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ON THE BREAKDOWN OF RATE-EQUILIBRIUM RELATIONSHIPS

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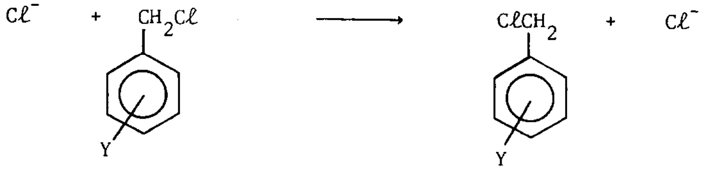
Summary. Rate-equilibrium relationships are shown to be valid for only those reactions in which charge is generated or destroyed at a site adjacent to the position of substitution.

Rate-equilibrium relationships constitute one of the basic concepts of physical organic chemistry.[1,2] This relationship, expressed in eq. 1, suggests that for a given reaction family perturbations on equilibria will only be partially reflected in reaction rates, i.e., α will

$$\Delta(\Delta G^{\ddagger}) = \alpha\Delta(\Delta G^{\circ}) \qquad (1)$$

take on values in the range 0 to 1.

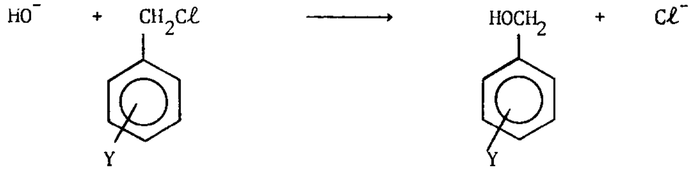
In this paper we wish to point out that there are many reaction families that do not obey a rate-equilibrium relationship. An example of such a reaction family for which there is no correlation between rates and equilibria is presented in eq. 2. For this family of identity



(2)

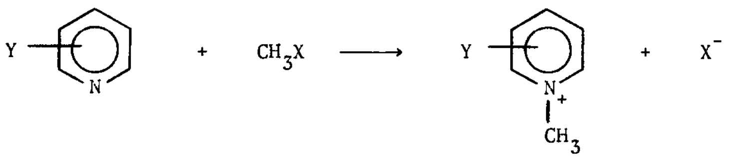
exchange reactions, a change in the substituent, Y, will have no effect on the reaction equilibrium: for this entire family $K = 1$. However a change in Y will modify the reaction rate. Clearly for this restricted family of reactions therefore, there is no rate-equilibrium relationship. A plot of log k against log K, of course, does provide a straight line — however the slope of that line ($\alpha = \infty$) leaves the usual mechanistic interpretations of α rather deficient.[3]

The question now arises as to why there is no true rate-equilibrium relationship for the reaction family of eq. 2 and what is the general rule that enables rate-equilibrium relationships to be observed in other reaction families. The rule may be stated as follows: reaction families in which the substituent is adjacent to a site at which charge is neither generated nor destroyed in the products will not exhibit a rate-equilibrium relationship. Conversely, reaction families in which charge is generated or destroyed in the products are likely to obey a rate-equilibrium relationship. Thus in the reaction family of eq. 2 the aryl group containing the substituent is adjacent to a benzylic carbon which bears no formal charge in both reactants and products. Since no charge change has taken place, no rate-equilibrium relationship is anticipated. On the basis of this principle it becomes apparent that the breakdown of the rate-equilibrium relationship occurs not just for identity reactions (for which, by definition, the change in charge, at all points in the molecules, is zero). Non-identity reactions, e.g. eq. 3, are also likely to show no correlation between rates and equilibria.



(3)

Let us now examine a typical reaction for which a rate-equilibrium relationship is observed (eq. 4)[6]. In this example the substituent is adjacent to a site (the nucleophilic N) in which



(4)

the formal charge changes from zero (in the free pyridine) to +1 (in the pyridinium ion) in accord with the rule expressed above. Proton[7] and electron[8,9] transfer reactions, which often obey rate-equilibrium relationships, fall into this same category.

In conclusion we note that correlations between reaction rates and equilibria, even for a limited reaction family, are far from general, and are only likely to arise for reactions described by the above mentioned rule. This, by necessity, will also contribute to breakdown in the reactivity-selectivity principle,[10,11] which derives its theoretical basis from the rate-equilibrium relationship (eq. 2).[10]

The question as to the mechanistic significance of the Bronsted α parameter for cases where a rate-equilibrium relationship *is* observed is a complex one. However anomalous α values[4] (especially the α value of infinity obtained for the reaction of eq. 2), suggest that deductions concerning TS structure based on α values are fraught with uncertainty. This uncertainty has been recognized previously[12-15] and attributed *inter alia* to the multistep character of certain reactions[12] and unusual solvation effects.[13] Similar conclusions have been reached regarding electron transfer reactions[9b] where it has been suggested that α values signify neither a measure of TS structure nor of charge development.

Our own work on the S_N2 reaction of methyl derivatives[16,17] based on the valence-bond configuration mixing (VBCM) model,[18] has suggested that even for one-step processes, in which no unusual solvent effect takes place, that α values may not provide a direct measure of TS structure or charge development.[16,17] Under the circumstances therefore we believe that this application of α (and β) values be undertaken with caution until a clearer understanding of the mechanistic implications of the Bronsted parameter is obtained. Work in this direction is currently under way.

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(3) In fact we confidently claim this anomalous α value to be the largest reported to date and substantially larger than previously reported values of ca. 1.5 - 1.8.[4,5]

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