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AN ESTIMATION OF THE NUCLEOPHILICITIES AND THE NUCLEOFUGICITIES OF ANIONIC NUCLEOPHILES STUDIED IN THE REVERSIBLE FINKELSTEIN REACTIONS OF BENZYL DERIVATIVES IN ACETONITRILE —— DISSOCIATIVE CHARACTER OF THE REACTION AS STUDIED BY THE NUCLEOFUGICITY APPROACH —— 1)

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Nucleophilic and nucleofugic reactivities of the variety of anions were studied in reversible Finkelstein reactions of benzyl derivatives. A leaving anion plays a major role in determining the reaction rate while an attacking anion shows only a limited role.

In an effort to examine the rate controlling factors of the S_N2 reaction, the present authors undertook the kinetic studies of the Finkelstein reactions of benzyl derivatives and the anionic nucleophile as quaternary ammonium salts.

Second order rate coefficients and equilibrium constants were determined in acetonitrile for the (reversible) reactions between benzyl chloride-^{36}Cl and the variety of nucleophiles and for their reverse processes, the reaction between benzyl derivatives and the $^{36}Cl^-$ ion:

$$PhCH_2{}^*Cl \ + \ R_4N^+X^- \xrightleftharpoons[k_b,\ K']{k_f,\ K} PhCH_2X \ + \ R_4N^{+*}Cl^-$$

K ; Equilibrium constant ($K' = K^{-1}$).
$k_{f,b}$; Second order rate coefficient for a forward (k_f) and a reverse (k_b) reaction.

The equilibrium constant determined by direct measurement of radioactivities and that from the kinetic treatment ($K = k_f/k_b$) were in fair agreement to verify the microscopic reversibility for these reactions (at least for entries 3--7).2)

Results in the Table show that, for the chlorine leaving group, the anions examined give the relative nucleophilicity difference as little as 80. Especially the halide ion and thiocyanate ion show quite a close nucleophilic reactivity.

Similar results are reported.3) However, the present results suffer little from the attenuating factors that make the results complex and often ambiguous. The scarce solubility of the attacking or the leaving anion, and the deactivation of the nucleophile due to the protic hydrogen bonding (sometimes [anion] << [protic impurity]3)) are the examples of such factors. Perhaps, the present work is the first that brings the contribution of the reverse process into accounts.

The reverse reactions disclose that, for the attacking nucleophile Cl^-, the different leaving groups give rise to a wide spread in reactivity extending 1 to 10^5 (or more). As the reactions cited are essentially reversible and there is little attenuation on the nucleophilic species in solution, k_b's obtained may serve as (a part of) the scale of the nucleofugicity in the S_N2 reactions.

Table. Kinetic and Thermodynamic Reactivities toward Benzyl Derivatives[a)]

Entry No.	R_4NX	$k_f/M^{-1}\cdot min^{-1}$	x_e [b)]	$K[=(\frac{x_e}{1-x_e})^2]$	$k_b/M^{-1}\cdot min^{-1}$
1	Et_4NN_3	0.798	>0.999	$>10^6$	$<10^{-6}$ c)
2	Et_4NCN	0.585	>0.997 c)	$>10^5$ d)	$<5x10^{-6}$ e)
3	Et_4NF	0.050 f)	$\simeq 0.9$ c)	$\simeq 10^2$	$\simeq 5x10^{-4}$ c)
4	Et_4NSCN	0.0101 g)	0.677	4.39	0.00323
5	Et_4NCl	0.0391	0.5	1	0.0391
6	Et_4NBr	0.0355	0.0609	0.00421	6.94
7	$n\text{-}Bu_4NI$	0.0363	0.0307	0.00100	35.5

a) At 30.00 ± 0.02 °C. b) Final mole fraction when the initial concentrations are [BzCl] = $[X^-]$. Generally $[X^-]$ = 0.1M. c) Calculated. d) K from the kinetic treatment. e) Reversibility was proved by liberation of $PhCH_2{}^*Cl$. f) Calculated from other temperature. cf. ref. 4). g) No BzNCS was found in 50hr. cf. ref. 7).

A linear free energy relationship between K' and k_b holds, although in a limited range (among entries 3--7; $\log k_b = 0.995 \log K' - 1.51$, $r = 0.995$). In other words, when the attacking nucleophile is specified, the driving force of the reaction turns out to be the difference in stabilities between the initial and the final state.

Very large K's estimated for CN^- and N_3^- imply that the S_N2 reactions with these nucleophiles are fairly exothermic (more reactant like transition state), and still k_f's seem to suggest a transition state not so much different from that for the other nucleophilies. The present authors reported a very hard nucleophile F^- was not effective enough to substantiate the tight transition state.[4)]

Present results suggest that the dissociation of the leaving group plays a major role in controlling the rate of the Finkelstein type S_N2 reactions. This implication of dissociative nature is also in accord with the loose transition state of these reactions assigned by the study of secondary α-deuterium isotope effect.[5)] Thus a simple nucleofugicity approach can be applied to the study of any S_N2 reactions provided a reference reaction is in hand. Such an approach was recently applied to the rate determining addition in the S_NAr reactions.[6)]

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References and Note

1) S_N2 Reactions in Dipolar Aprotic Solvents. IX. Address correspondence to Department of Chemistry, College of Liberal Arts and Science, Kyoto University.
2) The intervention of the substrate-nucleophile complex gave little effect on the equilibrium constant K, ascertaining the valid treatment in the frame-work of "association mechanism". cf. ref. 5).
3) a) A. J. Parker, Chem. Rev., 69, 1 (1969). b) C. L. Liotta, E. E. Grisdale, and H. P. Hopkins, Jr., Tetrahedron Lett., 4205 (1975).
4) J. Hayami, N. Tanaka, and N. Hihara, Bull. Inst. Chem. Res. Kyoto Univ., 50, 354 (1972).
5) J. Hayami, N. Hihara, N. Tanaka, and A. Kaji, Bull. Chem. Soc. Jpn., 52, 831 (1979).
6) G. Bartoli and P. E. Todesco, Acc. Chem. Res., 10, 125 (1977).
7) A. Fava, A. Iliceto, A. Ceccon, and P. Koch, J. Am. Chem. Soc. 87, 1045 (1965).

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