

CONCERNING THE OPTIMUM SCALING OF THE INDUCTIVE SUBSTITUENT
CONSTANTS IN SUBSTITUTED BENZENE REACTIVITIES.
ASPECTS FROM THE ANALYSIS OF QUINUCLIDINE BASICITIES

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abstract: Grob's basicity data sets of 4-substituted quinuclidines are successfully correlated with the LArSR Eq. 1, the correlation parameters of which indicate that the inductive substituent constants involved in σ_p^o just correspond to $0.74\sigma_I$.

The problem whether or not the inductive substituent constants (σ_I) derived from saturated systems can be applied with the identical scale to the apparent substituent constants such as σ_p or σ_p^o from aromatic unsaturated systems is one of the most fundamental subjects in the separation analysis of substituent effects.¹⁾ The so-called scaling problem for σ_I is just the question of the magnitude of γ in the expression of $\sigma_p^o = \gamma\sigma_I + \sigma_R^o$.²⁾ Essential importance of the subject is evident, because this magnitude is directly associated with the basis for definition of resonance substituent constants, as seen, for example, in Taft's DSP treatment:³⁾ $\bar{\sigma}_R = \bar{\sigma}_p - \sigma_I$.

In the separation analysis by Taft and his continuing development, $\gamma=1.00$ has been assumed at least as far as benzene reactivities are concerned, and its validity has been discussed.¹⁾ Exner suggested that the σ_I constant is out of scale with σ_p in the ionization of benzoic acids by a factor of 1.14 or 1.21.⁴⁾ We have proposed γ to be 0.74, as the basis for the inductive substituent constants in the LSFE treatment.⁵⁾ Thus, there exists still contention in the scaling problem.

Recently, Grob et al. reported the ionization constants of an extensive set of 4-substituted quinuclidinium perchlorates in water.⁶⁾ In this paper, critical tests of the scaling problem for σ_I are made by using the quinuclidine basicity sets and the important finding is stated that the inductive substituent constants involved in σ_p^o as well as in any ordinary sets of para substituent constants should be evaluated to be $0.74\sigma_I$ as an optimum scale.

4-Substituted[2.2.2]bicyclooctanecarboxylic acids have generally been accepted as the best model of the sigma skeleton of benzoic acids, though the number of substituents available is rather limited. In the same sense, 4-substituted quinuclidines are regarded as the best model of pyridines, and the current basicity sets are satisfactory to allow critical assessment of the following statistical treatment.

The substituent effects on the quinuclidine basicity which is essentially free from the resonance effect of substituents may be correlated linearly with σ_I constants but this relationship only implies a linearity between two saturated inductive reactivity sets. The present analysis is based on the application of the ordinary LArSR Eq. 1⁷⁾ to the saturated reactivities.

$$P - P_0 = \rho (\sigma^O + r^+ \Delta \sigma_R^+ + r^- \Delta \sigma_R^-) \quad (1)$$

Particularly noteworthy is that any saturated inductive scales are not involved in this treatment; all the substituent constants employed are those derived from aromatic reactivities. The basicity sets of quinuclidines are successfully correlated with the Eq. 1 in terms of a negative r^+ value of -0.43 for pi-donor substituents and $r^- = -0.83$ for pi-acceptors (Table 1). The resulted LArSR relationship is illustrated in Fig. 1 in which the resonance contribution is interpolated in a negative direction. The resonance effect is adequately eliminated from σ^O constant, and the remaining component is correlated in excellent precision linearly with the saturated reactivity data. The quantities $(\sigma^O - 0.43 \Delta \sigma_R^+)$ for pi-donors and $(\sigma^O - 0.83 \Delta \sigma_R^-)$ for pi-acceptors correspond to the inductive component involved in σ_p^O . The result implies the creation of the inductive scale applicable to saturated systems only from aromatic reactivity parameters.

Further, the same basicity sets are correlated also with the modified LArSR treatment based on σ_p instead of σ_p^O in Eq. 1. This treatment affords a relationship of the same ρ (=6.7) as that in the σ_p^O standard treatment only with a considerably large negative r^+ value of -0.7. Thus, the same inductive scale can be reproduced by appropriately eliminating the resonance component involved in the σ_p in terms of $r^\pm \Delta \sigma_R^\pm$.

The basicities of substituted pyridines and pyridine N-oxides were shown to be described precisely by means of the same LArSR treatment.^{5b, 7b)} In reference to the quinuclidine basicity as a standard of aromatic inductive effect, the substituent effects on the pyridines are characterized by the involvement of resonance effects to the extent of an r^+ of 0.6 for pi-donors and r^- of 0.3 for pi-acceptors. The pyridine N-oxide set provides a higher r^+ of 1.0 and r^- of 1.0 relative to the pyridine set, reflecting the specific functionality of the N-oxide unit; i.e., corresponding to the phenol functionality in the benzene system.

The most important fact is that the ρ value of 6.2 for the pyridine set^{5b)} which can be defined explicitly from the m -correlation is essentially equal to the ρ value for the quinuclidine set. The equality of the ρ value in the saturated and the corresponding unsaturated systems is consistent with a so-called field transmission of the inductive effects. Thus, we can summarize the substituent effects on the quinuclidines by using the common ρ value between the quinuclidines and pyridines.

$$(\Delta pK_a)_{Qu} = 6.5 (\sigma^O - 0.43\Delta\bar{\sigma}_R^+ - 0.83\Delta\bar{\sigma}_R^-) = 6.5 \sigma_i$$

Here, the σ_i is the inductive substituent constant newly defined from aromatic reactivities. The same data set can be treated with σ_I in the Taft scale from saturated reactivities as given by;⁸⁾ $(\Delta pK_a)_{Qu} = 4.6\sigma_I$.

A special note should be taken of the fact that the ρ_I value is significantly lower than the ρ_m value for structurally equivalent pyridine system. Namely, there is significant gap in the Taft inductive scale between saturated and aromatic reactivities. Our σ_i scale may be referred to the Taft scale by $\sigma_i = 0.74\sigma_I$; i.e., $\gamma = 0.74$. The present result provides a clear solution of the scaling problem on the basis of quinuclidine basicities. The optimum γ scale of the inductive substituent constants involved in σ_p^O from aromatic reactivities is concluded not to be 1.00 but to be 0.74.

From the general applicability of LArSR Eq. 1, we can derive a new expression of general reactivities based on the σ_i standard as

$$\log k/k_0 = \rho (\sigma_i + R^+\Delta\bar{\sigma}_R^+ + R^-\Delta\bar{\sigma}_R^-).$$

This is exactly the same as the LSFE Eq. by setting $0.43\Delta\bar{\sigma}_R^+ \equiv \sigma_\pi^+$ and $0.83\Delta\bar{\sigma}_R^- \equiv \sigma_\pi^-$.⁹⁾ Although a generalized form of substituent effect has sometimes been given as Eq. 2¹⁰⁾ by combining Taft and our LArSR Eq's, the present result

Table 1. Correlation Analysis of Basicities (ΔpK_a) of Quinuclidines^{a)}

System	Expression	$R^b)$ (n) ^{c)}
Quinuclidine ($\mu=0$);	$6.43 (\sigma^O - 0.43\Delta\bar{\sigma}_R^+ - 0.83\Delta\bar{\sigma}_R^-) + 0.380$	0.996 (21)
Quinuclidine ($\mu=0.1$);	$6.51 (\sigma^O - 0.43\Delta\bar{\sigma}_R^+ - 0.83\Delta\bar{\sigma}_R^-) + 0.360$	0.996 (21)
Quinuclidine ($\mu=0$);	$6.77 (\sigma - 0.71\Delta\bar{\sigma}_R^+ - 0.85\Delta\bar{\sigma}_R^-) + 0.311$	0.996 (19)
Quinuclidine ($\mu=0.1$);	$6.86 (\sigma - 0.72\Delta\bar{\sigma}_R^+ - 0.84\Delta\bar{\sigma}_R^-) + 0.286$	0.995 (19)
Quinuclidine ($\mu=0$);	$4.60 \sigma_I + 0.477$	0.988 (17)
Pyridine ^{5b)} ;	$6.27 (\sigma^O + 0.20\Delta\bar{\sigma}_R^+ - 0.48\Delta\bar{\sigma}_R^-) - 0.05$	0.995 (29)
Pyridine N-oxide ^{7b)} ;	$2.60 (\sigma^O + 0.59\Delta\bar{\sigma}_R^+ + 0.22\Delta\bar{\sigma}_R^-) - 0.06$	0.997 (20)

a) The substituent H is omitted for all quinuclidine correlations.

b) Correlation coefficient. c) Number of substituents.

evidently denies the necessity of any resonance substituent parameters other than $\Delta\sigma_R^+$ and $\Delta\sigma_R^-$.

$$\log k/k_0 = \rho (\sigma_I + \sigma_R^0 + r^+ \Delta\sigma_R^+ + r^- \Delta\sigma_R^-) \quad (2)$$

This is consistent with the result of statistical analysis by Nieuwdorp et al.¹⁰⁾ that only three substituent constants are required to describe general reactivities.

Further work is in progress, confirming basis for our definition of the inductive and pi-electronic effect substituent constants in the LSFE treatment.

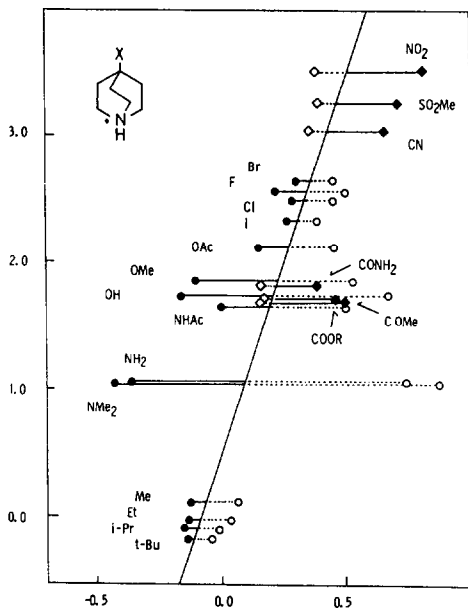


Fig. 1. The plots of ΔpK_a of quinuclidines ($\mu=0$) against σ^0 (●) or ($\sigma^0-1.0\Delta\sigma_R^+$) (○) for pi-donors and σ^0 (◆) or ($\sigma^0-1.0\Delta\sigma_R^-$) (◇) for pi-acceptors. A correlation line by LARSR Eq. 1 is drawn.

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