calculated.

cyclohexane (0.000). The low rate value on the other hand can be due to the fact that *n*-butylamine is not only a hydrogen-bond acceptor but also a hydrogen-bond donor.



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