major portion of the product. In either event, the combined solids were recrystallized from ethanol–concd. hydrochloric acid. Data for these compounds, including pharmacological properties are given in Table II.

1,1,1-Trichloro-2-alkoxy-3-dimethylaminopropane. General Procedure.—A slight excess of 5% sodium hydroxide was added to the 1,1,1-trichloro-2-alkoxy-3-aminopropane hydrochloride (0.20 mole). After separating the aqueous layer, a solution of formalin (0.22 mole) in 90% formic acid (0.50 mole) was added to the resultant amine. After standing for 15 minutes, the mixture was heated in an oil-bath at 130° for five hours. Concentrated hydrochloric acid (0.22 mole) was added and the mixture was evaporated to dryness under reduced pressure with warming on the steam-bath. The residue was dissolved in water. The solution was decolorized and made basic with ammonium hydroxide. Extraction with ether, drying over magnesium sulfate and removal of the ether left an oily residue which was distilled under reduced pressure. Data for these compounds are presented in Table III.

GREENCASTLE, INDIANA

[CONTRIBUTION FROM THE CHEMISTRY DIVISION OF THE OAK RIDGE NATIONAL LABORATORY]

The Rates and Migration Ratios Observed in the Unimolecular and Bimolecular Reactions of 2-Phenyl-2-(*p*-tolyl)-ethyl Tosylate and Related Compounds[1]

BY JOHN G. BURR, JR.

RECEIVED APRIL 17, 1953

The first-order acetolysis rates and the bimolecular rates of reaction with alkoxide ion of 2,2-diphenylethyl tosylate, 2-phenyl-2-(*p*-tolyl)-ethyl tosylate and of 2,2-di-(*p*-tolyl)-ethyl tosylate have been determined. The rates of the acetolyses have been found to stand in the respective ratios of 1.00/1.62/8.32. The bimolecular reaction rates have been found to stand in the respective ratios of 1.00/0.62/0.38. The use of 2-phenyl-2-(*p*-tolyl)-ethyl-1-C^{14} tosylate showed that the rearrangement of the *p*-tolyl group in the first-order reaction was 71.2% (migration ratio of *p*-tolyl to phenyl of 2.47), and in the second-order reaction was less than 2%. Thus the successive substitution of methyl groups in the para positions of the diphenylethanol system produces a *non-linear increase in the rates of first order acetolysis, but a linear decrease in the rates of bimolecular reaction.* The linear decrease in the rates of the bimolecular reaction indicates that the inductive effect of the substituted benzhydryl radical is a linear function of the number of *p*-methyl substituents. The non-linear increase in the rates of the first-order reaction considered together with the relative migrations of phenyl and *p*-tolyl group do not present a consistent picture. It does indicate that the anchimeric ability of a group in these rearrangements is affected by the nature of the non-migrating group. The various rate constants presented here reflect the effect of a unique structure variation upon the relative rates of both unimolecular and bimolecular types of reaction.

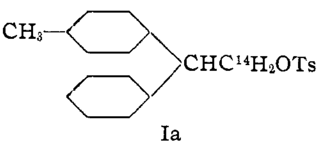
Introduction

The migration ratios observed in the Wagner–Meerwein rearrangement of several substituted 2,2-diphenylethanols-1-C^{14} were recently reported.[2] The results obtained were discussed in terms of the neighboring group type of participation of the aryl groups in this acid-catalyzed dehydration–rearrangement. Measurement of this type of participation can be obtained only from kinetic or stereochemical data, and since our results for the 2,2-diphenylethanols were obtained under conditions precluding any measurements of rates or stereochemistry we could at that time only indicate the possibility that the migration aptitudes of substituted aryl groups would be related to the rearrangement rates of the compounds containing these groups. It has seemed important to us to carry out one of these rearrangements under conditions where simultaneous indication of migratory aptitude and the rate of rearrangement could be obtained.

Since the diphenylethanol system, containing at most one center of asymmetry, is not amenable to stereochemical analysis, it was hoped that the acetolyses of the substituted 2,2-diphenylethyl tosylates would show relative rates indicating the relative anchimeric abilities of the substituted phenyl groups. This acetolysis has been shown[3] to produce stilbene from 2,2-diphenylethyl tosylate, indicating complete rearrangement. Our work also indicates stilbenes to be the only product.

Results

Such a kinetic analysis has now been accomplished for one such system: 2-phenyl-2-(*p*-tolyl)-ethyl tosylate (I), and the related compounds, 2,2-diphenylethyl tosylate (II) and 2,2-di-(*p*-tolyl)-ethyl tosylate (III). The relative migrations of phenyl and *p*-tolyl were observed in the acetolysis of 2-phenyl-2-(*p*-tolyl)-ethyl-1-C^{14} tosylate (Ia).



Ia

$(C_6H_5)_2CHCH_2OTs$

II

$(p\text{-}CH_3C_6H_4)_2CHCH_2OTs$

III

These compounds have been prepared and solvolyzed in glacial acetic acid. Their rates of acetolysis are recorded in Table I. At least two independent determinations of each rate were made and in general the agreement was excellent. Four independent determinations were made of the rate for the solvolysis of 2-phenyl-2-(*p*-tolyl)-ethyl tosylate since the rate constant for this compound tended to rise a little during each run. It was not a serious trend, however, and is reflected chiefly in a somewhat inferior precision for the constant. The data for a typical run on each compound are reported in Table II.

For reasons which will become apparent in the following section, it was found desirable to measure the rate of reaction of these same three esters in a

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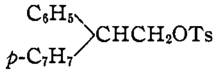
[1] This document is based upon work performed under contract Number W-7405-eng-26 for the Atomic Energy Commission at the Oak Ridge National Laboratory.

[2] J. G. Burr, Jr., and L. S. Ciereszko, THIS JOURNAL, **74**, 5426 (1952).

[3] S. Winstein, B. K. Morse, E. Grunwald, K. C. Schreiber and J. Corse, *ibid.*, **74**, 1113 (1952).

TABLE I

SUMMARY OF RATE CONSTANTS

Compound (concn., *M*)	Solvent	Reagent (concn., *M*)	Temp., °C.	k_1 sec.$^{-}$	k_2 liter mole^{-1} sec.$^{-1}$
$(C_6H_5)CHCH_2OTs$					
(0.0513)	HOAc	....	99.40	$3.51 \times 10^{-5} \pm 0.04$[a]	
(0.0460)	MC[b]	NaOMe (0.0460)	78.30		0.0187 ± 0.0016
 $(C_6H_5)(p\text{-}C_7H_7)CHCH_2OTs$					
(0.0478)	HOAc	....	99.50	$5.68 \times 10^{-5} \pm 0.16$	
(0.0460)	MC	NaOMe (0.0460)	77.80		0.0117 ± 0.0005
$(p\text{-}C_7H_7)_2CHCH_2OTs$					
(0.0526)	HOAc	....	99.22	$29.2 \times 10^{-5} \pm 0.05$	
(0.0460)	MC	NaOMe (0.0460)	78.00		0.00718 ± 0.0029

[a] Winstein, *et al.*, reports 3.81 ± 0.27.[3] [b] Methyl cellosolve at 99.58°.

TABLE II

SOLVOLYSES IN ACETIC ACID

Solvolysis of 0.0513 *M* 2-phenyl-2-(*p*-tolyl)-ethyl tosylate at 99.50°			Solvolysis of 0.0526 *M* 2,2-di-(*p*-tolyl)-ethyl tosylate at 99.22°		
Time[a] sec.	Net ml. of 0.0510 *M* KOAc in HOAc	$k \times 10^5$ sec.$^{-1}$	Time, sec.	Net. ml. of 0.0510 *M* KOAc in HOAc	$k \times 10^5$ sec.$^{-1}$
1800	0.0894	5.67	960	0.0869	30.7
3600	1.555	5.46	1920	1.509	30.5
5400	2.117	5.40	2940	1.979	29.5
7200	2.565	5.54	5460	2.759	30.4
10920	3.255	5.71			
15250	3.715	5.84		Av.	30.2 ± 0.04
Inf.	4.270	..			
	Av.	5.60 ± 0.17			

[a] 5.00-ml. sample titrated for each time period.

bimolecular process. Some difficulty was encountered in accomplishing this. The esters proved to be too insoluble in ethanol or methanol to consider the use of these solvents, alone or diluted with water, as a reaction medium. Similarly, it was found difficult to achieve complete solution both of the ester and of the alkali in 75% dioxane-water, and in addition the reaction proved to have a complex order. It was finally found that the reaction of these esters with 0.05 *M* sodium methoxide in dry methyl cellosolve was cleanly second order. The bimolecular rate constants observed for these three compounds in this reaction are shown in Table I, and the data for a typical run are shown in Table III. It was not determined by product analysis whether these reactions were elimination (E_2) or substitution (S_N2); however, it is presumably the same for all three of the compounds and thus the relative inductive effect of the three substituent radicals would be reflected in the relative reaction rates of the respective molecules.

TABLE III

REACTIONS WITH SODIUM METHOXIDE IN METHYL CELLOSOLVE

2-Phenyl-2-(*p*-tolyl)-ethyl tosylate, $T = 77.80°$; $M = 0.0460$

Time, sec.	NaOH backtiter, ml.	k liter mole^{-1} sec.$^{-1}$
0	1.272[a]	....
360	1.840	0.0185
780	2.358	.0217
1200	2.650	.0187
1800	2.840	.0187
2700	3.027	.0163
3600	3.245	.0175
	Av.	0.0186 ± 0.0011

[a] Each 5.00 ml. of sample was added to 5.00 ml. of 0.0529 *M* HCl and back-titrated with 0.0514 *M* NaOH.

The migration ratios in these rearrangements were observed by techniques previously developed,[2] using carbon-14 labeled esters (Ia). The product from the acetolysis of phenyl-(*p*-tolyl)-ethyl-1-C^{14} tosylate even in the crude state obtained by pouring the acetolysis mixture into water was a solid material. Since it is our experience that these stilbenes are difficult to obtain crystalline when impure, we conclude that there is evidently little product formed in the acetolysis other than the stilbene. In any case, since the stilbene was isolated and purified before radiocarbon assay and degradative oxidation, the relative migrations of phenyl and *p*-tolyl so measured would be independent of other products formed in the acetolysis.

Conclusions

The relative rates and migration ratios observed in the course of this work are shown in Table IV.[4] It is evident that the expectations which accompanied the planning of this work have been qualitatively realized. It was observed previously[2] that the *p*-tolyl group has a greater migration aptitude than phenyl and thus it would be expected that the substitution of *p*-tolyl groups for phenyl groups in the diphenylethanol system would increase the rate of a rearrangement reaction, and this is actually the case.

However, a more detailed examination of the data reveals certain inconsistencies. It is evident from the ratio $k_{IV}/k_{II} = 3.62$ that a methyl group in the non-migrating aryl is rate-enhancing for a migrating tolyl group. It would be expected that a methyl group in the non-migrating aryl would also enhance the rate for a migrating phenyl group. However, since $k_{III}/k_{II} = 0.93$, it appears that a non-migrating tolyl group actually depresses the rate when phenyl is the migrating group.

It is apparent in any case that the effect upon the acetolysis rate of substituting methyl groups into this diphenylethanol system depends upon the groups already present. The implication is that

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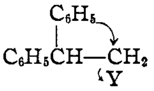
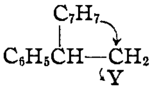
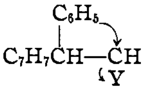
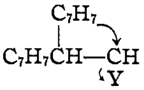
[4] The author is indebted to the referee for suggesting this arrangement of the data,

TABLE IV

RELATIVE RATES AND MIGRATION RATIOS

Reaction	 I (k_I)	 II (k_{II})	 III (k_{III})	 IV (k_{IV})
Relative bimolecular rate	1.00	0.626		0.384
p-Tolyl migration, %		<2		
Apparent relative acetolysis rate	1.00	1.62		8.32
p-Tolyl migration, %		71.2		
Relative acetolysis rate per aryl	0.50 or 1.00	1.15[a] or 2.30	0.466[a] or 0.93	4.16 or 8.32

[a] These values were obtained by multiplying 1.62 by, respectively, the percentage migration of p-tolyl and phenyl groups in the rearrangement.

the anchimeric ability of a migrating group in these rearrangements is a complex function of the nature of the migrating group and also the non-migrating group. Further study of other systems similar to this one, but with different substituent groups, will probably be necessary to determine the nature of this interaction.

The interaction of substituents on the α- and β-carbons of the ethane or ethylene systems is well known,[3] and is presumably caused by geometric considerations. However, the interaction of two substituents both of which are on the β-carbon can only depend upon the interplay of inductive forces or upon the conformation of the various groups in the molecule at the instant of reaction.[5]

This evidence for the complexity of the actual situation is supported by a consideration of the various factors which might be important in determining the relative rates of these three acetolyses. These factors include: (a) the inductive retardation of the rate produced by substituting an aryl group for a hydrogen atom[3]; (b) the enhancement of rate owing to the relief of steric strain in ionization without participation[3]; and (c) interaction between two participating aryl groups as was mentioned above.

Considerations of steric strain can be ignored in this case since the rearrangement is concerned not with the comparison between groupings of differing bulk but with the comparison within the molecule of two aryl groups with essentially the same bulk at the site of reaction.

Winstein[3] has estimated the depressing effect of β-phenyl substitution for hydrogen to be one power of ten in the rate constant, for each phenyl group. From a variety of rate and equilibria measurements,[6] it may be estimated that the relative inductive effect of a p-tolyl group compared to phenyl is about 0.8 (*i.e.*, the inductive retardation of the rate by a p-tolyl group would be less than that of a phenyl by a factor of 0.8). However, it seemed to us that a more direct and accurate comparison of the inductive effect of the p-tolyl and phenyl groups could be achieved by measurement of the rates of reaction of the above three substances (I, II and III) in a reaction where rearrangement did not occur and where the relative rates would reflect only the net changes in the electrostatic and hyperconjugative effects in going successively from benzhpdryl to 4-methylbenzhydryl to 4,4′-dimethylbenzhydryl groups. Such a reaction might be the ionization of the correspondingly substituted acetic acids. Actually we chose, for obvious reasons, the bimolecular reaction of the correspondingly substituted methyl tosylates with alkoxide ion, as described in Results. The linear change observed in the reaction rates indicates that the inductive effect of the benzhydryl group in these particular molecules changes linearly with successive substitution of methyl groups for p-hydrogen atoms.

This study has failed to produce the desired quantitative relationship between the rates of acetolysis of the esters I, II and III and the relative migration tendency of phenyl and p-tolyl groups. However, the rate constants measured have considerable intrinsic interest which is derived from the uniqueness of the structure variation presented in these three esters. The net result of this variation is to introduce two methyl groups successively at essentially the same point in the molecule. The effect of this unique variation has been shown not only upon the first-order solvolysis of these molecules but also upon the bimolecular reactions of the same system. There is in the literature very little actual comparison of the same molecule under conditions designed to induce and thus to compare first S_N1 and then S_N2 types of reactions. It is comforting to note that the predictions of the electronic theory with respect to the effect of methyl substitution upon the rates of S_N1 and S_N2 reactions are verified.[7]

Experimental[8]

2-Phenyl-2-(p-tolyl)-ethyl-1-C^{14} Tosylate.—Both labeled and unlabeled carbinol were prepared as previously described.[2] The tosylate was prepared by mixing 6 g. of the

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[5] This dependence of participation upon conformation is discussed by Winstein (ref. 3, footnote 10). It introduces a note of almost insoluble complexity into the situation.

[6] L. P. Hammett, "Physical Organic Chemistry," 1st. Ed., McGraw-Hill Book Co., Inc., New York, N. Y., 1940, pp. 188–189.

[7] M. J. S. Dewar, "The Electronic Theory of Organic Chemistry," 1st Ed., The Clarendon Press, Oxford, 1949 pp. 69–73, 112. Also see C. G. Swain and W. P. Langsdorf, Jr., THIS JOURNAL, **73**, 2813 (1951), and S. Winstein, E. Grunwald and H. W. Jones, *ibid.*, **73**, 2700 (1951), for alternate systems which classify reactions by one mechanistic catagory rather than two distinct ones.

[8] Melting points were taken upon a Kofler Hot Bench. Carbon-14 assays were accomplished by a wet combustion of the compounds (J. G. Burr, Jr., *Anal. Chem.*, in press) and ionization chamber counting of the evolved carbon dioxide upon a vibrating reed electrometer. Microanalyses for carbon, hydrogen and sulfur were done by Dr. H. W. Galbraith, Knoxville, Tenn.

carbinol, 6 g. of redistilled *p*-toluenesulfonyl chloride and 15 ml. of dry pyridine. The solution was allowed to stand overnight and then poured into ice-cold 6 *N* sulfuric acid. The 14 g. of crude ester so obtained was crystallized twice from ethyl acetate–hexane to give 9.35 g. of long needles melting at 108°.

Anal. Calcd. for $C_{22}H_{22}O_3S$: C, 72.2; H, 6.03; S, 8.76; equiv. wt. on acetolysis, 366. Found: C, 71.9; H, 6.27; S, 8.73; equiv. wt., 373.

The labeled ester was prepared similarly from 2.55 g. of carbinol to give 3.4 g. of purified ester, m.p. 106°. *Anal.* 1.625, 1.650, 1.640 μc. of carbon-14/mmole.

Acetolysis of 2-Phenyl-2-(*p*-tolyl)-ethyl-1-C^{14} Tosylate.—Two 500-mg. samples of the above mentioned labeled tosylate were heated separately 16 hours with dry acetic acid at 100°. Each was then poured into water and the solid precipitates recrystallized from methanol to give about 200 mg. each of 4-methylstilbene, m.p. 110°. This stilbene assayed 1.605, 1.611 μc. of carbon-14/mmole. Each sample of stilbene was then oxidized with alkaline potassium permanganate, and the terephthalic acid isolated as before.[2] Assay of terephthalic acid: (1) 1.150, 1.155, 1.155 μc. of carbon-14/mmole; (2) 1.155, 1.175 μc. of carbon-14/mmole. This corresponds to an average of 71.6% *p*-tolyl group migration or a migration ratio of *p*-tolyl to phenyl of 2.47.

Reaction of 2-Phenyl-2-(*p*-tolyl)-ethyl-1-C^{14} Tosylate with Sodium Methoxide in Methyl Cellosolve.—A 1.00-g. sample of the labeled tosylate was heated at 90° (steam-bath) with 100 ml. of a 0.0460 *M* solution of sodium methoxide in methyl cellosolve. The solution was poured into water and the resultant oil ether-extracted, dried and oxidized with alkaline permanganate. It oxidized with difficulty. The resulting terephthalic acid was filtered from hot dilute hydrochloric acid, washed with alcohol and ether and vacuum sublimed. Assay of this acid showed carbon-14 activity only slightly over background, corresponding at most to 1.9% *p*-tolyl group migration.

Di-(*p*-tolyl)-ethyl Tosylate.—The corresponding carbinol was prepared in the usual[2] fashion from di-(*p*-tolyl)-acetonitrile *via* hydrolysis to the acid and reduction of the acid, m.p. 144°, to the carbinol with lithium aluminum hydride. The product of this reaction was an oil which crystallized spontaneously. The over-all yield of carbinol was 44 g. from 110 g. of the corresponding benzhydryl chloride and 40 g. of cuprous cyanide. It crystallized from low-boiling petroleum ether as a cottony mass which melted at 51°.

Anal. Calcd. for $C_{16}H_{18}O$: C, 84.9; H, 8.04. Found: C, 84.9; H, 8.13.

The tosylate was prepared as above from 7 g. of the carbinol, 6 g. of tosyl chloride, and 15 ml. of pyridine at room temperature overnight. The crude ester weighed 12 g. and melted at 72°. Recrystallization twice from hexane gave 7.0 g. of ester with an unchanged melting point.

Anal. Calcd. for $C_{23}H_{24}O_3S$: C, 72.6; H, 6.33; S, 8.43; equiv. wt. on acetolysis, 380. Found: C, 72.7; H, 6.59; S, 8.41; equiv. wt., 388.

Rate Measurements.—Acetic acid was distilled from acetic anhydride and sulfuric acid. It analyzed by titration 99.70% acetic acid. The solution of potassium acetate was prepared from this acetic acid and 4.92 g. of potassium acetate per liter of solution. It was standardized against a solution of *p*-toluenesulfonic acid monohydrate in acetic acid and proved to be 0.0533 *M*. The toluenesulfonic acid was in turn standardized against sodium hydroxide and had an equivalent weight of 190.6. The methyl cellosolve was purified by distillation at atmospheric pressure, and the fraction boiling at 121–122 used. The solutions for solvolysis were prepared by adding a standardized (0.046 *M*) solution of sodium methoxide in this reagent to an accurately weighed amount of the ester in a volumetric flask. In every case the amount of ester was sufficient to make the resulting solution 0.0460 *M* in ester. The measurement of acetolysis rates was accomplished by the sealed ampule technique exactly as previously described.[3] A 5.00-ml. sample was taken for each titration. The measurements of alkoxide solvolysis were also made by the sealed ampule technique. A 5.00-ml. aliquot of each ampule was withdrawn, added to 5.00 ml. of 0.0529 *M* HCl, and the resulting suspension titrated with 0.0514 *M* NaOH, using phenolphthalein as indicator. The thermostat employed used the saturated vapor of a boiling liquid as the constant temperature source of heat. For measurements at 100°, this liquid was water and for measurements at 78°, the liquid was alcohol. Temperatures were measured with a thermometer calibrated in 0.1° steps.

OAK RIDGE, TENNESSEE

[CONTRIBUTION FROM THE GENERAL ELECTRIC RESEARCH LABORATORY]

The Reaction of Peroxides and Hydroperoxides with Lithium Aluminum Hydride

BY GLEN A. RUSSELL

RECEIVED JUNE 8, 1953

Hydroperoxides and polymeric peroxides are much more reactive toward lithium aluminum hydride than are most monomeric dialkyl peroxides. A stepwise chain degradation involving cyclic intermediates has been proposed to explain the facile reduction of polymeric peroxides to glycols. Lithium aluminum hydride will not readily catalyze the basic decomposition of peroxides containing an α-hydrogen atom activated by a phenyl group.

Prior to the start of this investigation, there had been no reports of the reduction of alkyl peroxides by lithium aluminum hydride although reductions of benzoyl peroxide,[1] 1,2,3,4-tetrahydronaphth-1-yl hydroperoxide[2] and 2-cyclohexen-1-yl hydroperoxide[2] had been noted. Recently, the reduction of several 9,10-diarylanthracene photo-peroxides,[3] triphenylmethyl peroxide,[3] ascaridole,[4] *t*-butyl peroxide,[4] methyl 1,2,3,4-tetrahydronaphth-1-yl peroxide,[4] and the ozonide of phenylskatole[5] have been reported.

To determine the scope of this reaction, we have attempted to reduce a series of hydroperoxides and peroxides, including polymeric peroxides, by lithium aluminum hydride in butyl ether or dioxane solution. It was hoped that the reduction might occur quantitatively at low temperatures and thus provide a general method of analysis for alkyl peroxides.

Results and Discussion

A number of reductions were attempted or performed on an analytical scale by slowly adding a 0.1 *M* solution of a peroxide or hydroperoxide in butyl ether or dioxane to a 0.1 *M* solution of lithium aluminum hydride in butyl ether. The hydrogen evolved during reaction was collected at constant pressure and measured to ±2% in a thermostated gas buret. When the gas evolution

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[1] F. A. Hochstein, THIS JOURNAL, **71**, 305 (1949).

[2] D. A. Sutton, *Chemistry and Industry*, 272 (1951).

[3] A. Mustafa, *J. Chem. Soc.*, 2435 (1952).

[4] M. Matic and D. A. Sutton, *ibid.*, 2679 (1952).

[5] B. Witkop and J. B. Patrick, THIS JOURNAL, **74**, 3855 (1952).