The Relation between Reactivity and Selectivity

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Brown and his coworkers have pointed out the existence of the linear relation between the logarithm of the para partial rate factor of toluene, $\log p_f$, which they called a measure of activity of reagent and the selectivity factor which is expressed as the logarithm of ratio of para vs. meta partial rate factor, $\log(p_f/m_f)$[1]. As they have mentioned, the relation can be derived from the Hammett equation and is expressed as

$$\log p_f = \frac{\sigma_p}{\sigma_p - \sigma_m} \log(p_f/m_f) \qquad (1)$$

However, the term of $\log p_f$ is not the reactivity, but the distribution of a given reagent between benzene and toluene, or intermolecular selectivity and it is not surprising that the intermolecular selectivity is proportional to the intramolecular selectivity, $\log(p_f/m_f)$.

The reactivity of a reagent should be expressed as a value related to the rate constant for the reaction between a standard substance and the reagent at a standard condition or k_0. The value of k_0, however, depends on the reaction mechanism, the concentration of the actual attacking species, the environment and conditions. Hence it is difficult to compare the value of k_0 at a standared condition. Nevertheless, as shown in Table I, A-1 and A-2 the qualitative parallelism is sometimes observed between k_0 and the absolute value of ρ or the sensitivity of the rate to the change of substituent in closely related reactions[1e].

If frequency factors are constant, the relative

TABLE I

(A) COMPARISON OF DIFFERENT ATTACKING REAGENTS

A-1) Aromatic alkylation

Reaction	Solvent	$-\rho$	$\log k_0$ l. mol^{-1} sec^{-1}	Ref.
ArH+MeBr, $AlCl_3$	1,2,4-$Cl_3C_6H_3$	3.64	−2.444	6
ArH+MeBr, $GaBr_3$	ArH	3.06	−1.301	7
ArH+EtBr, $GaBr_3$	ArH	2.66	−0.799	7
ArH+*i*-PrBr, $GaBr_3$	ArH	2.54	+2.505	7

A-2) Electrophilic halogenation at 25°C (X; H or CH_3)

Reaction	$-\rho$	$\log k_0$, l. mol^{-1} sec^{-1}	Ref.
C_6H_5X+HClO	7.77	−3.380	8
C_6H_5X+HBrO	6.05	−0.234	9

A-3) Electrophilic addition[10]

Reaction	Products: 1-Halo-compound	Products: 2-Halo-compound
CH_2=CH−CH_3+HClO	$ClCH_2CHOHCH_3$ (90%)	$CH_2OHCHClCH_3$ (10%)
CH_2=CH−CH_3+HCl	None	$CH_3CHClCH_3$
CH_2=CH−CH_2Cl+HClO	$ClCH_2CHOHCH_2Cl$ (30%)	$CH_2OHCHClCH_2Cl$ (70%)
CH_2=CH−CH_2Cl+HCl	None	$CH_3CHClCH_2Cl$

(B) COMPARISON OF DIFFERENT SUBSTRATES

Second-order rate constants of chlorination[11], l. mol^{-1} min^{-1}

R	*p*-Me	H	*m*-NO_2
1. R−C_6H_4CH=CHCOPh	800	61	0.23
2. R−C_6H_4CH=CH−CO_2H	103	4.9	0.011
k_1/k_2	7.76	12.4	20.9

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b) H. C. Brown and W. H. Bonner, ibid., **76**, 605 (1954).
c) H. C. Brown and C. W. McGary, Jr., ibid., **77**, 2300 (1955).
d) H. C. Brown and C. R. Smoot, ibid., **78**, 6255 (1956).
e) L. M. Stock and H. C. Brown, ibid., **81**, 3233 (1959), **82**, 1942 (1960).

rate constant of substituted and unsubstituted reactants is expressed as

$$\ln(k/k_0) = -\frac{\Delta H^{\neq} - \Delta H_0^{\neq}}{RT} = \sigma\rho \qquad (2)$$

Hence it is rational that the absolute value of ρ with constant σ decreases with an increase of temperature[2] which accompanies an increase of the rate constant in the same reaction series. Furthermore, it is supposed from Eq. 2 that the absolute value of $\Delta H^{\neq} - \Delta H_0^{\neq}$ approaches zero, when both $\Delta H^{\neq}$ and $\Delta H_0^{\neq}$ approach zero or k_0 becomes very large. Therefore, the ρ value with constant σ tends to decrease with an increase of k_0 under this limitation. Thus the very fast reaction such as protonation have a constant value of rate constants (3×10^{10} l. mol^{-1} sec^{-1} at 18∼30°C) or the ρ value of zero[3].

The selectivity may be expressed with either intramolecular selectivity, i. e., orientation, or intermolecular selectivity, i. e., relative rate. Since the former selectivity is proportional to the latter in aromatic compounds[4,5], as shown in Eq. 1, the reactivity-selectivity relation can be tested with any of these selectivities.

Table I shows A) comparison of different attacking reagents and B) comparison of some groups of substrates with different reactivities.

Summary

The proportionality between $\log p_f$ and $\log (p_f/m_f)$ reported by Brown[1] seems to express the proportionality between inter- and intramolecular selectivities. The standard rate constant k_0 may be a measure for the reagent activity; the parallelism between $1/k_0$ and $|\rho|$ or selectivity is observed in very limited reactions.

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4) L. M. Stock and H. C. Brown, *J. Am. Chem. Soc.*, 81, 2320 (1959).
5) The same is true with aliphatic compounds in which polar effect alone is important.

6) H. Jungk, C. R. Smoot and H. C. Brown, *J. Am. Chem. Soc.*, 78, 2185 (1956).
7) H. C. Brown and H. Jungk, ibid., 77, 5584 (1955).
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