sample was worked up in the usual manner and the nmr spectra were recorded in $CDCl_3$.

Attempted Reactions of 2a–c with Hydrazoic Acid. Sodium azide (0.02 mol) was allowed to react with a slight excess of hydrobromic acid in 50 ml of DMF at room temperature for 10 min. Then 0.02 mol of **2a–c** was added and the mixture was stirred for the same time as given in procedure B. The nmr spectra, after work-up, indicated no reaction. The α-bromovinyl ketones **2a–c** were recovered in 76–86% yield.

Dehydrobromination of 1a–c. Dibromides **1a–c** (0.1 mmol) and 0.2 mol of sodium acetate were stirred in 200 ml of dry DMF at room temperature for the appropriate reaction time (0.5 hr for **1a**, 5 hr for **1b**, and 1 hr for **1c**). After work-up the following yields were obtained: 90% **2a** in a cis/trans ratio of 80/20, 90–92% *cis*-**2b**, and 89% **2c** in a cis/trans ratio of 60/40.

Cis–trans Isomerization of Vinyl Bromides 2. *cis*-α-Bromoethylideneacetophenone **(2a)** isomerized spontaneously and quantitatively into *trans*-**2a** (mp 66.5–67.0°, petroleum ether) within 1 day upon standing at room temperature. When *cis*-α-bromochalcone **(2b)** was heated under nitrogen at *ca.* 160° for 1 hr, the nmr spectrum showed a large decrease of the τ 2.87 absorption relative to the aromatic multiplet indicating a cis/trans ratio of about 30/70. This reaction mixture was allowed to crystallize from *n*-hexane at low temperature, and yielded *trans*-**2b** as a pale yellow crystalline product, mp 38–39° (lit.[10] mp 42°).

Anal. Calcd for $C_{15}H_{11}OBr$ (387): C, 62.74; H, 3.86. Found: C, 62.95; H, 3.92.

Isomerization also occurred to an extent of 40% cis/60% trans when a chloroform solution of *cis*-**2b**, containing some iodine, was warmed at 60° for 1 day.

Similarly, a chloroform solution of α-bromobenzylideneacetone **(2c)** (cis/trans = 60/40), with trace amounts of iodine, isomerized completely to *trans*-**2c** at 60° within 4 hr.

Reaction of *trans*-Ethylideneacetophenone with Bromine Azide. Bromine azide (0.1 mol) in 200 ml of methylene chloride[8] was added to 200 ml of nitromethane containing 6 g of 30% fuming sulfuric acid at 0°. This solution was poured into 300 ml of nitromethane containing 0.04 mol of *trans*-ethylideneacetophenone and the mixture was allowed to stand for 2 hr at room temperature. Usual work-up gave 10.4 g of a brown oil which was chromatographed on silica gel with petroleum ether–benzene as the eluent. One of the fractions (2.0 g) was a pure mixture of the regioisomers **7a** and **9a**.

Anal. Calcd for $C_{10}H_{10}BrN_3O$ (268): C, 44.77; H, 3.73; Br, 29.85; N, 15.67. Found: C, 44.71; H, 3.89; Br, 30.06; N, 15.49.

3-Benzoyl-5-phenylisoxazole (15). A mixture of 39.6 g of *meso*-1,2-dibenzoylethylene dibromide **(13)** and 0.22 mol of sodium azide (14.3 g) was stirred in 500 ml of dry DMF at room temperature. The reaction was exothermic and nitrogen evolved. After 3 hr, the mixture was worked up with water–ether and the isoxazole was obtained in *ca.* 90% yield. It was recrystallized from 500 ml of ethanol (yield 61%): mp 86–87° (lit.[13] mp 89–90°); nmr ($CDCl_3$) τ 1.5–2.8 (m, 10 H), 2.98 (s, 1 H).

Anal. Calcd for $C_{16}H_{11}NO_2$ (249): C, 77.09; H, 4.45. Found: C, 77.21; H, 4.35.

Acknowledgment. This investigation was supported by Public Health Service Grant CA-4474 from the National Cancer Institute and by Grant GP-19253 from the National Science Foundation. G. L'abbé is indebted to "Nationaal Fonds voor Wetenschappelijk Onderzoek, N.F.W.O. Belgium" for a postdoctoral fellowship and to the Educational Foundation for a Fulbright–Hays travel grant.

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Base-Catalyzed β-Elimination Reactions in Aqueous Solution. V. Elimination from 4-(*p*-Substituted-phenoxy)-2-butanones[1]

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Abstract: Reactions of 4-(*p*-X-phenoxy)-2-butanones (X = CH_3O, CH_3, H, Cl, and CN) in aqueous solution to give 3-buten-2-one and para-substituted phenols are general base catalyzed by tertiary amines. Saturation kinetics observed at high amine buffer concentrations provide kinetic evidence for the ElcB mechanism wherein partitioning of the enolate anion is kinetically important. Relative to $\rho' = 1$ for the ionizations of para-substituted phenols, $\rho' = 0.066 \pm 0.002$ for formations of enolates, and $\rho' = 0.67 \pm 0.08$ for the decompositions of the enolates to products in 2-dimethylaminoethanol buffers.

The β eliminations of para-substituted benzoates from 4-(*p*-substituted-benzoyloxy)-2-butanones are general base catalyzed and are virtually insensitive to the nature of the para substituent;[2] β elimination of methanol from 4-methoxy-2-butanone is specific base catalyzed and the rate of general base catalyzed α-methylene proton exchange in D_2O is faster than the rate of elimination.[3] Although a case can be made for alternative mechanisms, the ElcB mechanism of eq 1

$$\mathrm{SH} \underset{k_2(\mathrm{BH}^+)}{\overset{k_1(\mathrm{B})}{\rightleftarrows}} \mathrm{S}^- \xrightarrow{k_3} \text{products} \qquad (1)$$

unifies these results. Thus for SH possessing good leaving groups, $k_3 > k_2(\mathrm{BH}^+)$ and k_1 is rate determining; for SH possessing poor leaving groups, $k_2(\mathrm{BH}^+) > k_3$ and k_3 is rate determining. If the above reactions do indeed proceed *via* the ElcB mechanism, then for SH possessing leaving groups with pK values intermediate between carboxylic acids (pK = 4) and methanol (pK = 16) partitioning of the intermediate S^- could be kinetically significant and experimentally detectable.[4] For this condition the mechanism of eq 1 predicts that the rate of elimination be first order with respect to B (B $\neq$ OH^-) at low base concentrations and zero order with respect to B at high base concentrations. The base-catalyzed

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(1) Taken in part from the Ph.D. Dissertation of W. R. G.

(2) R. C. Cavestri and L. R. Fedor, *J. Amer. Chem. Soc.*, **92**, 4610 (1970).

(3) L. R. Fedor, *ibid.*, **91**, 908 (1969).

(4) T. I. Crowell, R. T. Kemp, R. E. Lutz, and A. A. Wall, *ibid.*, **90**, 4638 (1968).

Table I. 4-(*p*-Substituted-phenoxy)-2-butanones

Compd	Reaction time, hr (temp, °C)	Bp [mp], °C (*P*, mm)	% yield[d]	Analysis: Calcd % carbon	Analysis: Calcd % hydrogen	Analysis: Found[e] % carbon	Analysis: Found[e] % hydrogen
1 (CH_3O)	97 (25)	107–109 (0.2) [32.5–33.5][a]	31	68.02	7.27	68.04	7.36
2 (CH_3)	99 (25)	74–79 (0.1–0.12) [36–36.5][b]	35	74.13	7.92	74.27	7.72
3 (H)	72 (25)	73–76 (0.25)	25	73.15	7.36	72.94	7.37
4 (Cl)	57 (25) 65 (80)	82–90 (0.07–0.1) [41.5–43][c]	25	60.46	5.58	60.36	5.65
5 (CN)	52 (53)	[43–44][c]	1.2	69.83	5.86	69.59	5.83

[a] CCl_4. [b] Pentane. [c] Hexane. [d] Analytical purity. [e] Elemental analyses were performed by Galbraith Microanalytical Laboratories, Knoxville, Tenn.

eliminations of para-substituted phenols from 4-(*p*-substituted-phenoxy)-2-butanones (eq 2, X = CH_3O

$$p\text{-}XC_6H_4OCH_2CH_2COCH_3 + B \longrightarrow p\text{-}XC_6H_4O^- + CH_2{=}CHCOCH_3 + BH^+ \quad (2)$$

(**1**), CH_3 (**2**), H (**3**), Cl (**4**), CN (**5**), p*K* range of the phenols = 7.95–10.21) were examined to test the mechanism of eq 1 under conditions possibly favorable for the kinetic detection of S^-.

Experimental Section

Apparatus. Gilford Model 2000 or 2400 and Perkin-Elmer or Beckman DB-G spectrophotometers were used for collection of rate data and for scanning reactions. Temperature was maintained in the cuvettes by circulating water of constant temperature from a Tamson T9 water bath through thermospacers. pH was measured using a Radiometer PHM 22 pH meter with a PHA 630P scale expander and a GK2021B combination electrode. The nmr spectra were taken on a Varian A-60 instrument with tetramethylsilane as internal standard and proton signals are reported in δ values downfield from TMS. Melting points were taken in open capillary tubes using a Mel-Temp apparatus and are uncorrected.

Reagents. Inorganic reagents were Fisher Certified ACS grade materials. Organic reagents were purchased from Aldrich Chemical Co. and from Distillation Products Industries (Eastman). Tap distilled water was redistilled through a Corning AG1a still before use. 4-(*p*-Substituted-phenoxy)-2-butanones were synthesized from 3-buten-2-one and para-substituted phenols according to the following procedure. Para-substituted phenol (0.1 mol) and 3-buten-2-one (0.05 mol) were stirred with a catalytic amount of *p*-toluenesulfonic acid in 100 ml of benzene for several days. The mixture was added to 500 ml of ether and washed with five 25-ml portions of cold 1 *N* NaOH and then with three 250-ml portions of water. The organic solution was dried ($MgSO_4$) and evaporated. Distillation or crystallization of the residue gave the product (Table I). The nmr spectra for **1–5** showed signals (δ) at 2.21–2.25 (s), 2.86–2.95 (t), 4.18–4.31 (t), and 6.83–7.28 (variable) for α-CH_3, α-CH_2, β-CH_2, and aromatic protons, respectively.

Kinetics. Reactions were carried out under pseudo-first-order conditions at 30 ± 0.1° in aqueous solution, μ = 1.0 *M* (KCl) unless otherwise specified.[2] pH was determined before every run and after most runs to ensure constancy of pH within ±0.02 unit. Reactions were monitored by following the appearance of phenoxide–phenol at the following wavelengths (mμ): 4-anisoxy-2-butanone (309), 4-cresoxy-2-butanone (298), 4-phenoxy-2-butanone (287), 4-(*p*-chlorophenoxy)-2-butanone (300), and 4-(*p*-cyanophenoxy)-2-butanone (278). Also, loss of 4-(*p*-cyanophenoxy)-2-butanone absorbance was monitored at 249 mμ. Pseudo-first-order rate constants determined for phenoxide–phenol appearance were calculated from slopes of plots of log $(OD_\infty - OD_{t=0})/(OD_\infty - OD_t)$ *vs.* time; rate constants determined for substrate absorbance loss were calculated from slopes of plots of log $(OD_{t=0} - OD_\infty)/(OD_t - OD_\infty)$ *vs.* time. pK_a values were determined by the method of fractional neutralization. Hydroxide ion activity was determined from K_w/a_H where $-\log K_w$ = 13.83 at 30°.[5] All calculations were performed on a Hewlett-Packard 9100A calculator using the linear regression and correlation coefficient program and the mean and standard deviation program from the program library provided.

Products. The spectra of the reactions of **1–5** in dilute KOH solutions were in agreement with the formation of para-substituted phenols (phenoxides) and 3-buten-2-one. At low wavelength, after completion of the reactions, the intensity of the absorbance gradually decreased with time, finally generating the spectrum of the substituted phenol–phenoxide. Absorbance loss at low wavelength (215 mμ) is due to 3-buten-2-one decomposition as shown by the near identity of the rate constants for absorbance loss at 215 mμ in dilute KOH by **1–5** and by 3-buten-2-one (Table II). The pseudo-first-order rate constants determined from the appearance of *p*-cyanophenoxide ion and from the disappearance of **5** were identical when 2-dimethylaminoethanol buffer (pH 9.41–9.42) and hydroxide ion (pH 11.22–11.90) were used as bases. Reaction rates were unaffected by the presence of a two–threefold excess of phenol over phenoxy ketone (*ca.* 10^{-4} *M*) demonstrating the irreversibility of the reactions under the experimental conditions employed.

Table II. Absorbance Loss at 215 mμ in 0.05 *N* Potassium Hydroxide Solution

Compd	k_{obsd}, min^{-1}	No. of runs
1 (CH_3O)	0.092 ± 0.002	3
2 (CH_3)	0.095 ± 0.001	3
3 (H)	0.096 ± 0.005	3
4 (Cl)	0.096 ± 0.003	3
5 (CN)	0.100 ± 0.002	3
3-Buten-2-one	0.098 ± 0.003	3

Results

The β eliminations of para-substituted phenols from 4-(*p*-substituted-phenoxy)-2-butanones (**1–5**) (eq 2) are catalyzed by tertiary amines and hydroxide ion. Under pseudo-first-order conditions at constant pH the rate of formation of products is given by eq 3 which was derived from eq 1 using the steady-state assumption.

$$(dP/dt)/(SH) = k_{obsd} = \frac{k_1(B)}{(k_2/k_3)(BH^+) + 1} + k_{OH}K_w/a_H \quad (3)$$

B is a tertiary amine and BH^+ is its conjugate acid. As predicted from eq 3, graphical plots of k_{obsd} *vs.* $(B)_{total}$ showed curvature for the following SH: 4-anisoxy-2-butanone (**1**), 4-cresoxy-2-butanone (**2**), 4-phenoxy-2-butanone (**3**) (Figure 1), and 4-(*p*-chlorophenoxy)-2-

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(5) R. A. Robinson and R. H. Stokes, "Electrolyte Solutions," 2nd ed, Butterworths, London, 1959, p 544.

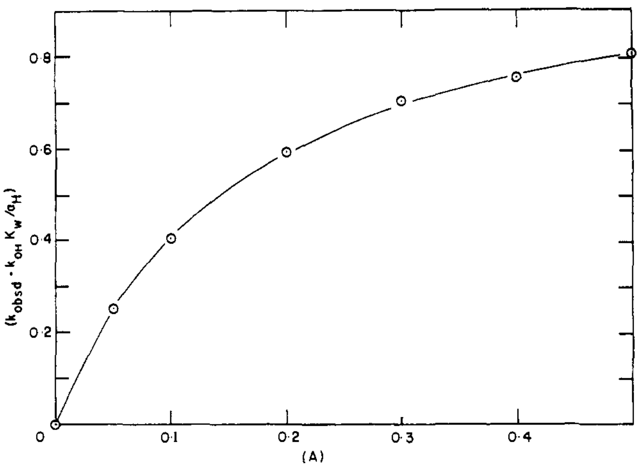

Figure 1. Plot of the pseudo-first-order rate constant (min^{-1}), corrected for hydroxide ion catalysis, for the reactions of **3** with triethylenediamine (A) *vs.* the molar concentration of total A buffer, $T = 30°$, $\mu = 1.0\ M$(KCl), pH 9.54. The solid line was calculated from eq 3 and the constants of Table III.

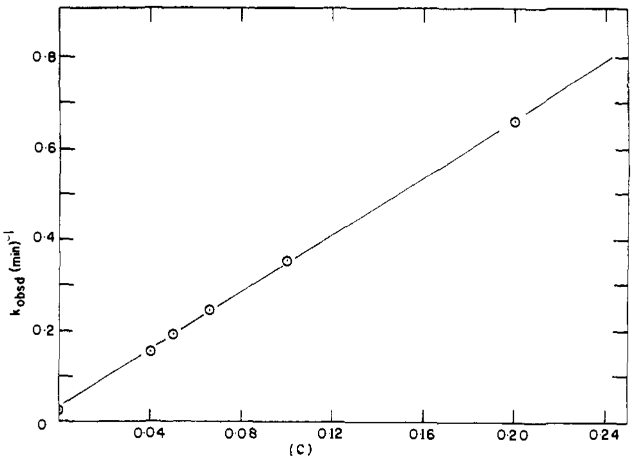

Figure 2. Plot of the pseudo-first-order rate constant for the reactions of **5** with hydroxide ion (I) and 2-dimethylaminoethanol (C) *vs.* the molar concentration of total C buffer, $T = 30°$, $\mu = 1.0\ M$ (KCl), pH 9.42. The least-squares line is drawn.

butanone (**4**). A similar plot for 4-(*p*-cyanophenoxy)-2-butanone (**5**) was linear (Figure 2).

The constants k_1 and k_2/k_3 (Table III) were evaluated using a method of double reciprocal plotting. Thus plots of $1/(k_{obsd} - k_{OH}K_w/a_H)$ *vs.* $1/(B)_{total}$ are linear with slope $(K_a + a_H)/k_1K_a$ and intercept $k_2a_H/k_1k_3K_a$ (Figure 3).

Values for k_2 and k_3 (Tables IV and V) were *calculated* from the data of Table III and from eq 4 using an approximation for the value of K_{SH}. These values were

$$k_1/k_2 = K_{SH}/K_a = (S^-)(BH^+)/(SH)(B) \qquad (4)$$

calculated from eq 5[6,7] (the Brønsted equation for the

$$\log k_a^{H_2O} = -0.6pK_{SH} + 2.495 \qquad (5)$$

ionization of various carbon acids) using values for $k_a^{H_2O}$ (eq 6) which in turn were estimated assuming that

$$SH + H_2O \underset{k_b^{H_2O}}{\overset{k_a^{H_2O}}{\rightleftharpoons}} S^- + H_3O^+ \qquad (6)$$

$k_a^{H_2O}/k_a^{OH} = 1.74 \times 10^{-9}$,[6,8] which is the value for acetone, and from k_{OH} (Table III).

The constant k_{OH} for **1–5** was evaluated from $k_{obsd}/(K_w/a_H)$ for reactions run in dilute potassium hydroxide solution (Table III).

The sensitivity of **3** toward base catalysis is provided by eq 7 (statistically corrected); the sensitivity of **3**$^-$ toward acid catalysis by the conjugate acids of the bases used to obtain eq 7 is provided by eq 8.

$$\log k_1 = 0.29 \pm 0.03pK_a - 2.016 \qquad (7)$$

$$\log k_2 = -0.70 \pm 0.03pK_a + 12.40 \qquad (8)$$

For **1–5** plots of $\log k_{OH}$, $\log k_1$, and $\log k_3$ (2-dimethylaminoethanol) *vs.* σ' gave $\rho' = 0.092 \pm 0.006$, 0.066 ± 0.002, and 0.67 ± 0.08, respectively. Here σ' is derived in the usual way from the ionization constants of phenols.[9] For para-substituted phenoxyacetic acids, $\rho' = 0.12 \pm 0.01$.[10]

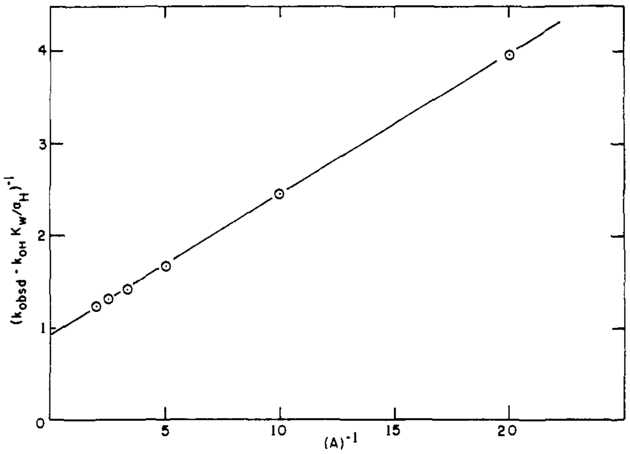

Figure 3. Plot of the reciprocal of the pseudo-first-order rate constant (min^{-1}), corrected for hydroxide ion catalysis, for the reactions of **3** with triethylenediamine (A) *vs.* the reciprocal of the molar concentration of total A buffer, $T = 30°$, $\mu = 1.0\ M$ (KCl), pH 9.54. The least-squares line is drawn.

Equation 9 characterizes the hydroxide ion catalyzed

$$\log k_{OH} = -1.16 \pm 0.07pK_a + 6.25 \qquad (9)$$

elimination reactions of **1–5**, 4-(*p*-X-benzoyloxy)-2-butanones (X = CH_3O, CH_3, H, Cl, NO_2), and as well the general base catalyzed exchange reaction of the α-methylene protons of 4-methoxy-2-butanone in D_2O.[3] The pK_a values of eq 9 are those for para-substituted phenoxyacetic acids, para-substituted benzoyloxyacetic acids, and methoxyacetic acid.

A tenfold change in ionic strength (0.1–1.0 *M*) did not appreciably affect the rate of the general base catalyzed reaction of **3** with 2-dimethylaminoethanol, nor was the rate affected when KCl was replaced with tetramethylammonium chloride (Table III).

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Table III. Rate Constants for the Reactions of 4-(*p*-Substituted-phenoxy)-2-butanones (**1–5**) with Bases[a]

Compd	Base	k_1 or k_{OH}, M^{-1} min^{-1}	k_2/k_3, M^{-1}	pK_a	pH	Concn, *M*	Corr coeff	No. of runs
3 (H)	A	4.55^b	22.0	8.76^b	8.88	0.04–0.20	0.9774	12
3	A	4.73^b	21.0		9.02	0.02–0.50	0.9621	24
3	A	4.09^b	17.2		9.06	0.05–0.50	0.9836	6
3	A	5.00^b	26.2		9.46	0.02–0.20	0.9991	12
3	A	4.38^b	24.4		9.54	0.05–0.50	0.9999	6
		4.55 ± 0.35	22.2 ± 3.4					
3	B	4.39	6.11	9.30	9.30	0.05–0.50	0.9984	6
3	C	4.11	5.55	9.45	8.42	0.05–0.20	0.9852	9
3	C	4.67	6.36		9.03	0.04–0.20	0.9988	11
3	C	4.04	4.67		9.42	0.04–0.20	0.9700	12
3	C	4.94	9.21		9.97	0.04–0.20	0.9961	15
		4.44 ± 0.44	6.45 ± 1.97					
3	C^c	5.31	7.26		9.19	0.04–0.20	0.9969	10
3	C^d	4.55	4.80		9.32	0.04–0.20	0.9983	9
3	D	4.47^b	10.7	9.15^b	9.45	0.05–0.50	0.9976	6
3	D	4.92^b	10.8		8.84	0.05–0.50	0.9930	6
		4.70 ± 0.32	10.75 ± 0.07					
3	E	3.61	7.45	9.65	9.65	0.05–0.50	0.9976	6
3	E	3.44	3.99		9.25	0.05–0.50	0.9974	6
		3.53 ± 0.12	5.72 ± 2.45					
3	F	9.17	8.26	9.65	9.65	0.05–0.50	0.9987	6
3	G	11.67	8.99	9.70	9.70	0.05–0.50	0.9887	7
3	G	10.91	11.37		9.47	0.05–0.50	0.9981	8
3	G	10.90	10.90		9.12	0.05–0.50	0.9952	7
		11.16 ± 0.44	10.42 ± 1.26					
3	H	13.46	0.068	10.88	10.85	0.05–0.20	0.9972	9
3	I	385.7 ± 26.5		15.57^e	11.48–11.94	0.008–0.02		11
1 (CH_3O)	C	5.49	7.80	9.45	9.42	0.04–0.20	0.9863	15
2 (CH_3)	C	4.21	7.22		9.43	0.04–0.20	0.9959	12
4 (Cl)	C	5.00	3.18		9.42	0.04–0.20	0.9750	15
5 (CN)	C	6.62	0.162		9.42	0.04–0.20	0.9992	16
1	I	360.5 ± 38.6		15.57	11.50–11.91	0.008–0.02		8
2	I	382.1 ± 35.6			11.49–11.91	0.008–0.02		8
4	I	448.5 ± 26.8			11.50–11.92	0.008–0.02		8
5	I	582.4 ± 31.1			11.22–11.90	0.005–0.02		13

[a] Triethylenediamine (A), 2-dimethylaminoethyl ethyl ether (B), 2-dimethylaminoethanol (C), *N,N,N′,N′*-tetramethylethylenediamine (D), 1-dimethylamino-2-propanol (E), 3-dimethylaminopropyl methyl ether (F), 3-dimethylaminopropanol (G), triethylamine (H), hydroxide ion (I), solvent = H_2O, $T = 30 \pm 0.1°$, $\mu = 1\ M$(KCl). [b] Statistically corrected. [c] $\mu = 0.1\ M$(KCl). [d] $\mu = 1.0\ M$(tetramethylammonium chloride). [e] $-\log (K_w/55.5)$.

Table IV. Calculated Rate Constants for the Partitioning of the Anions of **1–5** in 2-Dimethylaminoethanol

Compd	pK_{SH}	k_2, M^{-1} min^{-1}	k_3, min^{-1}
1 (CH_3O)	14.49 (6)	6.11×10^5	7.83×10^4
2 (CH_3)	14.45 (3)	4.25×10^5	5.89×10^4
3 (H)	14.44 (7)	4.42×10^5	6.85×10^4
4 (Cl)	14.33 (8)	3.86×10^5	1.21×10^5
5 (CN)	14.14 (9)	3.31×10^5	2.04×10^6

Table V. Calculated Rate Constants for Partitioning of 4-Phenoxy-2-butanone (**3**) Anion[a]

Base	pK_a	k_2, M^{-1} min^{-1}	k_3, min^{-1}
A	8.76^b	2.22×10^6	1.00×10^5
B	9.30	6.17×10^5	1.01×10^5
C	9.45	4.42×10^5	6.85×10^4
D	9.15^b	9.31×10^5	8.66×10^4
E	9.65	2.21×10^5	3.87×10^4
F	9.65	5.75×10^5	6.97×10^4
G	9.70	6.25×10^5	6.14×10^4
H	10.88	4.98×10^4	7.32×10^5
I^c	15.57	2.90×10^1	5.27×10^7

[a] The bases are triethylenediamine (A), 2-dimethylaminoethyl ethyl ether (B), 2-dimethylaminoethanol (C), *N,N,N′,N′*-tetramethylethylenediamine (D), 1-dimethylamino-2-propanol (E), 3-dimethylaminopropyl methyl ether (F), 3-dimethylaminopropanol (G), triethylamine (H), hydroxide ion (I). [b] Statistically corrected by doubling the experimentally determined K_a value and taking its $-\log$. [c] k_2/k_3 value determined from $\log k_2/k_3 = -1.157\text{p}K_a + 11.752$.

Discussion

Rate saturation at high general acid–base buffer concentrations (Figure 1) provides kinetic evidence for the formation of an intermediate in the β-elimination reactions of **1–5**.[4] The ElcB mechanism of eq 1 wherein the partitioning of S^- is kinetically detectable reasonably accommodates the results of this study. From eq 1 and 3, at low catalytic buffer concentrations $1 > (k_2/k_3)(BH^+)$ and first-order dependence on general base concentration is observed; at intermediate buffer concentrations $(k_2/k_3)(BH^+)$ becomes appreciable and less than first-order dependence on buffer concentration is observed. Finally, at high buffer concentrations, $(k_2/k_3)(BH^+) > 1$, the reaction is kinetically specific base catalyzed only, and rate saturation with respect to buffer concentration is achieved.

In this study, in order to detect S^- kinetically, significant amounts of a sufficiently strong general acid must be present to favor collapse of S^- to SH and the leaving group of SH must be sufficiently poor (pK_a = *ca.* 9–10) so that k_3 is not much greater than k_2. Tertiary amine buffers in their reactions with **1**–**4** satisfy these requirements; curvature with 2-dimethylaminoethanol buffer and **5** (pK_a of *p*-cyanophenol = 7.95) is negligible. For the stronger base (weaker conjugate acid) triethylamine, curvature is quite modest for reactions with **3**. In practical terms, k_2/k_3 values should be in the range *ca.* 0.1–10: for very low values simple general base catalysis is observed;[2] for very large values specific base catalysis is observed in the presence of basic buffers.[3]

Examination of k_1 (Table III) shows that to a close approximation values for this constant increase with increasing basicity of the catalyst (eq 7, $\beta = 0.3$) and with increasing acidity of **1**–**5** in accord with the Brønsted catalysis "law." Similarly, the values for k_2 (Tables IV and V) increase with increasing acidity of the conjugate acid of the catalyst (eq 8, $\alpha = 0.7$) and with decreasing acidity of **1**–**5**.[11] For reactions of **1**–**5** with hydroxide ion and with 2-dimethylaminoethanol, $\rho'(k_1) < 0.1$ showing that these reactions are less sensitive to the nature of the substituents than are the ionizations of para-substituted phenoxyacetic acids ($\rho' = 0.12$).[10] Effectively ρ' measures the effect of the substituents on the acidity of **1**–**5** as is believed to be the case for 4-(*p*-substituted-benzoyloxy)-2-butanones in their base-catalyzed elimination reactions (ρ = *ca.* 0.15).[2]

For **1**–**5** there is a 1.8-fold difference in k_2 accompanying a 2.2-fold difference in K_{SH} for their reactions with 2-dimethylaminoethanol (Table IV). For the same reactions, k_3 varies 35-fold corresponding to $\rho' = 0.67$. Thus k_3 is markedly affected by the nature of the leaving group (*cf.* $\rho'(k_1) = 0.07$) and compared with $\rho' = 1$ for the ionization of phenols, where the σ' values are calculated for the equilibrium condition and therefore for completely ionized phenols, considerable bond breaking about the leaving group in the transition state is evident for eliminations from S$^-$ in accord with the E1cB mechanism of eq 1. Assuming $\rho'(k_3)$ varies between 0 (no charge separation about β-CO in the transition state) and 1 (complete charge separation about β-CO) in analogy to the ionization of para-substituted phenols and the Brønsted relationship, $\rho' = 0.67$ indicates that 67% of the charge in the transition state resides on the para-substituted phenoxy portion of S$^-$ and 33% of the charge resides on the incipient 3-buten-2-one portion of S$^-$.

The result that k_3 is dependent on the pK_a of general acids such that S$^-$ is stabilized toward elimination in low pK_a buffers relative to high pK_a buffers (Table V) suggests that S$^-$ is rather intimately associated with the conjugate acid of the base catalyst *via* a field effect, the association being strongest for the strongest acids. This result is in accord with those of Crowell, *et al.*,[4] who observed no deuterium exchange in the E1cB reactions of 4,4′-dichlorochalcone dichloride in absolute ethanol.

The results of the present study coupled with those of earlier studies[2,3] strongly suggest the generality of the E1cB mechanism of eq 1 for β-oxy ketones possessing leaving groups in the pK_a range 4–16. For good leaving groups, k_1 is rate determining; for poor leaving groups, k_3 is rate determining. For leaving groups of intermediate pK_a, partitioning of the enolate anion is important. The generality of the mechanism is reinforced by eq 9 which quantitatively establishes the mechanistic kinship of 11 β-oxy ketones.

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[11] For discussions of deviant Brønsted relationships involving base-catalyzed ionizations of nitroalkanes, which appear not to apply to the present study because of the substitution pattern in **1**–**5**, see Bordwell, *et al.*,[12] Marcus,[13] and Kresge.[14]

[12] F. G. Bordwell, W. J. Boyle, Jr., J. A. Hautala, and K. C. Yee, *J. Amer. Chem. Soc.*, **91**, 4002 (1969).

[13] R. A. Marcus, *ibid.*, **91**, 7224 (1969).

[14] A. J. Kresge, *ibid.*, **92**, 3210 (1970).