

Kinetics of reaction of ethyl bromoacetate with substituted phenoxyacetate ions

R S RAGHAVAN* and K KALAVATHY

Department of Chemistry, Pachaiyappa's College, Madras 600030, India

MS received 27 October 1984

Abstract. The reaction of ethyl bromoacetate with substituted phenoxyacetate ions in 90% aqueous acetone is found to follow total second order kinetics, first order in each reactant. The reaction is accelerated by electron-releasing and retarded by electron-withdrawing substituents in the phenoxyacetate ion. The reaction shows an excellent Hammett fit, $\rho = -0.242$ at 40°C. The attenuation ratio (π_2) is found to be 0.695, indicating the damping effect of the oxymethylene group $-O-CH_2-$. A satisfactory Brönsted correlation is observed for the reaction, $\alpha = 1.1$ at 25°C. The isokinetic relationship is obeyed in the present reaction series, β (isokinetic temperature) = 334 K.

Keywords. Substituent effects; damping effect of oxymethylene group; ion pairs.

1. Introduction

Bimolecular nucleophilic substitution reactions have been of immense fascination to mechanistic organic chemists in recent decades, especially because of the possibility that they afford correlation of substituent effects on reaction rates with the aid of the Hammett equation or its modifications (Bunnett and Zahler 1951; Hughes 1951; Bunnett 1958; Kosower 1968; Gould 1959). α -Haloketones and α -haloesters have been found to be considerably reactive towards nucleophiles and have been employed by numerous workers for such studies. Kinetics of the reactions of phenacyl bromide, substituted phenacyl bromides and substituted ω -bromoacetonephthones with various types of nucleophiles have been studied (Mohanty *et al* 1967; Mishra *et al* 1973; Ananthakrishna Nadar *et al* 1975, 1976, 1977; Srinivasan *et al* 1981a). Quite recently, detailed kinetic studies on the reaction of ethyl bromoacetate (EBA) with substituted benzoate ions (Srinivasan *et al* 1981b) and *trans*-cinnamate ions (Srinivasan *et al* 1982) were reported. Literature does not, however, record any extensive study of the reaction of this α -haloester with substituted phenoxyacetate ions. This prompted us to undertake the title investigation.

2. Experimental

Ethyl bromoacetate (Fluka) of high purity was used for the study. The substituted phenoxyacetic acids were prepared by treatment of the sodium salt of the appropriately substituted phenols with monochloroacetic acid (Vogel 1948) and purified by recrystallization. Acetone used was of AR grade.

The reaction of EBA with phenoxyacetate ions was studied in 90% acetone - 10%

* To whom all correspondence should be addressed

water mixtures at 30°, 35° and 40°C. The reaction was followed by withdrawing suitable aliquots of the reaction mixture at regular intervals into a solution of nitric acid and a definite, known excess of standard silver nitrate solution and titrating the excess, unconsumed silver nitrate against standard ammonium thiocyanate solution using ferric alum indicator.

The rate constants were calculated using the second order equation

$$k_2 = \frac{1}{t} \cdot \frac{x}{a(a-x)},$$

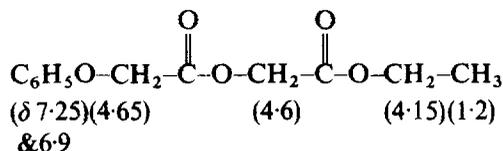
when the initial concentrations of the two reactants were equal, or the other second-order expression

$$k_2 = \frac{2.303}{t(a-b)} \log_{10} \frac{b(a-x)}{a(b-x)},$$

where a is the initial concentration of EBA, b the initial concentration of the phenoxyacetate ion and x the concentration of bromide ion formed in time t (sec), when the initial concentrations of the two reactants were unequal. The reaction was studied at three different temperatures and the E_a values were calculated from the slopes of the Arrhenius plots of $\log k_2$ versus T^{-1} . Using these E_a values, the value of ΔH^\ddagger , ΔS^\ddagger and ΔG^\ddagger were evaluated.

2.1 Product analysis

In order to isolate the product of the reaction, sodium phenoxyacetate and EBA were allowed to react in equal volumes in equimolar solutions in 90% aqueous acetone for two days and the solvent removed by evaporation under atmospheric pressure. The residual liquid was extracted with ether, dried (over Na_2SO_4) and relieved of ether by evaporation. A pleasant-smelling liquid was left behind. Its IR (film: [1750 (ester C=O stretching), 1020–1380 cm^{-1} (intense multiple bands, C–O stretching)]) and PMR [(90 MHz, CDCl_3 : δ 7.25 (t , 2H, $J = 7.5$ Hz), 6.9 (t , 3H, $J = 7.5$ Hz), 4.65 (s , 2H), 4.6 (s , 2H), 4.15 (q , 2H, $J = 6.5$ Hz) and 1.2 (t , 3H, $J = 6.5$ Hz))] spectra are consistent with structure I with the assignment of signals as shown.

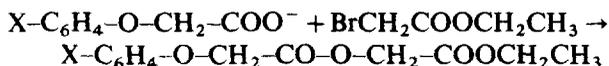


I

3. Results and discussion

3.1 Kinetic order and substituent effects

The reaction displays total second order kinetics with first order dependence on each reactant. EBA reacts with phenoxyacetate ions according to the equation



where X is a substituent in the benzene ring. The second order rate constants and the activation parameters for the reaction of EBA with 9 substituted phenoxyacetate ions are given in table 1. The kinetic data unmistakably indicate rate acceleration by electron-releasing and retardation by electron-withdrawing substituents and dependence of the reaction rate on the electron density on the oxygen atom of the phenoxyacetate anion. The overall order of reactivity is



and is analogous to those reported earlier by other workers (Mohanty *et al* 1967; Mishra *et al* 1973; Ananthakrishna Nadar *et al* 1976, 1977; Srinivasan *et al* 1981a) and readily explicable on the basis of the inductive, mesomeric and/or hyperconjugative effects of the substituent. It is pertinent to note that the phenoxyacetate ion reacts slower than the benzoate ion (Srinivasan *et al* 1981b), obviously due to the fact that the phenoxy group is a stronger electron-withdrawing group than the phenyl group.

The reaction shows an Hammett fit as the plots of $\log k_2$ of the *m*- and *p*-substituted phenoxyacetate ions against the corresponding σ values were quite linear. The slopes of these plots yielded ρ values of -0.242 (at 40°C , $r = 0.986$), -0.265 (at 35°C , $r = 0.997$) and -0.296 (at 30°C , $r = 0.990$). The negative sign of ρ signifies that the reaction is facilitated by electron release from the benzene ring towards the reaction centre. The decline in the value of ρ with rise of temperature is expected since σ is temperature independent. It has been shown that in simple cases ρ should vary as $1/T$ (Leffler 1955, 1957; Fischer and Vaughan 1957).

It is instructive to compare the ρ value in the present case with that for the similar reaction of EBA with benzoate ions. Since ρ has been reported for the latter to be -0.381 at 35°C by Srinivasan *et al* (1981b), we find that the substituent effect is much less pronounced in the present case. This is in keeping with the general observation that the effect of a substituent in the benzene ring on a particular kind of reaction in a side chain decreases with increasing length of the chain (More O'Ferrall and Miller 1964; Jaffé 1953; Trachtenberg and Odian 1958; Ananthakrishna Nadar and Petchinatha Pillai 1981). The attenuation ratio π_z ($= \rho/\rho_0$) works out to $(-0.265/-0.381) = 0.695$ at

Table 1. Second order rate constants and activation parameters for the reaction of phenoxyacetate ions with ethyl bromoacetate in 90% aq. acetone.

Substituent	$10^3 \times k_2 \text{ M}^{-1} \text{ s}^{-1}$			E_a	ΔH^\ddagger	ΔS^\ddagger	ΔG^\ddagger
	30°C	35°C	40°C	k cal/ mole	k cal/ mole	cal/mole/ deg	k cal/ mole
<i>o</i> -Me	0.586	0.905	1.370	16.02	15.42	-22.46	22.23
<i>p</i> -Me	0.542	0.872	1.350	17.39	16.79	-18.10	22.27
<i>m</i> -Me	0.517	0.812	1.260	16.78	16.18	-20.20	22.30
-H	0.463	0.760	1.230	18.46	17.86	-14.88	22.37
<i>p</i> -Cl	0.436	0.686	1.030	16.02	15.42	-23.05	22.40
<i>p</i> -Br	0.429	0.667	1.020	16.95	16.35	-20.01	22.41
<i>o</i> -Cl	0.308	0.517	0.852	19.36	18.76	-12.72	22.61
<i>p</i> -NO ₂	0.285	0.487	0.812	19.41	18.81	-12.71	22.66
<i>o</i> -NO ₂	0.249	0.444	0.762	20.80	20.20	-8.39	22.74

[Phenoxyacetate ion] = 0.02 M; [EBA] = 0.02 M

35°C in the present case. This ratio may be indicative of the effectiveness of the transmission of the electronic effects through the group Y in Ar-Y-COOH compared with that of similar benzoic acid derivatives. It measures in the present case the weakening of the effect of a substituent by the interposition of the oxymethylene group, -O-CH₂-. The magnitude of the damping effect of the oxymethylene bridge is thus revealed.

The applicability of the Brönsted equation was then tested by plotting $\log k_2$ (at 25°C) for the reaction of the *m*- and *p*- substituted phenoxyacetate ions against the pK_a of the corresponding conjugate acids. A good straight line was obtained and the Brönsted coefficient α in the present case was found to be 1.1 ($r = 0.954$), indicating an excellent fit with the Brönsted equation. The positive value of α is in accord with the expectation for a bimolecular nucleophilic substitution reaction, i.e., the rate increases with increasing basicity of the nucleophile. The rather high value of α signifies that there is substantial bond formation between the nucleophile and the reaction centre in the present case.

3.2 Temperature influence

The temperature influence on this reaction series has been studied in the range 30 to 40°C and the activation parameters evaluated as indicated earlier.

Inspection of the data on activation parameters indicates that electron-releasing substituents lower E_a while electron-withdrawing substituents increase it since the former lead to increased nucleophilicity and the latter to reduced nucleophilicity of the phenoxyacetate ion. However, the E_a values do not correctly or quantitatively reflect the electronic effect of the substituents. The entropy of activation is negative in all the cases, as expected for a bimolecular nucleophilic substitution reaction in which there is increased steric crowding in the transition state. The constancy of the ΔG^\ddagger values in all the cases points to the operation of the same mechanism throughout the series. This is a consequence of the variation in ΔH^\ddagger being compensated by the variation in ΔS^\ddagger . The isokinetic relationship $\Delta H^\ddagger = \Delta H_0^\ddagger + \beta \Delta S^\ddagger$ is found to hold good in the present reaction series and a plot of ΔH^\ddagger against ΔS^\ddagger is linear and the slope β (isokinetic temperature) = 334 K ($r = 0.998$).

3.3 Solvent influence

With a view to studying the effect of variation in solvent composition on the rate of the reaction, the reaction has been studied in acetone-water mixtures of various compositions. The reaction is found to become slower with increasing percentage of water. For example, at 40°C under the conditions, $[EBA] = 0.02 \text{ M} = [\text{phenoxyacetate ion}]$, $10^3 k_2$ decreases from 1.230 to $0.352 \text{ M}^{-1} \text{ sec}^{-1}$ when % water was increased from 10 to 25. This is as expected for a reaction in which the negative charge which was confined to the phenoxyacetate ion prior to reaction is dispersed over a somewhat larger area in the transition state. It is also possible that this result is due to greater solvation of the anionic nucleophile via hydrogen bonding by the protic component (water) of the medium resulting in diminished nucleophilicity of the anion.

3.4 Effect of [sodium phenoxyacetate] on rate: evidence for ion pairs

It is observed that the reaction velocity decreases with increasing concentration of the sodium phenoxyacetate. For example, at 40°C under the conditions, $[EBA] = 0.02 \text{ M}$ in

90% acetone-water mixture, $10^3 k_2$ decreases from 2.11 to 1.23 $M^{-1} \text{sec}^{-1}$ when [sodium phenoxyacetate] is increased from 0.0025 to 0.0200 M. This is not surprising since acetone is a poorly dissociating medium and it would be reasonable to suppose that the salt is not completely dissociated in 90% aqueous acetone. The phenoxyacetate and the sodium ions may be held together by electrostatic attraction to form ion pairs. At high concentrations of the salt this phenomenon would become more pronounced, causing a decline in the rate.

Acknowledgement

The authors are indebted to Prof B R Pai, Consultant, Research and Development, Amrutanjan Ltd., Madras for encouragement, spectral data and helpful suggestions. Partial financial support of the University Grants Commission is also thankfully acknowledged.

References

- Ananthakrishna Nadar P and Gnanasekaran C 1975 *Indian J. Chem.* **13** 1237
Ananthakrishna Nadar P and Gnanasekaran C 1977 *Indian J. Chem.* **B15** 277
Ananthakrishna Nadar P and Petchinatha Pillai 1981 *Indian J. Chem.* **B20** 904
Ananthakrishna Nadar P and Shunmugasundaram A 1976 *Indian J. Chem.* **A14** 805
Bunnett J F 1958 *Q. Rev.* **12** 1
Bunnett J F and Zahler R E 1951 *Chem. Rev.* **49** 273
Fischer A and Vaughan J 1957 *J. Chem. Phys.* **27** 976
Gould E S 1959 *Mechanism and structure in organic chemistry* (New York: Holt, Reinhart and Winston) Chap. 8
Hughes E D 1951 *Q. Rev.* **5** 245
Jaffé H H 1953 *J. Chem. Phys.* **21** 415
Kosower E M 1968 *An introduction to physical organic chemistry* (New York: John Wiley) p. 63
Leffler J E 1955 *J. Chem. Phys.* **25** 2199
Leffler J E 1957 *J. Chem. Phys.* **27** 981
Mishra P, Nayak P L and Rout M K 1973 *Indian J. Chem.* **11** 452
Mohanty R K, Behera G and Rout M K 1967 *Indian J. Chem.* **5** 259
More O'Ferrall R A and Miller S J 1964 *J. Am. Chem. Soc.* **86** 4016
Srinivasan C, Shunmugasundaram A and Arumugam N 1981a *Indian J. Chem.* **B20** 467
Srinivasan C, Shunmugasundaram A and Arumugam N 1981b *Indian J. Chem.* **B20** 1057
Srinivasan C, Shunmugasundaram A and Arumugam N 1982 *Indian J. Chem.* **B21** 355
Trachetenberg E N and Odian O 1958 *J. Am. Chem. Soc.* **80** 4018
Vogel A I 1948 *A textbook of quantitative organic analysis* (London: Longmans, Green & Co) I Edn, p. 653