

the preliminary reaction. Silver ion adsorption is indicated for both reactions. The reactions were studied over the *pH* range 3.7–8.5.

4. The catalyzed reduction of silver ion by hydroxylamine may be expressed by the equation

$$\text{Ag}^+ + \text{NH}_2\text{O}^- \longrightarrow \text{Ag} + \text{N} + \text{H}_2\text{O}.$$

The NH_2O radical, if it is formed, decomposes at a rate rapid in comparison with the reduction process.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY, UNIVERSITY OF TORONTO]

The Relative Rates of Alcoholysis of Certain Aralkyl *p*-Nitrobenzoates

BY LAURENCE F. KING

Previous investigations on the alcoholysis of esters, chiefly those of aliphatic alcohols, indicate that the nature of the functional alcoholic groups involved, and the amount of branching of the carbon chain of the alkyl rather than its length, are the chief factors determining both the relative velocity with which replacement of alkyl radicals occurs¹ and the extent to which reaction will proceed until equilibrium is attained.² Tertiary alkyls are less reactive than secondary, which in turn are less reactive than primary. The replacement values of straight-chain groups, derived from both types of measurement, are generally of the same order of magnitude no matter what the length of the carbon chain, and are greater than those of more centralized radicals. These generalizations are in disagreement with the observations of Bellet³ on rates of replacement of certain aromatic alkyls.

The present paper constitutes a method for measuring the velocities with which esters of aromatic alcohols react in a faintly alkaline medium with aliphatic alcohols of low molecular weight. In order to eliminate the necessity for the customary fractional distillation of the reaction mixture, methanol and ethanol were chosen as the solvent alcohols; separation could then be effected quantitatively at room temperature and analysis made by a methoxyl or ethoxyl determination. Rates of reaction of the readily purified solid esters with the sodium alkoxide in a large excess of the alcohol were studied, absolute ether being used as a diluent in most cases.

Pseudo first-order velocity coefficients decrease markedly but regularly with the progress of the reaction; the existence of side reactions is indicated whether the medium is methanol, ethanol

or diluted with ether. Kremann⁴ has shown that hydrolysis of the ester may be a relatively important factor, and in confirmation of this we observed that the rates of methanolysis of phenyl and benzyl *p*-nitrobenzoates are influenced to an abnormally high degree by slight variations in the concentration of alkali and water in the solvent. Hydrolysis is not the only disturbing side reaction, however, since the *K*-values in ethanol exhibit no greater constancy than those in methanol; in the latter case the concentrations of alkali and water are much higher than in the former. Assumptions of other than a simple first-order reaction lead to no greater constancy of *K*. In order to relate, more or less quantitatively, the reactivities of the ester alkyl groups, the first-order coefficients were averaged for the same reaction interval (15–40% ester conversion) and the benzyl radical was assigned a value of 100 (see Table I). The limits of accuracy shown are an indication only of the "fading" of the *K*-values and not of errors of measurement. The presence of anhydrous ether is apparently of little consequence as far as relative rates are concerned: for groups (1) and (2) the ratio K_1/K_2 is approximately equal to K_2/K_3 . The peroxide content of the ether is not a determining factor, identical re-

TABLE I
RELATIVE REACTIVITY OF ARALKYL GROUPS (R) IN ALCOHOLYSIS OF *p*-NITROBENZOATES

R	K_1 (CH ₃ OH)	K_2 (CH ₃ OH- ether)	K_3 (C ₂ H ₅ OH- ether)
(1) Benzyl	100 ^a ± 22	100 ± 16	100 ± 6
(2) 2-Ph-ethyl	37 ± 3	36 ± 6	30 ± 4
(3) 2-Ph-propyl		18 ± 3	16 ± 2
(4) 3-Ph-propyl		10 ± 1	16 ± 1
(5) 1-Ph-propyl		6 ± 1	6.0 ± 0.7
(6) 1-Ph-ethyl		5.0 ± 0.2	16 ± 1
(7) 2-Ph-isopropyl		1.0 ± 0.2	1.0 ± 0.07
(8) 1-Ph-isopropyl		0.0	0.0

^a K_1 for phenyl considerably >100.

(4) Kremann, *Monatsh.*, **26**, 788 (1905); **29**, 23 (1908).

(1) Pfannl, *Monatsh.*, **31**, 301 (1910); **32**, 509 (1911).

(2) (a) Fehlandt and Adkins, *THIS JOURNAL*, **57**, 193 (1935);
(b) Hatch and Adkins, *ibid.*, **59**, 1894 (1937).

(3) Bellet, *Compt. rend.*, **193**, 1020 (1931); **194**, 1655 (1932).

sults being obtained with peroxide-free solvent and with that giving a strong ferrous chloride test.

Although there is no simple, direct variation between the rate of alcoholysis and the molecular weight of the alcohol combined with the ester, the rate is strongly influenced by the length of the carbon chain. Introduction of one and two methylene groups into the benzyl radical to give 2-phenylethyl and 3-phenylpropyl results in successive, considerable decreases in reactivity. This order is the converse of that obtained by Fehlandt and Adkins^{2a} from equilibrium studies of the corresponding acetates in a slightly acid medium. Phenyl *p*-nitrobenzoate reacts with methanol much more rapidly even than the benzyl ester.

The effect of branching of the carbon chain is somewhat more difficult to interpret. As in a large number of other reactions, the substitution of a hydrogen on the α -carbon atom by phenyl or methyl results in lowered reactivity. The tertiary aralkyl (8) is practically inert under the same conditions for which the isomeric primary and secondary radicals react. The secondary propyl and isopropyl groups (5) and (7) are replaced less readily than the primary (3) and (4); and the secondary ethyl (6) is less reactive than the primary (2). The effect of branching at either the β - or the γ -position, such as in (3) and (4)—which of course does not alter the nature of the functional alcoholic group—is not perfectly apparent, although it is reasonable to suppose that any blocking effect will be reduced the farther the substitution occurs from the reactive carbon atom.

Our observation is that methanolysis is a far more rapid reaction than ethanolysis under similar conditions; for instance, reaction in absolute methanol is extremely fast even at low catalyst concentrations while that in absolute ethanol can be very conveniently measured. Fehlandt and Adkins found that methyl alcohol has the highest replacement value of all the alcohols they studied. A possible explanation may be found in a consideration of these alcohols as weak acids in the sense suggested by Brönsted.⁵ McEwen⁶ has shown that methanol is a stronger acid than ethanol; therefore, it is reasonable to conclude that since more methoxyl ions than ethoxyl ions are available for addition to the ester carbonyl, methanol-

ysis will be the faster reaction. McEwen has found that, in general, the relative acidity of alcohols is in the descending order, primary, secondary, tertiary, which is the same as for the alcoholysis of an ester. With the exception of (6), the order of relative reactivity toward both alcohols is the same. No explanation has been found for the apparently anomalous behavior of this ester.

Experimental Part

Two analytical procedures have been adopted: the first is applicable only to esters of alcohols possessing a certain solubility in water, *e. g.*, benzyl and 2-phenylethyl, while the second may be used for the esters of any alcohol provided that the latter has a sufficiently high boiling point. According to Method I the aryl alcohol formed during the reaction is removed prior to analysis; in Method II only the solvent alcohol is separated.

Method I

Reagents.—The methanol was C. A. F. Kahlbaum "zur Analyse," partially dehydrated by distilling from sodium. The fraction of b. p. 64.5–64.8° contained 0.60% water as determined according to Jones and Amstell.⁷ It was protected from atmospheric carbon dioxide. The sodium methoxide solution, standardized by Pregl's micro-procedure, showed no variation in concentration on standing for two months.

Procedure.—The ester (0.100 g.), dried several hours *in vacuo*, was dissolved in 7.00 ml. of methanol at the temperature of the thermostat (25.0 \pm 0.1° over short reaction periods and \pm 0.2° over longer intervals). For the benzyl ester 0.55 ml. of catalyst solution was added, and for the 2-phenylethyl ester, 0.52 ml. (0.0230 equivalent of sodium). The alcoholysis was stopped by adding a few drops of a hydrochloric acid-methanol solution. The solution was evaporated just to dryness on the water-bath, the residue was taken up in 5 ml. of ether and transferred to a 15-ml. separating funnel. The ethereal solution was allowed to drop slowly onto a micro filter (prepared according to Pregl for the halogen determination) which was supported in a Pyrex steam jacket attached to the outlet tube of a water-bath. The residual esters and aryl alcohol were separated by extracting the latter with water (5–10 ml.). After dissolving the esters in hot acetone (10 ml.), the solvent was removed, and the residue dried *in vacuo*, powdered fine and analyzed for methoxyl (in duplicate). Pregl's gravimetric method was found to be

TABLE II

METHANOLYSIS OF ARALKYL *p*-NITROBENZOATES

Benzyl		2-Phenylethyl	
Time, min.	Ester transformed, %	Time, min.	Ester transformed, %
5	30	15	25
10.4	52	30	57
20	75	45	73
30	82	60	81
50	95	90	92

(5) Brönsted, *J. Phys. Chem.*, **30**, 777 (1926).

(6) McEwen, *THIS JOURNAL*, **58**, 1124 (1936).

(7) Jones and Amstell, *J. Chem. Soc.*, 1316 (1930).

suitable without modification. The results are shown in Table II.

The efficacy of the method was demonstrated by submitting synthetic ester-alcohol mixtures to the entire procedure. Of the total weight of esters taken, 94-97% could be recovered.

Method II

Reagents.—The methanol (Kahlbaum "zur Analyse") contained 0.35% water, a value that remained constant during four months. The ether was Merck "anhydrous" dried with sodium and redistilled in 5-10 ml. lots just before use. The ethanol was prepared by dehydration of "absolute" alcohol with diethyl phthalate and sodium⁸ and was protected from carbon dioxide. Of the sodium methoxide solution the following volumes were used for 0.100 g. of ester: benzyl, 0.47 ml.; phenylethyl, 0.44 ml.; phenylpropyl, 0.41 ml. (0.0110 equivalent sodium per mole ester) and of the sodium ethoxide solution, 0.50 ml., 0.47 ml., and 0.44 ml. (0.0083 equivalent sodium).

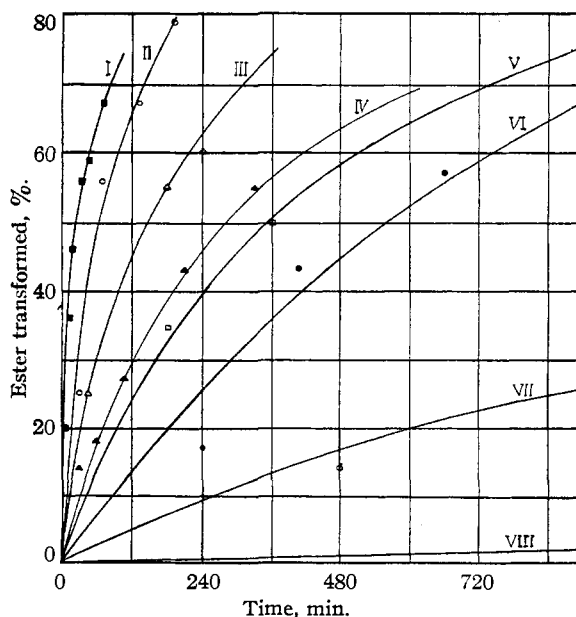


Fig. 1.—Rates of methanolysis of aralkyl *p*-nitrobenzoates at 25° in MeOH-ether; 0.0110 equiv. sodium as catalyst; 0.35% water in MeOH: Curve I ■, benzyl; II ○, 2-ph-ethyl; III △, 2-ph-propyl; IV ▲, 3-ph-propyl; V □, 1-ph-propyl; VI ●, 1-ph-ethyl; VII ◊, 2-ph-isopropyl; VIII 1-ph-isopropyl. Additional data: for V, 1080, 75.4%; 1770, 81.8%; VI, 1200, 79.5%; 1800, 89.5%; VII, 1020, 40.6%; 1740, 50.2%; VIII, 3180, 4.4%.

Procedure.—To 0.100 g. of dried ester were added 5.00 ml. of ether, 5.00 ml. of the alcohol, and the catalyst solution, all at 25.0°. The methanolyses were stopped as in Method I while for the ethanolyses a small piece of solid carbon dioxide was used. Both gave consistent results. The solution was transferred to a weighed 15-ml. centrifuge tube provided with a hook of nichrome wire and the solvent was removed *in vacuo* over sulfuric acid;

(8) According to Manske, *THIS JOURNAL*, **53**, 1106 (1931), the water content of alcohol so prepared is too small to be detected.

in order to prevent loss by bumping, the tube was provided near the top with a side-arm pulled out to a capillary of 1-2 mm. bore and the top of the tube was closed with a rubber stopper. Methanol could be removed quantitatively in two and one-half to three hours, ethanol in three and one-half to four hours. Control experiments proved that no measurable alcoholysis occurred during the separation. In some of the ethanolyses the intermediate ester-carbinol mixtures obtained were liquid or semi-liquid in which case last traces of solvent were removed in a drying pistol over phosphorus pentoxide. The residue was melted down and, when possible, allowed to crystallize by dipping the tube into ice water. The amount of methyl or ethyl ester present was determined by duplicate analyses.

Synthetic mixtures corresponding to (a) 50% and (b) 100% methanolysis of the original ester, when analyzed by Pregl's procedure, gave inconsistent results, due chiefly to insufficient heating of the sample (twenty minutes). The shorter, volumetric Vieböck method, as adapted by Lieff, Marks and Wright,⁹ together with a heating time of forty-five minutes, yielded reproducible values. The blanks were somewhat higher than the theoretical, because of partial codistillation of the aromatic iodide; at half-conversion the error was about 4% and at complete conversion, about 11%. Therefore, experimental points above 80% conversion were not considered. Determination of ethoxyl required seventy-five minutes of heating and higher reflux of the vapors in the apparatus. Liquid

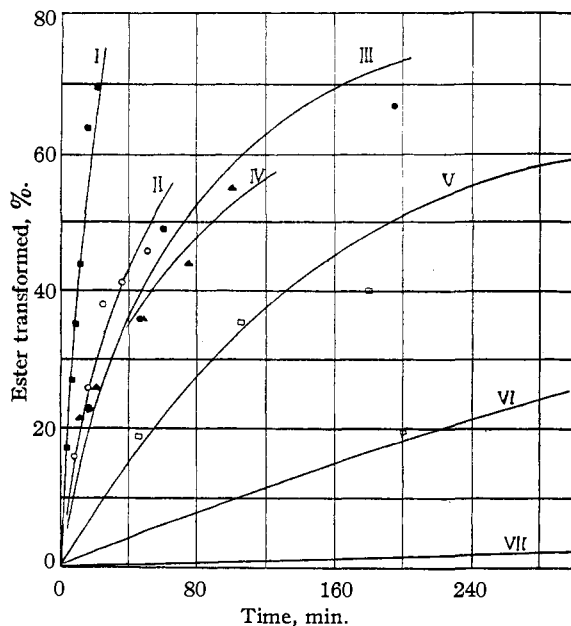


Fig. 2.—Rates of ethanolysis of aralkyl *p*-nitrobenzoates at 25° in EtOH-ether; 0.0083 equiv. sodium as catalyst; 0.0% water in EtOH: Curve I ■, benzyl; II ○, 2-ph-ethyl; III ●, 1-ph-ethyl; IV ▲, 2- and 3-ph-propyl (almost identical); V □, 1-ph-propyl; VI ◊, 2-ph-isopropyl; VII 1-ph-isopropyl. Additional data: for VI, 360, 24.1%; 720, 40.9%; 1380, 56.1%; VII, 1380, 4.6%.

(9) Lieff, Marks and Wright, *Can. J. Research*, **B15**, 529 (1937).

TABLE III
 PHYSICAL PROPERTIES OF THE ESTERS

Ester	Recrystn. ^a medium	Crystal form	M. p., ^b °C.	Carbon		Analyses (%) ^c		Nitrogen	
				Calcd.	Found	Calcd.	Found	Calcd.	Found
Methyl ^d	C ₆ H ₆ -ligroin	Plates	95.5-96.0						
Ethyl ^e	Aq. alc.	Needles	56.0-56.5						
Phenyl	Acetone-alc.	Needles	129-130						
Benzyl	Alc.	Plates	83.5-84.5						
1-Ph-ethyl	Alc.	Needles	42.5-43.5 ^f	66.39	66.23	4.83	4.68		
2-Ph-ethyl	Alc.	Plates	61.5-62.0					5.05	4.92
1-Ph-propyl	Alc.	Prisms	56.5-57.5 ^g						
2-Ph-propyl	Alc.	Plates	64.5-65.5					4.91	4.82
3-Ph-propyl	Alc.	Needles	46.5-47.5 ^h						
1-Ph-isopropyl ⁱ	Alc.	Long needles	136-137	67.35	67.51	5.30	5.20	4.91	4.82
2-Ph-isopropyl ⁱ	Alc.	Plates	61-62		67.50		5.35		5.06

^a Recrystallized to constant m. p. ^b M. p.'s corrected. ^c By Dr. H. Stantial. ^d Calcd.: CH₃O, 17.14; found 17.27. ^e Calcd.: C₂H₅O, 23.09; found 23.25. ^f Ward, *J. Chem. Soc.*, 453 (1927), gives m. p. 47-48°. ^g Meisenheimer, *Ann.*, **442**, 184 (1925), gives m. p. 59-60°. ^h Kirner, *THIS JOURNAL*, **48**, 1111 (1926), gives m. p. 45-46°. ⁱ Solubility in methanol and ethanol much less than other esters. ^j Prepared from both alcohols.^{11,12} M. p. and mixed m. p. both products identical.

or semi-liquid samples were analyzed by introducing them by a capillary pipet into a tin foil cup of double thickness. An ethanolysis blank on the 1-phenylpropyl ester was similar to those obtained for methanolysis. The experimental values (corrected on the basis of the controls) are shown graphically in Figs. 1 and 2.

Synthesis of the Compounds.—1-Phenylpropanol was prepared in 44% yield according to Klages' method¹⁰; b. p. 102-104° at 13-14 mm.

2-Phenylpropanol was synthesized in five stages: (1) α,α -phenylmethyl- β -chloroethanol was made by a slight modification of Tiffeneau's procedure¹¹ from chloroacetone and phenylmagnesium bromide. The reaction mixture was stirred mechanically at -10° during the addition of the Grignard reagent and then allowed to warm slowly to room temperature; a 55% yield of light-yellow liquid, b. p. 129-132° at 21 mm., was obtained. (2) The chlorohydrin was decomposed with sodium ethoxide¹² to give 79% of phenylmethylethylene oxide, a colorless liquid, b. p. 72-75° at 10-11 mm. (3) The oxide was isomerized to hydrochloric aldehyde, in 66% yield, by treating with hydrochloric acid.¹³ A fraction boiling at 80-87° at 10-11 mm. was collected. (4) Zinc dust-acetic acid reduction of the aldehyde¹³ gave 57% of 2-phenylpropyl acetate, b. p. 95-105° at 10-11 mm. Cohen, *et al.*, record a b. p. 125° at 14 mm. while Wohl and Berthold¹⁴ give 103-105° at 11 mm. (5) Saponification of the acetate¹³ gave 70% of 2-phenylpropanol, b. p. 110-113° at 11 mm.

2-Phenylisopropyl alcohol was prepared in 58% yield according to Austerweil and Cochin.¹⁵ Carpenter,¹⁶ using phenylmagnesium bromide and propylene oxide, obtained a mixture of this alcohol and 2-phenylpropanol. We obtained by this method only 2-phenylisopropyl alcohol (49% yield, b. p. 105-107° at 22 mm., the same

as that for the product of the other reaction). The phenyl urethane, prepared from both products, melted at 87-88°. Emde and Runne¹⁷ give a m. p. of 90°.

1-Phenylisopropyl alcohol resulted in 58% yield when Klages' procedure,¹⁸ with special precautions against too great a rise of temperature during the extraction, was used. Its b. p. was 95-96° at 14-15 mm.

The *p*-nitrobenzoyl esters of the aromatic alcohols, with the exceptions noted, were prepared from the alcohol and the acid chloride (10% excess) in dry pyridine. After standing for several hours at room temperature the ester was extracted with ether, the ether layer was shaken with dilute sulfuric acid, then with dilute sodium carbonate and dried over anhydrous sodium sulfate. The phenyl ester was prepared from the acid chloride and phenol without solvent.¹⁹ The methyl ester was made by dissolving the benzyl ester (2 g.) in methanol (10 ml.), adding about 0.1 equivalent of sodium and allowing the solution to stand one-half hour at room temperature. The ethyl ester was prepared by the action of a dilute sodium ethoxide solution on the ester residues from previous experiments.

Acknowledgments.—The author wishes to acknowledge the assistance given him by the late Dr. F. B. Allan, by Professor W. S. Funnell and Dr. G. F. Wright.

Summary

1. The relative rates of alcoholysis of several aralkyl *p*-nitrobenzoates in methanol, methanol-ether, and ethanol-ether have been studied.

2. Methanolysis takes place more rapidly than ethanolysis.

3. The relative reactivity of eight aralkyl groups has been shown to be dependent largely upon the molecular weight of the aryl alcohol

(10) Klages, *Ber.*, **36**, 621 (1903).

(11) Tiffeneau, *Ann. chim. phys.*, [8] **10**, 352 (1907).

(12) Klages, *Ber.*, **38**, 1969 (1905).

(13) Cohen, Marshall and Woodman, *J. Chem. Soc.*, **107**, 897 (1915).

(14) Wohl and Berthold, *Ber.*, **43**, 2185 (1910).

(15) Austerweil and Cochin, *Compt. rend.*, **150**, 1695 (1910).

(16) Carpenter, *Chem. Zentr.*, **107**, I, 2440 (1936).

(17) Emde and Runne, *Arch. Pharmazie*, **249**, 363 (1911).

(18) Klages, *Ber.*, **35**, 2639 (1902).

(19) Raiford, Taft and Lankelma, *THIS JOURNAL*, **46**, 2051 (1924).

and upon the nature of the functional alcoholic groups and to a smaller extent on the position of the benzene ring in the molecule.

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[CONTRIBUTION FROM THE NOYES CHEMICAL LABORATORY, UNIVERSITY OF ILLINOIS]

Acid Catalysis in Amines. II. The Catalytic Effect of Various Butylammonium Salts on the Aminolysis of Ethyl Phenylacetate in Anhydrous *n*-Butylamine

BY PAUL K. GLASOE, J. KLEINBERG AND L. F. AUDRIETH

Experimental evidence already has been presented to demonstrate that the ammonolysis of esters in anhydrous liquid ammonia is markedly catalyzed by the presence of ammonium salts.¹⁻⁴ The catalytic effect of equimolar concentrations of different ammonium salts has been found to decrease in the following order: $C_2H_3O_2^- > C_6H_5COO^- > Cl^- > Br^- > NO_3^- > I^- > ClO_4^-$.^{2,4} This result is quite unexpected, especially if this effect is to be interpreted as an example of acid catalysis in a non-aqueous solvent. This anion order is exactly opposite from what might be expected from a consideration of those physical properties of ammonium salts in liquid ammonia which presumably permit a quantitative estimation of the ammonium ion concentration.

In extending these studies from ammonia to amines it has been shown that aminolytic reactions are also catalyzed by the solvated proton, introduced into the reaction mixture in the form of the amine salt.⁵ In view of the anomalous behavior of ammonium salts in accelerating the ammonolysis of esters it became of distinct interest to determine whether the catalytic effect of equimolar concentrations of different amine salts also varied with the nature of the anion, as observed in the case of liquid ammonia. The present investigation was therefore undertaken to study the influence of various butylammonium salts on the rate of the reaction between anhydrous butylamine and ethyl phenylacetate.

Experimental

Procedure.—Due to the excessive solubility of the various butylammonium salts in anhydrous butylamine, and their hygroscopicity, the method used in the actual isolation and preparation of analogous cyclohexylammonium salts⁵ could not

be employed satisfactorily.⁶ Consequently, butylammonium salts were in most instances not isolated, but prepared in butylamine by adding a definite quantity of ammonium salt to an excess of amine. The resulting mixtures were then warmed on the steam-bath under slightly reduced pressure to effect removal of ammonia, yielding solutions of known content of butylammonium salts.

In preparing standard solutions for reaction velocity studies a definite quantity of ester was added to the amine solution of the specific salt and the mixture diluted with amine to exactly 25 cc. Two-cc. samples of this mixture were transferred to small Pyrex test-tubes which were immediately sealed and placed in a thermostat at 25°. At definite intervals of time tubes were removed, broken into an excess of standard hydrochloric acid and back titrated with standard sodium hydroxide using a methylene blue-methyl red indicator. The difference between these titrations and an initial one carried out at the beginning of each series of runs gave a measure of the amount of amine used and therefore a measure of the amount of ester which had reacted to form the *N*-substituted amide.

Discussion of Results

Ethyl phenylacetate reacts with butylamine in accordance with the equation: $C_6H_5CH_2COOC_2H_5 + C_4H_9NH_2 \rightarrow C_6H_5CH_2CONHC_4H_9 + C_2H_5OH$. The reaction is very slow, as is evident from Curve 11, Fig. 1, in which the % yield of amide is plotted as a function of time. Addition of butylammonium salts, presumably acting as acids in butylamine because of the presence of the $C_4H_9NH_2 \cdot H^+$ ion, accelerates aminolysis markedly. However, the magnitude of the cata-

(1) Slobutsky and Audrieth, *Proc. Natl. Acad. Sci.*, **23**, 611 (1937).

(2) Fellingner and Audrieth, *THIS JOURNAL*, **60**, 579 (1938).

(3) Audrieth and Kleinberg, *J. Org. Chem.*, **3**, 312 (1938).

(4) Shatenshtein, *THIS JOURNAL*, **59**, 432 (1937).

(5) Glasoe and Audrieth, *J. Org. Chem.*, **4**, 34 (1939).

(6) It was also observed in the attempted preparation of butylammonium nitrate from butylamine and ammonium nitrate that aminolysis with evolution of ammonia was limited to dilute solutions and that further quantities of ammonium nitrate could be dissolved subsequently in the amine without reaction.