253. *Reaction Kinetics and the Walden Inversion. Part II. Homogeneous Hydrolysis, Alcoholysis, and Ammonolysis of α-Phenylethyl Halides.*
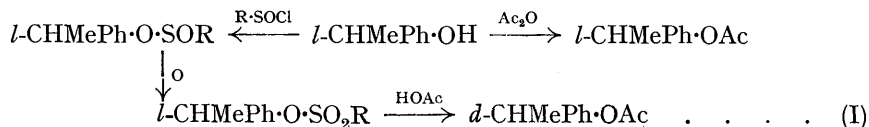
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The next case to be taken up in the kinetics-controlled stereochemical study of the replacement of Hal by OR is that in which, besides hydrogen and alkyl, an aryl group is attached to the asymmetric atom : we study now the hydroxylation, methoxylation or ethoxylation (also amination) of α-phenylethyl chloride and bromide.

It was necessary, as in the previous case, to fix maximal rotations and the relation of configuration to sign of rotation. Kinetic measurements showed that unimolecular hydroxylation was the only realisable hydroxylation, whereas both uni- and bi-molecular methoxylation and ethoxylation occurred : the rates of the separate and the simultaneous reactions were determined. For the investigation of the optical effect of substitution, the simultaneous reactions could be isolated (in part by calculation), so that again it was possible to determine the stereochemical effect associated with each mechanism. It was found that bimolecular substitution leads to inversion with little if any racemisation, whilst unimolecular substitution produces a predominating inversion with extensive, sometimes nearly complete, racemisation. The amount of racemisation accompanying unimolecular hydroxylation was increased when the water in the medium was replaced by acetone. Quantitative particulars are given.

THIS paper records a study of steric orientation in nucleophilic replacements of X in the system CHMePh·X. The reactions which we have investigated are the hydrolysis, methyl alcoholysis, ethyl alcoholysis, and ammonolysis of α-phenylethyl chloride, and the hydrolysis of the bromide.

We have first to consider the relation of sign of rotation to configuration amongst α-phenylethyl compounds, and the central part of this problem is the establishment of such a relation for the alcohol and the chloride. Concerning this point, Kenyon, Phillips, and Taylor (J., 1933, 173) have adduced a line of reasoning which, whilst superficially similar to that which Houssa, Kenyon, and Phillips applied with success to β-*n*-octyl alcohol and its chloride, is actually less convincing; it can, however, be made part of the basis of a conclusive argument. The inversion involved in the sequence

$$l\text{-CHMePh·O·SOR} \xleftarrow{\text{R·SOCl}} l\text{-CHMePh·OH} \xrightarrow{\text{Ac}_2\text{O}} l\text{-CHMePh·OAc}$$

$$\downarrow \text{O}$$

$$l\text{-CHMePh·O·SO}_2\text{R} \xrightarrow{\text{HOAc}} d\text{-CHMePh·OAc} \quad . \quad . \quad . \quad . \quad \text{(I)}$$

can occur only in reaction (I), since this is the only reaction in which a bond of the asymmetric carbon atom is exchanged. Kenyon, Phillips, and Taylor assume that this process is paralleled as to mechanism by reaction (II), which therefore may be presumed also to involve inversion :

$$l\text{-CHMePh·O·SO}_2\text{R} \xrightarrow{\bar{\text{Cl}}} d\text{-CHMePh·Cl} \quad . \quad . \quad . \quad . \quad \text{(II)}$$

Since the rotation of the chloride thus formed is opposite in sign to that of the original alcohol, it follows that an alcohol and chloride with rotations of like sign have similar configurations. The result is right, as we shall see, but the keystone of this argument is frail in that there is no evidence of the assumed identity of mechanism. One would be inclined *a priori* to presume the contrary. No acetate ions were added in the form of a metallic acetate in reaction (I), which is simply a decomposition of the sulphonate with the acetic acid solvent; it probably proceeds by a unimolecular mechanism (S_N1), kinetically dependent on the ionisation of the sulphonate. On the other hand, the reaction with the added chloride ions (II) may well be ordinary bimolecular replacement (S_N2).

We can, however, complete the demonstration in either of two ways, which both involve the use of other data. One method is as follows. Reaction (II) is a nucleophilic substitution which must be either unimolecular or bimolecular. If it is unimolecular, we may be sure that reaction (I) will be also; in this case, then, the reactions are analogous, so that the original conclusion holds. If, in the alternative, reaction (II) is bimolecular, then the proper analogy is with (III), which has been proved by the use of radioactive bromine to involve inversion (Hughes, Juliusburger, Scott, Topley, and Weiss, J., 1936, 1173) :

$$l\text{-CHMePh·Br} \xrightarrow{\bar{\text{Br}}} d\text{-CHMePh·Br} \quad . \quad . \quad . \quad . \quad \text{(III)}$$

Therefore in any case reaction (II) involves inversion, and the original conclusion stands.

The second argument depends on the demonstration given in this paper that for α-phenylethyl compounds unimolecular and bimolecular nucleophilic substitutions have the same type of steric orientation. Actually we shall show that the dominant steric orientation in this series is always inversion, but all that it is necessary to accept at this stage is what follows immediately from the experimental results, *viz.*, the *similarity* of orientation. Hence, without considering mechanism, we may be sure that reaction (II) involves inversion because we know that reactions (I) and (III) do so. This also establishes the original conclusion.

Kenyon, Phillips, and Taylor observed that much racemisation accompanied both the reactions (I) and (II), and we shall show that in the α-phenylethyl series a large amount of racemisation is characteristic of unimolecular nucleophilic substitutions. This is consistent with the view that reaction (I) occurs by the unimolecular mechanism. As to reaction (II) there are two possibilities : either it is unimolecular, racemisation being then a normal

accompaniment, or it is bimolecular and is succeeded by a racemising halogen exchange of the type of reaction (III).

We have now to extend the argument concerning the connexion of rotation with configuration to the other α-phenylethyl compounds which we have employed. Pickard and Kenyon have shown (J., 1911, **99**, 45), and we have confirmed, that on treatment with hydrogen chloride α-phenylethyl alcohol gives a chloride with an inverted sign of rotation; it follows from the foregoing that this reaction inverts configuration. We therefore assume an inversion of configuration in the reaction of hydrogen bromide with the alcohol. Contrary to Holmberg (*Ber.*, 1912, **45**, 997) who obtained a completely racemic bromide, we find that this reaction gives a bromide with an inverted sign of rotation.* It follows that the relation of rotation to configuration is similar for the chloride and bromide. A confirmatory observation is that when either the chloride or the bromide is hydrolysed by water the resulting alcohol has an inverted sign of rotation.

The alkylation of an alcohol through its sodium salt cannot involve a Walden inversion. When α-phenylethyl alcohol is methylated or ethylated by this method the methyl or ethyl ether has a rotation of the same sign as that of the original alcohol. It follows that the alcohol and its ethers with like signs of rotation have like configurations.

When α-phenylethyl chloride is treated with sodium methoxide in methyl-alcoholic solution a bimolecular substitution occurs. The methyl ether formed has an inverted sign of rotation, and therefore, by the preceding argument, an inverted configuration. A similar result follows when the reagent is sodium ethoxide in ethyl-alcoholic solution, and the inference is the same. It also follows directly from the results quoted later that the predominating stereo-orientation in unimolecular hydrolysis and in unimolecular and bimolecular methyl and ethyl alcoholysis is the same, *viz.*, inversion. We may assume that the same will be true for ammonolysis even though the kinetics are not experimentally established. The amine produced has an inverted sign of rotation. It follows that the chloride and amine when in the same configuration have rotations of the same sign.

Summarising, we find that when α-phenylethyl chloride, bromide, alcohol, methyl ether, ethyl ether, and α-phenylethylamine have rotations of the same sign their configurations are similar.

These preliminary questions settled, we may turn to the main part of the research, the object of which was to determine the changes of optical activity accompanying substitutions under conditions of defined reaction kinetics.

We have examined the hydrolysis of optically active α-phenylethyl chloride by the following reagents : (1) Water.—Two liquid phases were present, the aqueous layer, initially neutral, becoming acid with hydrochloric acid during the progress of hydrolysis. (2) Aqueous potassium hydroxide.—Again two liquid phases were present, and in the aqueous phase the alkali was about $1.7N$. (3) 60% Aqueous acetone.—The solution was homogeneous and acidic throughout hydrolysis. (4) Solution of potassium hydroxide in " 60% " aqueous acetone.—The solution was homogeneous and the alkali of the order of $0.03N$. (5) 80% Aqueous acetone.—The solution was homogeneous and acidic.

The relevant kinetic data may be summarised as follows : (1, 2).—When water is the only solvent the kinetics cannot be investigated in the ordinary way because the reaction mixtures have two phases; nevertheless there can be no doubt that hydrolysis is unimolecular under these conditions since semi-quantitative observation has shown that the rate is not increased by the presence of potassium hydroxide. (3, 4, 5).—Using 80% aqueous ethyl alcohol as solvent, Ward has shown (J., 1927, 445) that the hydrolysis of α-phenylethyl chloride is unimolecular, the rate being unaffected by added potassium hydroxide; and we have supplemented Ward's work by measurement of the unimolecular rate in " 60% " and " 80% " aqueous acetone.

As it appeared to be impossible to realise a homogeneous bimolecular hydrolysis of α-phenylethyl chloride, we took up the study of its methyl and ethyl alcoholysis. The smaller ionising power of alcoholic than of aqueous media is expected to depress the unimolecular reaction; at the same time, the greater reactivity of methoxide and ethoxide ions than

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* Holmberg did not use a solvent, whereas we carried out the reaction in acetic acid and also in benzene solution.

of hydroxide ions should facilitate bimolecular substitution. These anticipations were realised : already in methyl alcoholysis the bimolecular reaction could be made to predominate, although the unimolecular process remained important under the conditions investigated; for ethyl alcoholysis, however, we were able to examine a nearly exclusively bimolecular reaction.

The optically active chloride was alcoholysed by the following reagents : (6) Methyl alcohol.—The medium was acid throughout the change owing to the liberation of hydrogen chloride, which, however, slowly interacted with the solvent to form methyl chloride. (7) Methyl-alcoholic sodium methoxide (3·5N).   (8) Ethyl alcohol.—The liberated hydrogen chloride reacted rather extensively with the medium.   (9) Ethyl-alcoholic sodium ethoxide (2·8N).

The kinetic data applicable to these experiments are given in this paper. We have measured the unimolecular rates of alcoholysis in methyl and ethyl alcohol, and the total rates obtaining in the presence of sodium methoxide and ethoxide. From these results we can calculate the proportions in which the bimolecular and unimolecular substitutions occur under the conditions of the experiments with optically active material.

The optically active chloride has (10) been ammonolysed in liquid ammonia solution.

We are not able to express our results in an entirely satisfactory quantitative form because the rotatory power of optically pure α-phenylethyl chloride is not established. The highest recorded rotatory power, that obtained by McKenzie and Clough (J., 1913, **103**, 687), $[\alpha]_D^{20°} + 50\cdot6°$, or $\alpha_D^{20°}$ ($l = 10$ cm.) $+ 53\cdot8°$, has been equalled in some of Kenyon's investigations, and is probably not far from the maximum; for lack of any better datum we have calculated the rotations of our substitution products to correspond to chloride of this rotation. The rotary power of α-phenylethyl alcohol is known : $[\alpha]_D^{20°}$ $43\cdot4°$, or $\alpha_D^{20°}$ ($l = 10$ cm.) $44\cdot0°$; for hydrolysis, therefore, we are able to record the percentage optical purity of the product, and this is a lower limit to the percentage in which enantiomeric purity is retained during the substitution. By methylating α-phenylethyl alcohol through its sodium derivative we have obtained a methyl ether having $\alpha_D^{20°}$ ($l = 10$ cm.) $63\cdot6°$; but the rotatory power of the ether prepared by this method was not always the same, and we have no reason for believing that the highest rotation obtained represents optical purity. The same remark applies to the rotation, $\alpha_D^{20°}$ ($l = 10$ cm.) $74\cdot1°$, given by Kenyon and Phillips for similarly prepared α-phenylethyl ethyl ether (J., 1930, 1676; actually, the value here quoted is extrapolated from readings at other wave-lengths). In this connexion we have to remember that hydrogen in a benzyl side-chain, unlike paraffinoid hydrogen, is rather easily attacked by powerfully nucleophilic reagents such as the alkali metals, and that for these reactions, indeed for several of the reactions discussed in this paper, it is difficult to exclude the possibility of partial racemisation by mechanisms which are not directly dependent on the observed substitution. Optically pure α-phenylethylamine has $[\alpha]_D^{20°}$ $39\cdot5°$ or $\alpha_D^{20°}$ ($l = 10$ cm.) $37\cdot6°$.

Results and Conclusions.

The results are in Table I. The left-hand columns indicate the experimental conditions, the two centre columns the proportions in which the substitution is bimolecular and unimolecular, and the right-hand columns the rotatory powers of the factors and products. In the penultimate column the rotatory powers of the products (α-phenylethyl alcohol, methyl and ethyl ether, and α-phenylethylamine) have been calculated to correspond to chloride of rotation $\alpha_D^{20°}$ ($l = 10$ cm.) $+ 53\cdot8°$. The last column records the optical purity of the products calculated from the rotatory powers given in the previous column, and the rotations, where these are known, of the optically pure materials; only an insignificant part of the recorded racemisation is due to the attack of eliminated halide ions on the undecomposed halide. It has been shown by Ward (*loc. cit.*) that the first-order rate of halogen displacement from α-phenylethyl chloride in 80% aqueous alcohol is the same whether measured by chemical analysis or polarimetrically. We have extended Ward's work to include 80% aqueous acetone or anhydrous ethyl alcohol as solvent, and although we have detected the racemising attack of halide ions, the effect is too slight to warrant the application of a correction (cf. Part I) to the figures given in the table.

TABLE I.

Expt. No.	Solvent and temp.	Concn. of KOH, HCl, etc. (N). Initial.	Final.	Proportion of simultaneous reactions. S$_N$2 (%).	S$_N$1 (%).	Halide, $\alpha_D^{20°}$ ($l =$ 10 cm.).	$\alpha_D^{20°}$, obs.	Corr. to standard chloride.	Optical purity (%).†
		Hydrolysis of α-*phenylethyl chloride.*							
1a		0·00—0·13 HCl		0	100	−11·60°	+ 2·00°	− 9·3°	
1b	Water (20°) *	0·00—0·13 HCl		0	100	−47·12	+ 5·32	− 6·1	−17·5
2a		1·79—1·66 KOH		0	100	−39·20	+ 5·32	− 7·3	
2b		1·79—1·66 KOH		0	100	−47·12	+ 6·24	− 7·1	−16·4
3	60% Aqueous	0·00—0·04 HCl		0	100	−34·00	+ 1·32	− 2·1	
4	acetone (70°)	0·05—0·01 KOH		0	100	−34·00	+ 1·72	− 2·7	− 5·4
5a	80% Aqueous	0·00—0·19 HCl		0	100	+11·76	− 0·12	− 0·6	
5b	acetone (70°)	0·00—0·15 HCl		0	100	−34·00	+ 0·72	− 1·1	− 1·9
		Methyl alcoholysis of α-*phenylethyl chloride.*							
6	MeOH (70°)	0·00—0·14 HCl		0	100	+35·52	−10·24	−15·5	Low
7		3·6 —3·5 NaOMe		61	39	+35·52	−32·00	−48·2	High
		Ethyl alcoholysis of α-*phenylethyl chloride.*							
8a		0·00—0·14 HCl		0	100	−32·60	+ 6·80	−11·2	Low
8b	EtOH (70°) ‡	0·00—0·14 HCl		0	100	−14·48	+ 2·72	−10·1	
9a		2·85—2·7 NaOEt		92·5	7·5	−32·60	+22·00	−36·2	High
9b		2·85—2·7 NaOEt		92·5	7·5	−10·52	+ 7·00	−35·7	
		Ammonolysis of α-*phenylethyl chloride.*							
10	NH₃ (*ca.* 20°)	0·0 —3·0 NH₄Cl		0 (?)	100 (?)	+30·80	− 8·40	−14·6	−38·8
		Hydrolysis of α-*phenylethyl bromide.*							
11	Water (20°)	0·00—0·10 HBr		0	100	−12·80	+ 1·12	—	Low

* McKenzie and Clough (*loc. cit.*) paralleled expt. 2, but at 100°; they obtained a smaller retention of optical activity than we find at 20°.

† The negative sign signifies that configuration is inverted.

‡ Kenyon and Phillips alcoholysed the chloride by boiling it with ethyl alcohol in the presence of potassium carbonate (*loc. cit.*); their results were similar to those of expt. 8 (cf. also Bodendorf and Böhme, who describe an alcoholysis of the chloride in the presence of metallic chlorides; *Annalen*, 1935, **316**, 1).

The following conclusions may be drawn. All the substitutions, independently of mechanism, lead to a product with an inverted sign of rotation, and this, as we have proved, means in all cases an inverted configuration. Unimolecular substitutions are accompanied by much more extensive racemisation than bimolecular substitutions. In unimolecular hydrolysis racemisation becomes more and more nearly complete as the water is diluted with the inert solvent acetone. These findings are discussed in Part VI.

EXPERIMENTAL.

Optically Active α-*Phenylethyl Alcohol.*—For the preparation of the *dl*-alcohol we found the interaction of acetaldehyde and phenylmagnesium bromide more satisfactory than the reaction between benzaldehyde and methylmagnesium iodide. The product obtained by the former method was purer, the chief impurity being diphenyl, which, however, was eliminated when the alcohol was converted into its hydrogen phthalate. Ott's method of resolution was employed (*Ber.*, 1928, **61**, 2139), which consists essentially in crystallising the brucine salt of the hydrogen phthalate from acetone. The salt is not very soluble, and Houssa and Kenyon replaced ordinary crystallisation by repeated extraction (J., 1930, 2260). Even this process requires a large amount of acetone, and we have found it simpler merely to reflux the salt for a considerable time with a deficiency of this solvent, or to boil and cool the suspension repeatedly. Thus 400 g. of brucine salt of *l*-carbinyl ester were obtained almost optically pure by refluxing the originally precipitated salt, [α]$_D$ − 31°, with about 1400 c.c. of acetone. The *l*-alcohol was isolated by known methods. The *d*-alcohol was obtained in about 60% optical purity from the brucine salt in the mother-liquors. Residues of lower activity were also obtained.

Optically Active α-*Phenylethyl Chloride.*—(a) *From the alcohol and thionyl chloride.* The alcohol (8 c.c.) was added to thionyl chloride (20 c.c.), and, after the reaction was complete, the excess

of thionyl chloride was pumped off at room temperature and the product distilled, b. p. 83°/21 mm. The rotation of the product (Found : C, 68·3; H, 6·4; Cl, 25·2. Calc. : C, 68·3; H, 6·4; Cl, 25·3%) varied from one experiment to another, a typical result being that alcohol with $\alpha_D^{20°}$ ($l = 10$ cm.) $-34\cdot28°$ gave chloride with $\alpha_D^{20°}$ ($l = 10$ cm.) $- 32\cdot52°$. When the chloride is heated with thionyl chloride racemisation occurs.

(b) *From the alcohol and hydrogen chloride.* The alcohol (10 c.c.), $\alpha_D^{20°}$ ($l = 10$ cm.) $+ 29\cdot40°$, was treated with hydrogen chloride in benzene solution until the lower aqueous layer which was formed ceased to increase. After a further hour the benzene and excess of hydrogen chloride were removed in a vacuum, and the chloride was distilled from a small amount of solid potassium carbonate. It had b. p. 78°/12 mm., $\alpha_D^{20°}$ ($l = 10$ cm.) $- 2\cdot80°$.

Optically Active α-Phenylethyl Bromide.—(a) The alcohol (5 c.c.), $\alpha_D^{20°}$ ($l = 10$ cm.) $+ 30\cdot80°$, was slowly added to an acetic acid solution (10 c.c.) of hydrogen bromide (5 g.), and, at the conclusion of the vigorous reaction, carbon tetrachloride and water were added. The carbon tetrachloride extract was dried with potassium carbonate, and the α-phenylethyl bromide, b. p. 102°/23 mm., $\alpha_D^{20°}$ ($l = 10$ cm.) $- 11\cdot32°$, was distilled from this reagent.

(b) The alcohol, $\alpha_D^{20°}$ ($l = 10$ cm.) $- 37\cdot36°$, was treated with hydrogen bromide in benzene solution as described for the reaction with hydrogen chloride. The bromide had $\alpha_D^{20°}$ ($l = 10$ cm.) $+ 16\cdot20°$ (Found : C, 52·0; H, 5·0; Br, 42·8. Calc. : C, 51·9; H, 4·9; Br, 43·2%).

Hydrolysis, Methyl and Ethyl Alcoholysis, and Ammonolysis of Optically Active α-Phenylethyl Halides.—The following particulars of expts. 1a—11 are supplementary to those given in Table I.

(1a) (1b) The chloride (5·3 g.) was shaken with water (300 c.c.) for 2 hours. The product, extracted with ether, was freed from the last trace of halogen by shaking with water (300 c.c.) for a further 1·5 hours. The product, when again extracted, was free from halogen (no reaction with alcoholic silver nitrate) and from styrene (no reaction with bromine in chloroform), and on distillation gave the alcohol (4 g., b. p. 102°/22 mm.) (Found : C, 78·3; H, 8·2. Calc.: C, 78·7; H, 8·2%).

(2a) (2b) The chloride (5·3 g.) was shaken with 10% aqueous potassium hydroxide (300 c.c.) for 2 hours. The product, isolated and tested for freedom from halogen and styrene as described above, was α-phenylethyl alcohol (4 g., b. p. 105°/25 mm.) (Found : C, 79·1; H, 8·3%).

(3) The chloride (5·3 g.) was hydrolysed in a mixture of acetone (600 c.c.) and water (400 c.c.) at 70° for 14 hours. The product, extracted with chloroform after large dilution with water, yielded a trace of styrene and α-phenylethyl alcohol (3 g., b. p. 98°/19 mm.) (Found : C, 77·7; H, 8·3%). The styrene was isolated and identified as its dibromide.

(4) Hydrolysis of the chloride (6·5 g.) was conducted for 22 hours at 70° in a mixture of acetone (720 c.c.), water (480 c.c.), and potassium hydroxide (3 g.). The α-phenylethyl alcohol was isolated by extraction with ether after dilution with water, and tested as usual (3 g., b. p. 98°/19 mm.) (Found : C, 77·9; H, 8·2%).

(5a) (5b) The chloride (5·3 g.) was hydrolysed in a mixture of acetone (160 c.c.) and water (40 c.c.) at 70° for 48 hours (yield of alcohol, 3 g.; b. p. 96°/17 mm., 98°/19 mm.).

(6) A solution of the chloride (6·5 g.) in methyl alcohol (300 c.c.) was kept at 70° for 18 hours. After being cooled it was diluted with 3 l. of water and extracted with ether. The product, 4 g., b. p. 66°/17·5 mm., was α-phenylethyl methyl ether, free from halogen and from styrene (Found : C, 79·2; H, 8·7. Calc. : C, 79·4; H, 8·8%).

(7) The chloride (7 g.) was alcoholysed at 70° for 18 hours with a solution of sodium methoxide prepared from sodium (50 g.) and methyl alcohol (600 c.c.). The ether (6 g.) isolated as usual contained about 15% of styrene (identified by the m. p. and mixed m. p. of its dibromide), and was therefore treated with a small excess of bromine in cold chloroform, and again isolated by distillation. It had b. p. 66°/17 mm. (Found : C, 79·3; H, 9·1%).

(8a) (8b) These experiments were conducted analogously to no. 6, the period of heating being 18 hours in one case and 45 hours in the other. The product contained a very small trace of styrene, which was removed by bromination. The α-phenylethyl ether (3·4 g.) had b. p. 82—83°/26 mm. (Found : C, 79·7; H, 9·3. Calc. : C, 80·0; H, 9·3%).

(9a) (9b) The chloride (7 g.) was alcoholysed for 18 or 45 hours at 70° with a solution of sodium ethoxide prepared from sodium (23 g.) and ethyl alcohol (350 c.c.). The styrene formed (m. p. and mixed m. p. of the dibromide) was removed by bromination. The ether (3 g.) had b. p. 74°/16 mm. (Found : C, 80·4; H, 9·6%).

(10) The chloride (10·5 g.) and liquid ammonia (15 c.c.) were kept in a closed tube at room temperature for 6 weeks. The solution was then evaporated, and the residue treated with aqueous hydrochloric acid and extracted with ether. The aqueous solution was basified and

re-extracted, and the primary base, b. p. 86°/20 mm., was distilled (Found : C, 79·3; H, 9·2; N, 11·6. Calc. : C, 79·3; H, 9·1; N, 11·6%).

(11) α-Phenylethyl bromide (4·5 g.) was shaken with water (250 c.c.) at 20° for 1 hour. The product, isolated and tested as usual, had b. p. 102°/23 mm. (Found : C, 78·3; H, 8·2. Calc.: C, 78·7; H, 8·2%).

Methylation and Ethylation of Optically Active α-Phenylethyl Alcohol.—The alcohol (6 g.) was heated under reflux with sodium (1·2 g.) in dry ether (50 c.c.) until reaction was complete (15 hours), and then methyl iodide was added, and the heating was continued for a further 2 hours. The ethereal solution was filtered, the residue was washed with ether, and the combined filtrate and washings were distilled, the α-phenylethyl methyl ether passing over at 69—71°/19 mm. Alcohol having $\alpha_D^{20°}$ (l = 10 cm.) + 29·20° and + 16·00° thus yielded ether with $\alpha_D^{20°}$ (l = 10 cm.) + 34·20° and + 23·12° respectively (Found : C, 79·0; H, 8·8. Calc.: C, 79·4; H, 8·8%). These rotatory powers are inconsistent. Similarly inconsistent results were obtained on ethylating the alcohol with ethyl iodide (cf. Kenyon and Phillips, *loc. cit.*).

Rate of Hydrolysis of α-Phenylethyl Chloride.—The analytically determined unimolecular velocity constants in 60% acetone at 67° and in 80% acetone at 70° were 1·35 × 10⁻³ sec.⁻¹ and 9·04 × 10⁻⁵ sec.⁻¹ respectively, whilst for the last-named conditions the polarimetrically determined constant rose from 9·2 × 10⁻⁵ to 11·5 × 15⁻⁵ sec.⁻¹ during the run, the mean value being 10·0 × 10⁻⁵ sec.⁻¹. A typical experiment is described below, and the results are recorded in Table II.

Samples (5 c.c.) of a solution of α-phenylethyl chloride (2 g.) in acetone (80 c.c.) and water (20 c.c.) were enclosed in glass bulbs and kept at 70·0° for known times. The bulbs were subsequently broken under ethyl alcohol (150 c.c.), and their contents were titrated with 0·0447N-aqueous sodium hydroxide, lacmoid being used as indicator. The value of $a - x$ in the formula $k_1 = (2·303/t) \log_{10} a/(a - x)$ was got from the " infinity " titre.

TABLE II.

Time (mins.)	1	16	31	46	61	76	106
Titre (c.c.)	0·03	1·29	2·63	3·85	5·10	6·10	8·06
$k_1 \times 10^5$ (sec.⁻¹)	—	—	8·56	8·69	9·01	8·95	9·15

Time (mins.)	136	181	241	306	391	4320	8640
Titre (c.c.)	9·65	11·80	13·78	15·30	16·75	18·37	18·40
$k_1 \times 10^5$ (sec.⁻¹)	9·18	9·50	9·59	9·73	—	—	—

Rate of Methyl Alcoholysis of α-Phenylethyl Chloride.—The method for the estimation of the unimolecular constant k_1 at 70·0° was just the same as for hydrolysis except that the solvent was methyl alcohol. One of the bulbs was used in order to obtain the value of a : it was broken under alcohol, and the material treated with excess of silver nitrate, which was back titrated with ammonium thiocyanate. Owing to the slow interaction between the liberated hydrogen chloride and the solvent methyl alcohol, the constants fall towards the end of a run, as is illustrated by the experiment in Table III; hence the special measures adopted to secure an " infinity titre " undisturbed by this effect.

In order to obtain a predominantly bimolecular reaction it was necessary to use large concentrations of sodium methoxide. The method of sealed bulbs was again employed. They were broken under ether, and the solutions extracted twice with water. The aqueous solution was acidified with nitric acid, treated with excess of standard silver nitrate, and back-titrated with ammonium thiocyanate, ferric alum being used as indicator. The total reaction was thus measured, and the part due to the unimolecular process was calculated from the known value of k_1 and subtracted; the residual reaction was then used for the calculation of the bimolecular constant k_2.

At 70·0° we find k_1 = 4·35 × 10⁻⁴ sec.⁻¹, and for concentrations of sodium methoxide in the neighbourhood of 3N (but low concentrations of chloride), k_2 = 2·46 × 10⁻⁴ sec.⁻¹ g.-mol.⁻¹ l.

TABLE III.

Time (mins.)	10	11	15	20	25	35	45	55	80	∞ *
Titre (c.c.)	5·14	5·65	7·00	8·25	9·18	10·80	12·35	13·05	14·60	18·80
$k_1 \times 10^4$ (sec.⁻¹)	4·41	4·63	4·56	4·37	4·10	3·81	3·76	3·43	3·02	—

* From the decomposition with silver nitrate.

Rate of Ethyl Alcoholysis of α-Phenylethyl Chloride.—The unimolecular constant k_1 was estimated as described for methyl alcoholysis, but owing to the smaller rate of ethyl alcoholysis

there is more opportunity for the subsequent reaction between hydrogen chloride and the solvent alcohol. Consequently the constants calculated in the course of a run fall markedly, and, indeed, the titres cease rising after a time and even begin to fall again. An experiment is reported in Table IV. The reaction between hydrogen chloride and the solvent alcohol was demonstrated by following this reaction at the same temperature, 70° :

Time (hours)	0·00	7·50	15·25	24·00	39·50	90·00
Titre (c.c. of 0·0447N-alkali)	13·70	11·40	9·60	8·00	5·95	2·90

The bimolecular constant k_2 was measured as described for methyl alcoholysis except that, as the whole reaction is predominantly bimolecular in the presence of moderate concentrations of sodium ethoxide, the concentrations used were of the order of N.

At 70·0° we find $k_1 = 3·75 \times 10^{-5}$ sec.$^{-1}$, and $k_2 = 1·67 \times 10^{-4}$ sec.$^{-1}$. g.-mol.$^{-1}$ l. Determined by the polarimetric method, k_1 rose from $4·0 \times 10^{-5}$ to $5·4 \times 10^{-5}$ sec.$^{-1}$ during the run, the mean value being $4·62 \times 10^{-5}$ sec.$^{-1}$.

TABLE IV.

Time (mins.)	60	120	180	240	300	450	810	1020	1440
Titre (c.c.)	1·75	4·10	5·85	7·20	8·30	10·20	11·65	11·60	10·50
$k_1 \times 10^5$ (sec.$^{-1}$) ...	2·99	3·81	3·83	3·81	3·70	3·37	2·36	1·86	—

The " infinity " titre in the absence of the reaction between hydrogen chloride and the solvent is 17·06 c.c., this figure being obtained as described for methyl alcoholysis.

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