

Linear Free Energy Relationship in the Reaction Between Piperidine and Benzyl Bromides

S. RANGA REDDY and P. MANIKYAMBA*

Department of Chemistry, Kakatiya University, Warangal-506 009, India

E-mail: mani_prerepa@yahoo.co.in

The reaction between piperidine and benzyl bromides in methanol medium is observed to be overall second order. The reaction is retarded by electron-donating group and accelerated by electron-withdrawing groups compared to the unsubstituted substrate. Correlation of $\log k$ with Hammett's substituent constant σ resulted in a linear plot with positive reaction constant ($\rho = 0.4$). The operation of minimum substituent effect is attributed to the fact that the isokinetic temperature (291.7 K) is nearer to the experimental range of temperatures (303-318 K).

Key Words: Piperidine, Benzyl bromide, Linear free energy relationship, Isokinetic temperature, Substituent effect.

INTRODUCTION

Study of the effect of substituent on rate and application of linear free energy relationship (LFER) occupies a prime position in kinetic studies. Important conclusions regarding the type of the reaction, the nature of the reaction centre and the reaction pathway can be drawn by studying the effect of the substituent attached to the benzene ring on the reactivity of an aromatic substrate. With this end in view the authors studied the kinetics of benzylation of some secondary amines hitherto not reported in the literature, using benzyl bromide as the substrate. In addition to the substituent effect the authors also conducted solvent effect studies with a view to finding out the specific solvation process and derived linear solvation energy relationships (LSER)¹⁻⁴. In the present communication we report the results of the studies of the substituent effect on benzylation of piperidine (PPD) which is a cyclic secondary amine.

EXPERIMENTAL

Benzyl bromide (Riedel), *p*-NO₂, *p*-CH₃, *p*-Br benzyl bromides (Fluka) and piperazine (Sd-Fine) were used without further purification. Solvent methanol (Sd-fine) was used after distilling following literature method.

Temperature of the reaction mixture was maintained constant using a thermostat (INSREF make) with an accuracy of ± 0.2 °C. The progress of the reaction was followed by measuring the conductance of the reaction mixture at different time intervals. Solutions of piperidine of appropriate concentrations were prepared by dissolving weighed quantities in methanol.

The other experimental details were described in our earlier papers¹⁻⁵. The reaction was found to be first order with respect to both piperidine and benzyl bromide. Second order rate constants *k* have been computed from

the slopes of the linear plots obtained when $\frac{C_\infty}{C_\infty - C_t}$ is plotted against time according to the equation⁶

$$k = \frac{1}{a} \left[\frac{C_\infty}{C_\infty - C_t} \right]$$

where 'a' is the initial concentration of the reactants, C_t and C_∞ are the conductances of the reaction mixture at time *t* and after completion of the reaction.

The product separated at the end of the reaction was identified as the corresponding benzyl piperidine from its IR spectral analysis. Its IR spectrum does not show any sharp absorption band around 3300 cm^{-1} due to the N-H bond, while this band is observed in the reactant. Further, the absorptions around 2800 and 1460 cm^{-1} confirm the presence of the N-CH₂ group⁷.

RESULTS AND DISCUSSION

The reactions between substituted benzyl bromides and piperidine have been studied in the temperature range 303-318 K using methanol as the medium. The second order rate constants computed from these studies are presented in Table-1. These values indicate that the structural effects operating on the reaction system are minimal. It is observed that in the benzylation of diphenylamine¹, benzimidazole⁴ and piperazine⁸ also the variation in the rate constants of different benzyl bromides is less. In the

TABLE-1
EFFECT OF SUBSTITUENT ON RATE CONSTANT
[BENZYL BROMIDE-PIPERIDINE SYSTEM]
Solvent : methanol; [BzBr] = [PPD] = 0.02 mol dm⁻³; T* = 303 K

BzBr	σ	$k \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1} \text{ T/K}$				(KJ mol ⁻¹)			* ΔS^\ddagger (JK ⁻¹ mol ⁻¹)
		303	308	313	318	E _a	* ΔH^\ddagger	* ΔG^\ddagger	
-H	0.00	256.66	433.32	616.64	920.24	49.01	46.49	83.45	-122
<i>p</i> -CH ₃	-0.17	209.55	320.00	501.08	708.35	63.18	60.66	84.60	-80
<i>p</i> -Br	0.23	312.00	580.71	789.02	1100.00	82.68	80.16	82.99	-9
<i>p</i> -NO ₂	0.78	520.82	833.32	1282.00	1833.00	65.33	62.81	81.69	-69

present system the two electron withdrawing groups, $-\text{NO}_2$ and $-\text{Br}$ at the *para* position to $-\text{CH}_2\text{Br}$ group enhance the rate of the reaction, while the electron donating $-\text{CH}_3$ group retards compared to the unsubstituted compound. To verify the applicability of Hammett's linear free energy relationship $\log k$ values are plotted against Hammett's substituent constant σ ⁹ at different temperatures studied. At each temperature these plots are linear (Fig. 1) with positive slopes. The slopes of these linear plots which are the reaction constant (ρ) are 0.4 in each case. This ρ value is a measure of the sensitivity of the reaction towards electronic effects. A low value of ρ (< 1) suggests that the electronic effects do not influence much the reactivity of the substrate. A positive ρ value, in general, indicates either the development of a negative charge or the disappearance

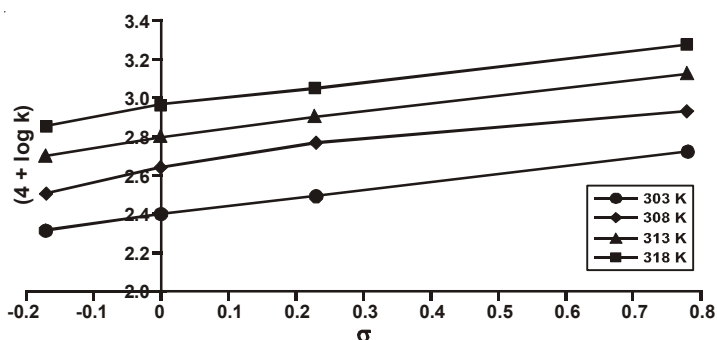
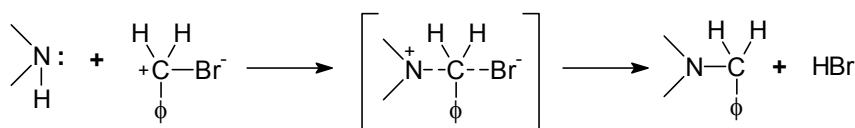


Fig. 1. Hammett's plot of $\log k$ vs. σ (benzyl bromide - piperidine system)

of a positive charge at the reaction centre during the reaction. In the present case of $\text{S}_{\text{N}}2$ reaction it is attributed to the disappearance of positive charge at the benzylic carbon atom. In view of this, the reaction scheme is represented as shown below.



Scheme-I

From the slopes of the Arrhenius plots of $\log k$ against $1/T$, the energies of activation E_a and hence the other activation parameters ΔH^\ddagger , ΔS^\ddagger and ΔG^\ddagger are evaluated and presented in Table-1. This data indicates that E_a , ΔH^\ddagger and ΔS^\ddagger are also influenced by the nature of the substituent. The entropies of activation ΔS^\ddagger are also negative as expected for a reaction system involving polar transition state. According to Leffler¹⁰, a reaction series which follows Hammett's relationship (LFER), where enthalpy and

entropy changes are temperature independent must be either isoentropic or the ΔS^\ddagger should vary linearly with ΔH^\ddagger according to the equation.

$$\Delta H^\ddagger = \Delta H^{\circ\ddagger} + \beta \Delta S^\ddagger$$

where β is isokinetic temperature. In the present system when ΔH^\ddagger is correlated with ΔS^\ddagger the following relationship is obtained.

$$\Delta H^\ddagger = 82.5 + 291.7 \Delta S^\ddagger; r = 0.99$$

The value of isokinetic temperature (291.7 K) is nearer to the experimental range of temperature (303-318 K) indicating the reason for low ρ value.

According to Peterson and coworkers¹¹, in order for an isokinetic relation to be significant, the range of observed ΔH^\ddagger ($\Delta \Delta H^\ddagger$) should exceed twice the maximum possible error (δ) in ΔH^\ddagger . In the present system the calculated value of $\delta \approx 8.0$ KJ while $\Delta \Delta H^\ddagger$ is 33.67 KJ mol⁻¹ indicating that ΔH^\ddagger - ΔS^\ddagger relationship is significant. The free energy of activation is nearly constant (83.18 ± 1.40 KJ mol⁻¹) suggesting the operation of similar reaction scheme with all the substituted benzyl bromides used in the present study.

REFERENCES

1. S.R. Reddy and P. Manikyamba, *Indian J. Chem.*, **43A**, 1092 (2004).
2. S.R. Reddy, P. Kalyani and P. Manikyamba, *Indian J. Chem.*, **44A**, 1831 (2005).
3. S.R. Reddy, P. Kalyani and P. Manikyamba, *J. Chem. Res. S*, **6**, 354 (2006).
4. S.R. Reddy and P. Manikyamba, *Indian J. Chem.*, **45A**, 1844 (2006).
5. S.R. Reddy and P. Manikyamba, *J. Chem. Sci.*, **118**, 257 (2006).
6. A.A. Frost and R.G. Pearson, *Kinetics and Mechanism*, Wiley Eastern, New Delhi, India, p. 37 (1970).
7. R.M. Silverstein, G.C. Bassler and T.C. Morill, *Spectrometric Identification of Organic Compounds*, John Wiley & Sons, edn. 4, p. 190 (1981).
8. S.R. Reddy, Ph.D. Thesis, Kakatiya University (2005).
9. R.A.Y. Jones, *Physical and Mechanistic Organic Chemistry*, Cambridge University Press, p. 87 (1979).
10. J.E. Leffler, *J. Org. Chem.*, **20**, 1202 (1955).
11. R.C. Peterson, J.H. Markgraf and S.D. Ross, *J. Am. Chem. Soc.*, **83**, 3819 (1961).