anism is operative. The carbonium ion reacts with the acetic acid solvent to form the acetate.

The electron-transfer reactions may occur at or near the solid surface, or within the crystal lattice. The crystal is composed of channels surrounded symmetrically by six heteropoly ions.[13] The channels are probably large enough to allow some penetration by the aromatic hydrocarbon, and the immediate availability of other heteropoly ions accounts for the ease of carbonium ion formation. The carbonium ion would then either diffuse out to react with other hydrocarbon molecules or react with the water in the lattice to form alcohol.

The aromatic radical cation is formed by outer-sphere electron transfer. Inner-sphere electron transfer is eliminated by the stability and nondestruction of the tungstate framework, which totally screens the cobalt(III) oxidant from direct interaction with the aromatic π system.

It is also significant that the oxidation occurs by outer-sphere electron transfer in a heterogeneous system. Such reactions are usually thought to occur by direct coordination to a metal on a surface or in a crystal.

The above results indicate that it is unnecessary to seek an inner-sphere electron transfer mechanism in the oxidation of alkyl aromatics in homogeneous systems,[2-4] *e.g.*, by direct coordination, since outer-sphere electron transfer is feasible.

Registry No.—Potassium 12-tungstocobaltate(III), 12419-42-0; toluene, 108-88-3; *o*-xylene, 95-47-6; *m*-xylene, 108-38-3; *p*-xylene, 106-42-3.

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Alkylation of N-Carbethoxy Tertiary Amines with Ethyl Bromoacetate

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The alkylation of ethyl 1-piperidineacetate (I), ethyl 4-morpholineacetate (II), ethyl N,N-diethylglycinate (III), and ethyl N,N-di-*n*-butylglycinate (IV) at 25, 40, 50, and 60° with ethyl bromoacetate in absolute methanol follows second-order kinetics. The k_2, ΔE, and ΔS values at 25° are 8.86, 0.89, 5.71, and 4.22 $\times 10^{-6}$ l./(mol sec), 17.2, 18.1, 14.6, and 14.8 kcal/mol, and 26.0, 27.6, 35.6, and 35.6 eu, respectively, for the above amines.

This research study investigated the effect of the structure of tertiary amines upon the reaction rate, the energy of activation, and the entropy of activation in the alkylation of the amines with ethyl bromoacetate in absolute methanol. The four amines investigated were ethyl 1-piperidineacetate (I), ethyl 4-morpholineacetate (II), ethyl N,N-diethylglycinate (III), and ethyl N,N-di-*n*-butylglycinate (IV).

The kinetics of the reactions were determined by potentiometric titration of the bromide ion produced using a silver nitrate solution with a glass electrode and a silver–silver bromide reference electrode. The reaction rates were determined from the slopes of the second-order plots. Activation energies were determined from the slope of the Arrhenius plots, and entropies of activation were calculated from the Eyring equation.

Results and Discussion

The experimental rate constant data are summarized in Table I where a is the initial molar concentration of ethyl bromoacetate and the tertiary amine in absolute methanol. The bimolecular rate constant, k_2, is defined by the familiar equation

$$dx/dt = k_2(a - x)^2 \quad (1)$$

The values of k_2 were calculated from the titration data by plotting

$$F(x) = x/(a - x) \quad (2)$$

vs. time where the slope of the plot is equal to ak_2. All of the $F(x)$ *vs.* t plots were linear to 200 hr and remained so for several samples for as long as 800 hr. The per cent of conversion to the quaternary salt varied from 2% for II at 20° to 83% for I at 60°. Most of the experiments were carried to 800 hr and longer, and deviations from linearity were noted in several runs at the higher temperatures. The average percentage error in determining $F(x)$ between two or more identical samples was 2.8% with a standard deviation of 6.1%. This percentage is based upon a population of 144 $F(x)$ determinations. Since the scatter of points increases with an increase of temperature, the accuracy of the $F(x)$ determinations was considerably improved for

TABLE I
Reaction Rate Constants[a]

Temp, °C (±0.1°)	$k_P \times 10^6$	$k_M \times 10^6$	$k_E \times 10^6$	$k_B \times 10^6$
5	1.47	0.106		
20	5.56	0.506		
25	8.86	0.890	5.71	4.22
40	33.9	4.00	20.8	15.2
50	80.5	10.0	49.4	32.6
60	150	23.1	86.7	60.0

Comparison of the Reaction Rates

Temp, °C, (±0.1°)	k_P/k_M	k_P/k_E	k_P/k_B	k_E/k_B
5	14.0			
20	11.0			
25	10.0	1.55	2.10	1.35
40	8.46	1.63	2.24	1.37
50	8.08	1.63	2.46	1.51
60	6.46	1.72	2.49	1.44

[a] P = ethyl 1-piperidineacetate, M = ethyl 4-morpholineacetate, E = ethyl N,N-diethylglycinate, B = ethyl N,N-di-*n*-butylglycinate.

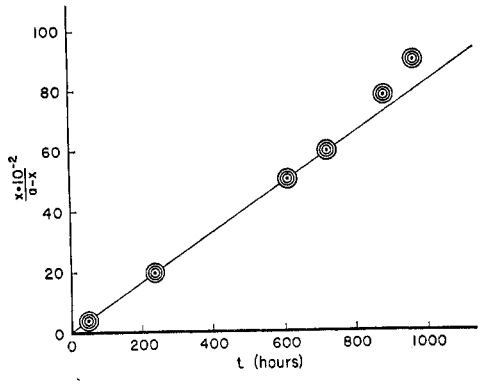

Figure 1.—Ethyl N,N-di-*n*-butylglycinate (25 ± 0.1°).

titrations below 200 hr. With a population of 76 F(x) determinations below 200 hr, the percentage error was 1.8% with a standard deviation of 2.3%. At least three samples were run at each temperature for each tertiary amine.

It has been reported that methanol will methanolyze an alkyl halide.[1] We experimentally determined the methanolysis reaction at 25 and 60° and found the following results for ethyl bromoacetate: room temperature for 240 hr, 0.55% methanolysis, and at 60° for 240 hr, 6.68% methanolysis. The alcoholysis reaction is evident in Figure 1 for the experimental points exceeding 800 hr.

The comparison between the rate constants is shown in Table I in ratio form. Compound I is much faster than II as expected with a hetero-oxygen atom in the ring. Compounds III and IV are much less reactive than the piperidine amine (I) because of the less basic character of the open-chain amines *vs.* the ring-structured amines (pK_a: piperidine, 11.22; morpholine, 8.36; diethylamine, 10.98; and di-*n*-butylamine, 11.25).[2] The longer alkyl chain of the *n*-butyl group does not appreciably decrease the rate of alkylation as compared to the ethyl group (k_E/k_B = 1.35 at 25°). These results are in agreement with Bunton who states that the steric factor of an aliphatic chain does not increase materially with increasing chain length beyond the ethyl group.[3]

The decrease in the ratio of k_P/k_M (Table I) as the temperature increases can be explained by the field-effect model in conjunction with the conformational isomers of morpholine (Figure 2). It is well established that a saturated six-carbon ring may exist in either the chair conformation or the boat conformation with a difference in energy of approximately 5 kcal/mol.[4] When a methylene group is replaced with a hetero atom, the energy of the boat form is less because of fewer interactions between consecutive methylene groups.[5] Consequently, one would expect II to have a higher concentration of the boat conformer as the temperature is increased.

In the boat conformation (Figure 2), the hetero-oxygen atom represents the negative end of a dipole which acts to increase the electron density on the nitrogen atom more so than in the chair conformation. Consequently, the reversed substituent effect of the oxygen atom should accelerate the rate of the alkylation and be more enhanced with a higher concentration of the boat conformers at the higher temperatures.[6]

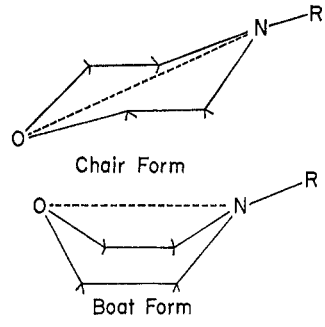

Figure 2.—Conformations of ethyl 4-morpholineacetate.

The experimental evidence for the reverse substituent effect was first reported by Stock[7] in his comparison of the pK_a values for dibenzobicyclo[2.2.2]octa-2,5-diene-9-carboxylic acid (pK_a = 6.04) and 16-chlorobicyclo[2.2.2]octa-2,5-diene-9-carboxylic acid (pK_a = 6.25). Roberts and Carboni[8] suggested a field effect for a chloro atom in *o*-chlorophenylpropiolic acid when the inductive effect was not so great as expected for the *o*-chloro group.

Since the entropy term (Table II) for II is more negative than for I, one can rule out a steric argument for a rate increase. If II had a preferred conformation for a more favorable attack by the ethyl bromoacetate, then one would expect to find the entropy term less negative. The entropy term for II is probably more negative than for I because of the steric interference that may result for the hetero-oxygen atom and the carboxyl oxygen atoms of the two N-carbethoxymethyl groups.

TABLE II

RATE CONSTANTS, ACTIVATION ENERGIES, AND ENTROPIES FOR TERTIARY AMINES AT 25°

Amine	$k \times 10^6$, l./(mol sec)	ΔE, kcal/mol	$-\Delta S$, cal/(mol deg)
N-Carbethoxymethylpiperidine (I)	8.86	17.2	26.0
N-Carbethoxymethylmorpholine (II)	0.89	18.1	27.6
Ethyl N,N-diethylglycinate (III)	5.71	14.6	35.6
Ethyl N,N-di-*n*-butylglycinate (IV)	4.22	14.8	35.6

The activation energies (Table II) indicate no irregularities from what one would predict. The close agreement between III and IV is justified if one accepts the steric similarity[3] between the *n*-butyl and the ethyl groups.

The larger (less negative) entropy terms for III and IV compared to I and II are undoubtedly the results of restricting the freedom of movement of the alkyl groups in the quaternary ammonium salt product compared to the tertiary amine reactant. In the case of morpholine and piperidine, there is no restriction of movement in

(1) B. D. Coleman and R. M. Fuoss, *J. Amer. Chem. Soc.*, **77**, 5472 (1955).
(2) H. K. Hall, Jr., *ibid.*, **79**, 5443 (1957).
(3) C. A. Bunton, "Nucleophilic Substitution at a Saturated Carbon Atom," Elsevier Publishing Co., New York, N. Y., 1963, p 27.
(4) M. Balasubramanian, *Chem. Rev.*, **62**, 591 (1962).
(5) W. D. Kimler and A. C. Huntric, *J. Amer. Chem. Soc.*, **78**, 3369 (1956).
(6) *Note:* Solvation, as suggested by a reviewer, may play an important part in explaining these small differences in energy since piperidine could be solvated quite differently from morpholine.
(7) R. Golden and L. M. Stock, *ibid.*, **88**, 5928 (1966).
(8) J. D. Roberts and R. A. Carboni, *ibid.*, **77**, 5554 (1955).

the alkyl groups in going from the tertiary amine to the salt because they are part of the heterocyclic ring.

The activation energies and frequency factors of the study compared favorably with those for triethylamine and ethyl iodide as reported by Wolff[9] (Table III).

TABLE III
FORMATION OF QUATERNARY AMMONIUM SALTS (100°)
(ETHYL IODIDE AND TRIETHYLAMINE)

Solvent	$k \times 10^6$, l./(mol sec)	E, kcal/mol
Acetone	26.5	11.9
Nitrobenzene	138.3	11.6

Experimental Section

Compounds I (bp 50° at 0.150 mm), II (bp 68° at 0.60 mm), III (bp 50° at 3.54 mm), and IV (bp 75° at 1.15 mm) were prepared by reacting ethyl bromoacetate with a one molar excess of the respective secondary amine. All four tertiary amines were purified by distillation through an annular spinning-band[10] column under reduced pressure. The purity of the tertiary amine was established by vpc.[11]

To establish the identity of the tertiary amines, each amine (compound IV was an exception) was converted to a quaternary ammonium salt by reaction of the tertiary amine with ethyl bromoacetate. Compound I formed N,N-dicarbethoxymethylpiperidinium bromide. The diester was recrystallized from absolute ethanol, mp 134–134.5°.

Anal. Calcd for $C_{13}H_{24}O_4NBr$: C, 46.16; H, 7.15; N, 4.14; mol wt, 338.2. Found: C, 46.22; H, 7.03; N, 4.12; mol wt ($AgNO_3$ titration), 339.6.

Compound II formed N,N-dicarbethoxymethylmorpholium bromide. The diester was recrystallized from absolute ethanol, mp 157–158°.

Anal. Calcd for $C_{12}H_{22}O_5NBr$: C, 42.36; H, 6.52; N, 4.12; mol wt, 340.2. Found: C, 42.42; H, 6.32; N, 3.97; mol wt ($AgNO_3$ titration), 344.2.

Compounds III and IV failed to form a solid ester when treated with ethyl bromoacetate in absolute methanol. Consequently, the viscous diesters were hydrolyzed with 48% HBr refluxing for 2 hr. The diethyl N,N-dicarboxymethylammonium bromide was recrystallized from glacial acetic acid, mp 172–174°.

Anal. Calcd for $C_8H_{16}O_4NBr$: C, 35.57; H, 5.97; N, 5.19; mol wt, 270.13. Found: C, 35.56; H, 5.92; N, 5.19; mol wt ($AgNO_3$ titration), 270.2.

Compound IV could not be converted successfully to the quaternary ammonium diester or diacid. Consequently, the identity of the amine was established by comparing its boiling point, infrared spectrum, and vpc retention time with those of III. These comparisons indicated that compound IV had been successfully prepared.

Sample Preparation.—The samples for the kinetic study were prepared by weighing in separate flasks to ±0.1 mg sufficient tertiary amine and ethyl bromoacetate to make 50 ml of 0.0500 *M* solution. Each of these flasks was diluted with approximately 20 ml of absolute methanol (Baker Analyzed Reagent) and placed in a constant-temperature bath capable of maintaining a temperature of ±0.1°. Each sample of tertiary amine and ethyl bromoacetate was mixed in preheated 50-ml volumetric flasks and diluted with preheated methanol to 50 ml which established each sample at 0.0500 *M* in tertiary amine and ethyl bromoacetate. Three duplicate samples of each compound were prepared and studied at the same time. No correction was made for the expansion of the glassware or the solvent.

Procedure for Potentiometric Titration.—Three samples of a given compound at each temperature were titrated at 15-min intervals. From each of these samples, three 1.00-ml aliquots were diluted with 10.0 ml of cold 0.10 *N* H_2SO_4 within 30 sec of each other. Aliquots were titrated within 10 min after being withdrawn.

The bromide ion was titrated with 0.0500 *M* $AgNO_3$ from a 10-ml graduated buret. The Beckman expandomatic pH meter with a Beckman No. 39167 glass electrode and a laboratory constructed Ag|AgBr electrode were used in the titration. The accuracy of this technique was established by titrating 1.00-ml aliquots of 0.0050 *M* tetra-*n*-butylammonium bromide in 10 ml of 0.10 *N* H_2SO_4. The addition of 1.00 ml of ethyl bromoacetate did not interfere with the determination of a standard bromide ion concentration.

Silver nitrate was added in 0.05-ml increments until the end point was passed as indicated by a 100 mV or more change on the expanded scale.

Registry No.—Ethyl bromoacetate, 105-36-2; I, 23853-10-3; II, 3235-82-3; III, 2644-21-5; IV, 2644-24-8; N,N-dicarbethoxymethylpiperidinium bromide, 6262-05-6; N,N-dicarbethoxymethylmorpholium bromide, 23853-15-8; diethyl N,N-dicarboxymethylammonium bromide, 23853-16-9.

(9) H. G. Grimm, H. Reif, and J. Wolff, *Z. Phys. Chem.*, **B13**, 301 (1931).
(10) Nester–Faust annular spinning-band distillation column, Model NFT-50.
(11) Beckman GC-2A with thermotrac temperature programmer, 6-ft, 0.25-in. silicone column.