

ethanol, weighed 196 mg. and had a m.p. of 136–137°. Upon oxidation^{2a} with 300 mg. of KMnO_4 in 20 cc. of acetone, 5 cc. of water and 2 cc. of glacial acetic acid there was obtained 40 mg. of benzoic acid and a benzophenone fraction which yielded 123 mg. of 2,4-dinitrophenylhydrazone. The purified products were assayed for radioactivity: the benzoic acid (m.p. 122°) contained 0.9505 mc. per mole of carbon-14 and the benzophenone derivative (m.p. 239–40°) 0.019 \pm 0.002 mc./mole, corresponding to a maximum of 1.9% rearrangement after 24 hours.

(b) Benzhydryl phenyl ketone (502 mg.) labeled in the 1-phenyl position (0.5954 mc./mole) and in the carbonyl-carbon (1.137 mc./mole) was heated under reflux with 15 cc. of formic acid (98–99%) for 18 hours. The reisolated ketone was crystallized once from ethanol to yield 372 mg. whose m.p. was 136°. It was cleaved^{9,11} with nitric acid in acetic acid followed by chromic acid to yield benzophenone which was converted to 272 mg. of 2,4-dinitrophenylhydrazone; m.p. 239–40°, radioactivity assay 0.024 mc./mole. This assay corresponds to a maximum rearrangement of the total radioactivity of 1.3%.

(c) Benzhydryl-²H₁ phenyl ketone (272 mg.) obtained through the rearrangement of Ie in cold, concentrated sul-

furic acid was heated under reflux in 10 cc. of formic acid (98–99%) for 23 hours. The reisolated ketone was crystallized once from ethanol (m.p. 136–137°), and exhibited an infrared spectrum identical with that of authentic benzhydryl phenyl ketone, but different from that of the original ketone.

(d) In a typical experiment, 161 mg. of triphenylacetaldehyde (crude, m.p. 98–100°) was dissolved in 108 cc. of 95% ethanol, and to it was added 54 cc. of 9.39 *N* H_2SO_4 . After 0.5 hour at room temperature and 0.5 hour at 48–50°, the temperature was raised to 80° for one hour. The reaction was quenched, and the reisolated material was converted to 231 mg. of 2,4-dinitrophenylhydrazone (86.6% of theory), m.p. 208–210° (crude). This is the same yield obtained when a sample of the triphenylacetaldehyde was converted directly to 2,4-dinitrophenylhydrazone. Finally, the experiment was repeated upon 83.5 mg. of triphenylacetaldehyde, dissolved in 50 cc. of 95% ethanol and 25 cc. of 9.39 *N* H_2SO_4 . The solution was maintained at 46° for 4 hours, then at 70° for 17 hours. The reaction was quenched, and the reisolated aldehyde was converted to 124 mg. (89.5% of 2,4-dinitrophenylhydrazone, m.p. (crude) 208–210°.

OAK RIDGE, TENN.

[CONTRIBUTION FROM THE CHEMISTRY DIVISION, OAK RIDGE NATIONAL LABORATORY, AND THE DEPARTMENT OF CHEMISTRY AND CHEMICAL ENGINEERING, STANFORD UNIVERSITY]

Molecular Rearrangements. XV. The Stereochemistry of the Solvolytic and Deamination Reactions of 1,2,2-Triphenylethyl Derivatives¹

BY CLAIR J. COLLINS, WILLIAM A. BONNER AND CHARLES T. LESTER

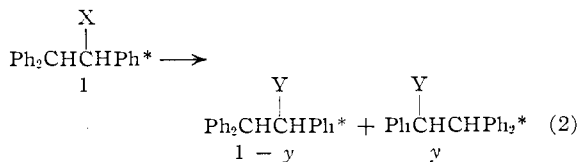
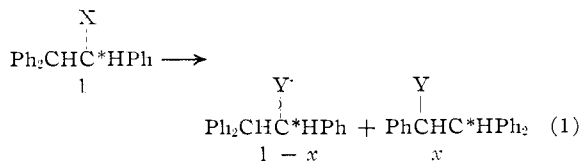
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The solvolytic and deamination reactions of 1,2,2-triphenylethanol and its derivatives, previously reported with respect to radiochemistry, have now been studied stereochemically. It has been found that (1) the products of hydrolysis and acetylation of 1,2,2-triphenylethyl tosylate and (2) the deamination product from the reaction of 1,2,2-triphenylethylamine with nitrous acid are formed with some racemization plus retention of configuration. The products from the deamination of labeled (–)-amine at 36.9° and of labeled (+)-amine at 25° were separated into olefin, acetate and carbinol fractions. Each carbinol fraction was further separated into retained and racemic material, then all fractions were subjected to oxidative degradation, and the carbon-14 distribution of each was determined. From these data it can be shown that there is more rearrangement of the carbon-14 label in carbinol of inverted configuration than in carbinol of retained configuration, thus completely excluding bridged ions as the cause of configuration retention. These results, however, are compatible with our previously proposed^{4–6} mechanism involving equilibrating, classical carbonium ion intermediates. Retention of configuration is explained by (1) a rate of rotation (k_x , equation 4) about the central carbon-carbon bond which is not extremely rapid with respect to the rate of phenyl migration (k_y , equation 4), and (2) a preferential frontside attack by the entering group owing to steric shielding from back-side attack (Fig. 1) by an *o*-hydrogen of one of the adjacent phenyls.

Introduction

The radiochemistry of the Wagner–Meerwein rearrangement of several carbon-14 labeled 1,2,2-triphenylethyl compounds has been the subject of previous papers.^{2–6} It was shown that the reactions studied could be explained most simply if it is assumed that open or classical carbonium ions, capable of phenyl migration, are the intermediates. In particular reactions of the 1,2,2-triphenylethyl system neither the chain nor the ring labels achieved their statistical values; for example, if equation 1 represents the reactions of the chain-labeled reactants, and equation 2 represents the reactions of the ring-labeled reactants, then the mole fractions x and y , respectively, of rearranged products, were less than the statistical values of 0.500 and 0.667. For a given reaction, however, y was al-

ways greater than x by an amount generally⁶ predictable on the basis of the equilibrating classical carbonium ion mechanism. Certain other reactions of 1,2,2-triphenylethyl derivatives, notably



acetoxy exchange,⁵ did proceed to statistical conclusions (that is, $x = 0.500$ and $y = 0.667$), and were explained on the basis of the same general mechanism.

The idea of a bridged "bromonium" ion was invented by Roberts and Kimball⁷ and was subse-

(1) This paper is based in part upon work performed for the Atomic Energy Commission at Oak Ridge National Laboratory, operated by Union Carbide Corporation. Paper XIV, C. J. Collins, W. T. Rainey, W. B. Smith and I. A. Kaye, *THIS JOURNAL*, **81**, 460 (1959).

(2) W. A. Bonner and C. J. Collins, *ibid.*, **75**, 5372 (1953).

(3) C. J. Collins and W. A. Bonner, *ibid.*, **75**, 5379 (1953).

(4) C. J. Collins and W. A. Bonner, *ibid.*, **77**, 92 (1955).

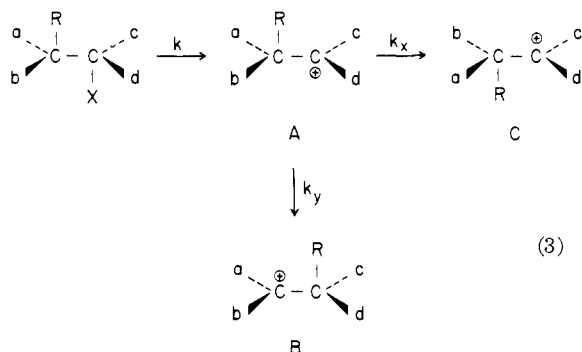
(5) W. A. Bonner and C. J. Collins, *ibid.*, **77**, 99, 6725 (1955).

(6) W. A. Bonner and C. J. Collins, *ibid.*, **78**, 5587 (1956).

(7) I. Roberts and G. E. Kimball, *ibid.*, **59**, 947 (1937).

quently employed⁸ by Winstein and Lucas to explain the stereochemistry of the reaction of optically active 3-bromobutan-2-yl with hydrobromic acid. The bridged-ion hypothesis was extended⁹ to include a carbon bridge, and the phenonium ion concept was developed by Cram and his co-workers¹⁰ to rationalize the stereochemistry of a great number of solvolytic and elimination reactions. The concept of a symmetrical phenonium ion in which the phenyl bridge was equidistant between the migration origin and the migration terminus was later expanded to include the idea of an "unsymmetrical" phenonium ion.^{11,12}

Although stereospecificity is required during concerted migrations and also during those reactions which require phenonium ion intermediates,¹⁰ the converse is not necessarily true. Stereospecificity can, in theory at least, be involved in reactions which are not concerted, and in which bridged ions do not intervene, even though the sole cationic intermediates are classical or open carbonium ions^{13,14}; it is only necessary that the rate of rotation (k_x , equation 3) about the carbon-carbon bond is not very fast compared with the rate of migration (k_y).



In nitromethane, in acetaldehyde and in difluoromethylborane, whose geometries probably approach that of an open carbonium ion, the rotational energy barriers are 6, 14 and 1,150 cal., respectively, per mole.¹⁵ In the simple ethane molecule it has been calculated that the barrier to rotation is about 2800 cal. per mole,^{16a} and Pitzer^{16b} has assumed that in more complicated molecules this value is no less than 3600 cal. per mole. Bondi^{16c} has shown that barriers to free rotation can be much greater.

(8) S. Winstein and H. J. Lucas, *THIS JOURNAL*, **61**, 1576 (1939).

(9) T. P. Nevell, E. DeSalas and C. L. Wilson, *J. Chem. Soc.*, 1188 (1939).

(10) D. J. Cram, *et al.*, *THIS JOURNAL*, **71**, 3863, 3871, 3875 (1949); **74**, 2129, 2137, 2159 (1952); **75**, 3189 (1953).

(11) J. D. Roberts and C. M. Regan, *ibid.*, **75**, 2069 (1953).

(12) D. J. Cram and F. A. Abd Elhafez, *ibid.*, **75**, 3189 (1953).

(13) This fact has been stated previously; see, for example, S. Winstein and E. Grunwald, *ibid.*, **70**, 835 (1948); S. Winstein and B. K. Morse, *ibid.*, **74**, 1134 (1952); S. Winstein and L. L. Ingraham, *ibid.*, **77**, 1739 (1955).

(14) This statement is meant to exclude those cases in which the leaving group shields the front side of the carbonium ion being formed, thus favoring inversion. See C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, pp. 381-386.

(15) E. B. Wilson, *Proc. Nat. Acad. Sci.*, **43**, 816 (1957).

(16) (a) D. H. R. Barton and R. C. Cookson, *Quart. Revs.*, **10**, 44 (1956); (b) K. S. Pitzer, *Chem. Revs.*, **27**, 39 (1940); (c) A. Bondi, *J. Phys. Chem.*, **58**, 929 (1954); (d) see also the discussion by W. G. Dauben and K. S. Pitzer in "Steric Effects in Organic Chemistry," John Wiley and Sons, Inc., New York, 1956, Chapter 1.

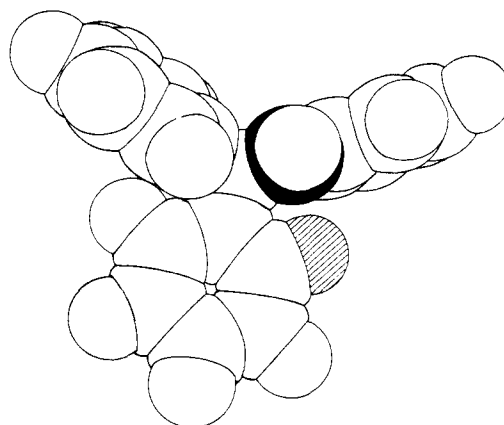


Fig. 1.

Since the activation energies for migration processes such as $A \rightarrow B$ are unknown there is no reason to assume, therefore, that they are necessarily always greater than the rotational ($A \rightarrow C$) energy barriers.

From our previous work²⁻⁶ it appears that the sole cationic intermediates in the several reactions of 1,2,2-triphenylethanol and its derivatives are equilibrating, open, "classical" carbonium ions. A stereochemical study of these same reactions should be enlightening with respect to the relative rates of processes $A \rightarrow B$ and $A \rightarrow C$. Since these reactions are presumed not to involve those intermediates which are normally associated with stereospecificity, it is important to determine whether stereospecificity, in fact, can be associated with the "classical" or open carbonium ion. We report in this paper the results of these stereochemical studies.

Results

Given in Table I is a summary of the stereochemical results for (a) the deamination of optically active 1,2,2-triphenylethylamine, (b) the hydrolysis and (c) the acetolysis of optically active 1,2,2-triphenylethyl tosylate. Included also are the radiochemical results for these same reactions. That the hydrolysis and acetolysis of optically active 1,2,2-triphenylethyl tosylate proceed with a net retention of configuration follows from the sign of rotation of the products so obtained, for in the preparation of the tosylate the carbon-oxygen bond of the asymmetric center is never broken. For example, (+)-carbinol on conversion to tosylate followed by either hydrolysis or acetolysis affords (+)-carbinol and (+)-1,2,2-triphenylethyl acetate, respectively, the latter compound yielding (+)-carbinol on reduction with lithium aluminum hydride. The deamination of optically active 1,2,2-triphenylethylamine has been shown also to proceed with retention of configuration to yield carbinol of the same sign of rotation as the amine from which it was produced. The assignment of like configuration to 1,2,2-triphenylethylamine and 1,2,2-triphenylethanol of like sign of rotation is based upon data obtained through well-established¹⁷ methods of configurational relationship.

(17) (a) D. J. Cram and John E. McCarty, *THIS JOURNAL*, **76**, 5740 (1954); (b) A. McKenzie and G. O. Wills, *J. Chem. Soc.*, **127**, 290 (1925); (c) A. McKenzie and A. C. Richardson, *ibid.*, 79 (1925);

Although some of these methods, such as (1) the ammonolysis^{17a} of the tosylate of (-)-1,2,2-triphenylethanol, (2) an attempted interrelation through mandelic acid and phenylglycine^{17b,c,d} and (3) an application of Freudenberg's "Displacement Rule"^{17e} were unsuccessful, our assignment of configuration is based on the following facts: (1) Double-labeling experiments upon the solvolytic and deamination reactions of 1,2,2-tri-

TABLE I

SUMMARY OF STEREOCHEMICAL AND RADIOCHEMICAL RESULTS FOR SOLVOLYTIC AND DEAMINATION REACTIONS OF 1,2,2-TRIPHENYLETHYL-1-C¹⁴ DERIVATIVES

Reaction	Conditions	C ¹⁴ , % rearr. ^a	Reten- tion, %	In- ver- sion, %
Deamination	-2°	23	72	28
Deamination	-2°	..	75	25
Deamination	-2°	22	77	23
Deamination	12.5°	..	69	31
Deamination	25° ^b	27	64	36
Deamination	36.9° ^b	24	67	33
Deamination	36.9° ^b	..	64	36
Deamination	36.9° ^b	22	70	30
Tosylate hydrolysis	Acetone-H ₂ O,	22° ^c	64	36
Tosylate hydrolysis	reflux	..	69	31
Tosylate hydrolysis	Acetone-H ₂ O,	..	64	36
Tosylate hydrolysis	reflux	..	62	38
Tosylate acetolysis	HOAc, NaOAc, 85°	40° ^c	54	46
Tosylate acetolysis	HOAc, NaOAc, 85°	..	58	42
Tosylate acetolysis	HOAc, NaOAc, 85°	..	54	46
Tosylate acetolysis	HOAc, NaOAc, 85°	..	53	47

^a Of the chain label in 1,2,2-triphenylethyl-1-C¹⁴ derivative. ^b In the runs at 25° and 36.9°, in addition to 2-4% olefin, there was produced 5-8% of triphenylethyl acetate (see Tables II and III). When the product was separated from olefin, the $[\alpha]^{25D}$ of the mixed carbinol and acetate was not appreciably different from the carbinol obtained upon reduction of this mixture with LiAlH₄. ^c Taken from ref. 6.

phenylethyl derivatives have demonstrated that both types of reaction proceed through the same open carbonium ion intermediates, and whereas the solvolytic reactions have been shown to take place with retention of configuration, then, with a very high probability the deamination reaction can also be said to proceed with retention of configuration; (2) in an application of the Fredga^{17f} method of solid-liquid phase relationships of enantiomers of derivatives of carbinol and amine, although there was no evidence of the formation of quasi-racemates or eutectics, the *solidi* were characteristically different in the case of (+)-1,2,2-triphenylethyl acetate with (+)- and (-)-N-acetyl-1,2,2-triphenylethylamine, sufficient to allow a tentative conclusion that the two compounds of like sign possess like configuration; (3) the optical rotary dispersion curves of (+)-1,2,2-triphenylethyl acetate and of (+)-N-acetyl-1,2,2-triphenylethylamine (kindly determined by Professor Carl Djerassi) are very similar,

(d) C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, pp. 386 and 397; (e) K. Freudenberg, "Stereochemie," Franz Deuticke, Leipzig and Vienna, 1933, p. 699 ff.; (f) A. Fredga in "The Svedberg," Almqvist and Wiksells, Uppsala (Sweden), 1944, pp. 261 ff.; A. Fredga, *Arkiv för Kemi*, **11**, 23 (1957); K. Mislow and M. Heffer, *THIS JOURNAL*, **74**, 3668 (1952); K. Mislow and W. C. Meluch, *ibid.*, **78**, 5920 (1956); (g) R. Huisgen and C. Rütchardt, *Ann.*, **601**, 21 (1950); (h) E. I. White, *THIS JOURNAL*, **77**, 6014 (1955).

and although both dispersion curves are simple they offer presumptive evidence of like configuration; and finally, (4) the thermal decomposition, in a non-polar solvent, of the N-nitroso derivative of (+)-N-acetyl-1,2,2-triphenylethylamine yielded (+)-1,2,2-triphenylethyl acetate.¹⁸ Since the work of Huisgen^{17g} and of White^{17h} demonstrates that under these conditions such thermal decompositions take place with configurational retention, (+)-1,2,2-triphenylethylamine, (+)-1,2,2-triphenylethyl acetate and (+)-1,2,2-triphenylethanol can now be said to possess the same configuration.

Given in Tables II and III are summaries of experiments which were performed with (-)- and (+)-1,2,2-triphenylethyl-1-C¹⁴-amine, respectively.

TABLE II

SUMMARY OF RADIOCHEMICAL DATA FOR VARIOUS FRACTIONS OBTAINED ON DEAMINATION OF (-)-1,2,2-TRIPHENYLETHYL-1-C¹⁴-AMINE AT 36.9°

Product	Yield, %	$[\alpha]^{25D}$	C ¹⁴ rearrange- ment, %
Ph ₂ C [*] =*CHPh	4	...	37
(-)-Ph ₂ CHC [*] HPh	8	-23° ^a	13 ^b
(-)-Ph ₂ CHC [*] HPh ^d	88 ^d	Fract. 1 ^c - 0 Fract. 2 - 5.4 Fract. 3 - 91 Fract. 4 - 119	24.5 24.6 20.7 20.6

^a This value is calculated from $[\alpha]^{25D}$ determinations of three different fractions. ^b This value was obtained by oxidation of a fraction whose $[\alpha]^{25D}$ was -3°. ^c In addition to fractions 1-4 there were several intermediate fractions. ^d The crude carbinol had an $[\alpha]^{24.7D}$ of -47.9°, corresponding to 70% net retention.

TABLE III

SUMMARY OF RADIOCHEMICAL DATA FOR VARIOUS FRACTIONS OBTAINED ON DEAMINATION OF (+)-1,2,2-TRIPHENYLETHYL-1-C¹⁴-AMINE AT 25.0°

Product	Yield, %	$[\alpha]^{25D}$	C ¹⁴ rearrange- ment, %
Ph ₂ C [*] =*CHPh	2.5	...	25.5
(+)-Ph ₂ CHC [*] HPh	5.5	...	24.0 ^a
(+)-Ph ₂ CHC [*] HPh ^b	92	Fract. 1 0° Fract. 2 +121°	28.1 26.5

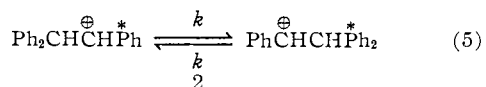
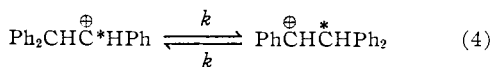
^a Of total acetate fraction. ^b The crude carbinol had an $[\alpha]^{24.7D}$ of +34.9°, corresponding to 64% net retention.

The deamination products from each of these reactants—one reaction carried out at 36.9°, the other at 25.0°—were separated into olefin, acetate and carbinol fractions. The carbinol fractions were then resolved into samples of completely retained configuration and into racemic material. The percentages of rearrangement of the carbon-14 label were determined for each of the foregoing fractions.

(18) Mrs. Joan B. Christie, unpublished work. When (+)-N-acetyl-1,2,2-triphenylethylamine, $[\alpha]^{25D}$ +110° (dioxane), obtained from (+)-1,2,2-triphenylethylamine, $[\alpha]^{25D}$ +74.6° (ethanol) was converted¹⁷ⁱ to the N-nitroso derivative and subjected to thermal decomposition in carbon tetrachloride, the 1,2,2-triphenylethyl acetate so obtained had a positive rotation. $[\alpha]^{25D}$ +26°, corresponding to 70% of the (+)-enantiomer and 30% of the (-)-isomer.

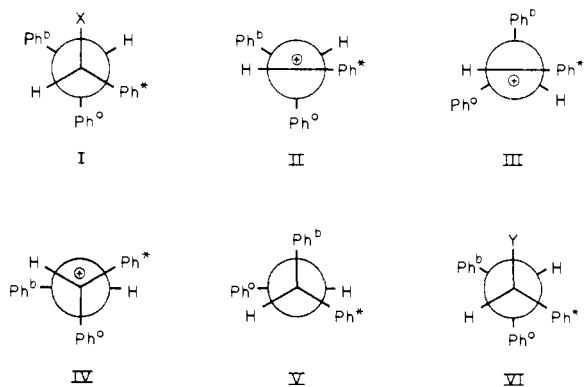
Discussion

The data of Tables I, II and III clearly indicate that although hydrolysis and acetolysis of 1,2,2-triphenylethyl tosylate and deamination of 1,2,2-triphenylethylamine proceed with considerable racemization, each product is formed with a net retention of configuration. We must now answer the question of how retention of configuration is possible in view of our postulation²⁻⁶ that open, equilibrating carbonium ions (equations 4 and 5)



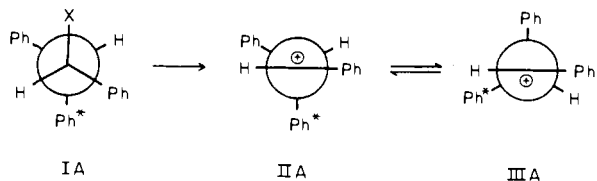
are the only intermediates necessary to explain our previous²⁻⁶ radiochemical data.¹⁹

In Fig. 1 is a drawing of a Fisher-Hirshfelder model of the benzhydryl phenyl carbonium ion in conformation II, and in a position of maximum steric shielding. It can be seen from Fig. 1 that



the *o*-hydrogen (shaded in the drawing) of the phenyl (Ph^a) below the plane of the carbonium center completely shields the positively-charged carbon (solid in drawing) from rearward attack (that is, from below ion II). Attack from the front-side (top) of the ion, however, is sterically favorable. Conformational considerations¹⁶ suggest that I is the most probable rotational isomer for 1,2,2-tri-

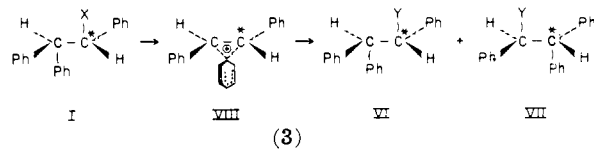
(19) An examination of equation 5 discloses that because of our choice of the position of the ring label, carbonium ion II (which represents a particular conformation of the unrearranged ions of equation 5) initially formed from the ring-labeled reactant I could rearrange to ion IV with exclusive migration of only one (Ph^a) of the two possible migrating phenyls, and still fulfill the requirements imposed upon equation 4 and 5 by our choice of specific rate constants for these reactions. It is only after ion IV has been formed that these rate constants require the two phenyls (Ph^* and Ph^a) to possess equal opportunities for migration. This would not be true if the ring-labeled reactants were labeled as in IA. In this case it would be



possible to identify which of the phenyls on carbon-2 migrates initially. Only in the event that the labeled and unlabeled phenyls of IA should migrate equally (that is, the concentrations of IIA and IIIA are equal) would the specific rate constants of equations 4 and 5 be applicable to the reactions of IA.

phenylethylamine, the corresponding carbinol and derivatives of each, and also that II (*cf.* Fig. 1) should be the preferred conformation of the ions derived therefrom. Conformation II which is shielded by Ph^a (*cf.* Fig. 1) from attack below the plane of the ion, may follow any one of three paths: (1) It may undergo migration of Ph^a to produce rearranged ion IV; (2) it may rotate about the central carbon atoms to produce its rotational isomer III, which, if it then reacts from below the plane of the positively charged carbon, produces *inverted* product; or (3) it may react to produce unrearranged product VI whose configuration is the same as that of reactant I. Ion III, of course, may rearrange to produce ion V; then III, IV and V may undergo similar fates. If rotation of II to produce III is slow with respect to the migration of Ph^a and conversion to product, then predominant retention of configuration will result. It is interesting that the relation of the fraction of chain label to the fraction of ring label rearrangement from previous double-labeling experiments^{4,6} is not exactly as predicted by the classical carbonium ion mechanism in the absence of internal return but always slightly higher. At least in the case of the deamination reaction, this may be ascribed to the as yet incomplete equilibration of the rotational isomers of the initially rearranged carbonium ions of equations 4 and 5.

The foregoing hypothesis is thus compatible with previous²⁻⁶ double-labeling data and with the present (Table I) stereochemical results. The question arises, however, as to whether the intermediates in the reactions studied might be mixtures of bridged ions and open ions, the *trans*-bridged ions (VIII) accounting for the retention of configuration in the product as well as for the scrambling of the carbon-14 labels, and the open ions leading to racemization. The data of Tables II and III allow us to state with complete assurance that bridged ions are not the cause, in the present instance, of configurational retention. Consider, for example (equation 6), the radiochemical consequences of the deamination of 1,2,2-triphenylethyl-1- C^{14} -amine (I, $\text{X} = \text{NH}_2$) to the carbinol (VI and VII, $\text{Y} = \text{OH}$) through the *trans*-phenonium ion VIII. Any portion of the reaction proceeding by this path would be expected to produce unrearranged

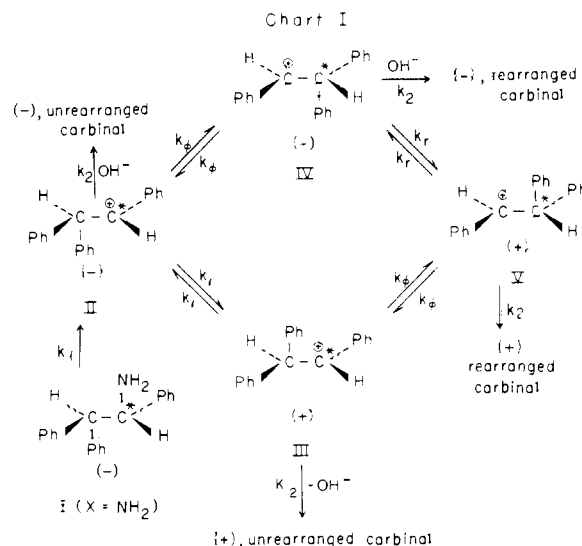


(VI) and rearranged (VII) product in equal proportions. Further, the product (VI and VII) should possess the same configuration as reactant (I); *i.e.*, configuration should be *retained*. (To the extent that the *trans*-phenonium ions are not "symmetrical" but might be considered "unsymmetrical,"^{11,12} the retained product should fail to have an equal carbon-14 distribution between the two central carbons.) Similar reasoning demonstrates that *cis*-phenonium ions should yield configurationally retained, unrearranged product, plus inverted product which has undergone complete

(100%) isotope position isomerization. Thus, compound I reacting through the *cis*-ion should yield inverted product whose carbon-14 is contained only in the 2-position. Accordingly, we separated the olefin, acetate and carbinol fractions from the deamination of (-)-1,2,2-triphenylethyl-1-C¹⁴-amine at 36.9°, and from the deamination of the (+)-amine at 25°. Each carbinol fraction, as shown in Tables II and III, was further resolved into a racemic carbinol and into a (-)- or (+)-carbinol. In each deamination the carbinol of *inverted* configuration had undergone more rearrangement of its carbon-14 label than had the product of *retained* configuration. From these data we can now draw the following conclusions: (1) the mechanism of the deamination of I cannot involve the direct formation of bridged ions alone which go directly to product, for whether or not such bridged ions are "symmetrical"¹⁰ or "unsymmetrical"^{11,12} with varying proportions of *cis* and *trans* character such a mechanism would require the inverted product to contain *all* of its carbon-14 in the 2-position; the data of Tables II and III therefore refute such a mechanism. (2) The direct formation of bridged ions (of any type) and open ions, in which the open ions do not rearrange, and in which both types of ion go directly to product can also be ruled out, for such a scheme would not allow more rearrangement of the ring-label than of the chain-label during deamination; since we have demonstrated⁶ adequately that the phenyl label undergoes considerably more rearrangement than does the chain label, the foregoing mechanism is also refuted. (3) The formation of bridged ion of the *trans* variety either symmetrically¹⁰ or unsymmetrically^{11,12} bridged plus open ions, all of which are interconvertible, is also not possible, for such a mechanism could never provide more rearrangement of the inverted than of the retained product. (4) Finally, we may rule out a mechanism in which the intermediates are mixtures of *cis* and *trans* bridged ions, symmetrical¹⁰ or unsymmetrical,^{11,12} plus open ions, all of which may interconvert to some degree before going to product, since the data of Table II alone, or the data of Table III, when combined with prior radiochemical results,⁶ are stoichiometrically incompatible with any such scheme. Since experiments of the type reported in Tables II and III were not performed for the hydrolyses and acetolyses (Table I), we can only state by analogy with the deamination reaction that we believe the mechanisms of all three reactions to be similar. However, when one considers the incredible degree of coincidence required for any mixture of bridged and open ions to relate the rearrangements of chain and ring label⁶ one to the other by the two limiting equations derived solely on the basis of our equilibrating, classical carbonium ion mechanism, the hydrolyses and acetolyses can be said also, with a high degree of assurance, not to owe their configurational retention to bridged ions.

It is clear, therefore, that retention of configuration during the deamination of 1,2,2-triphenylethylamine cannot be ascribed to bridged ions. Given in Chart I is the mechanism previously employed⁶ by us to explain the results of double-

labeling experiments upon deamination of 1,2,2-triphenylethylamine, but so expanded to account for the stereochemical results reported in this paper. An examination of Chart I discloses that the extent of carbon-14 rearrangement exhibited by the (+)- or (-)-carbinol is a function of the specific rate constants k_1 , k_2 , k_ϕ and k_r . Lacking knowledge concerning the relative values of these specific rate constants, it is not possible to predict whether the fraction of rearrangement of the (-)-carbinol should be equal to, greater or less than the fraction of rearrangement exhibited by the (+)-carbinol. The mechanism of Chart I allows any of these three possibilities.



The reasons for the rather large differences in amounts of rearrangement undergone by the olefin, carbinol and acetate fractions during deamination at 36.5° (Table II) are not clear. Although the olefin is known⁴ to rearrange under acid catalysis at higher temperatures, it is particularly difficult to understand why the acetate fractions from both deaminations (Tables II and III) should exhibit *less* rearrangement than the carbinol fractions. It may be that the mechanism proposed by Huisgen^{17b} for the thermal decomposition of N-acyl nitroso derivatives is also applicable to that portion of the deamination reaction which yields acetate. These questions will be the subject of future papers.

The greater extent of racemization during hydrolysis and acetolysis of 1,2,2-triphenylethyl tosylate than during deamination of 1,2,2-triphenylethylamine is possibly due to internal return between the triphenylethyl carbonium-ion and the tosylate anion.

In summary, the present data, combined with previous radiochemical experiments²⁻⁶ upon the solvolytic, elimination, and deamination reactions of 1,2,2-triphenylethyl derivatives, are best explained on the basis of equilibrating, classical carbonium ions which predominantly retain their configurations because of (1) steric shielding from rear-ward attack by the entering group and (2) rates of phenyl migration (k_x , equation 4) and rotation (k_y , equation 4) about the central carbon-carbon bond which do not differ greatly in magnitude.

Further, the possibility that bridged ions can be the cause of retention of configuration or rearrangement of the label during deamination of 1,2,2-triphenylethylamine is excluded.^{20,21}

Experimental

(+)- and (-)-1,2,2-Triphenylethylamine.—Racemic 1,2,2-triphenylethylamine⁶ (115.4 g.) was dissolved in ethanol (426 ml.) and the solution was treated with a warm solution of (+)-camphor-10-sulfonic acid (98.0 g.) in water (426 ml.). The mixture was seeded with (-)-1,2,2-triphenylethylammonium (+)-camphor-10-sulfonate from a previous resolution and allowed to crystallize. The solid was filtered, pressed well, air-dried and weighed, 135.3 g., $[\alpha]^{25D} + 15.6^\circ$ (*c* 2.6, ethanol). It was then crystallized repeatedly from dilute ethanol, 2 ml. of 95% ethanol and 2 ml. of water being employed per gram of salt. After the fourth crystallization the 62.8 g. of salt had $[\alpha]^{25D} + 10.1^\circ$ (*c* 2.3, ethanol), a rotatory value which did not change sensibly on further crystallization. The salt was treated with excess aqueous sodium hydroxide, and the liberated amine was extracted thoroughly with ether. The extract was washed with water, dried over anhydrous sodium sulfate and was decolorized by being filtered through a bed of Norit. After removal of the solvent from the filtrate—last traces *in vacuo*—there remained 35.2 (61% of the (-)-amine) of clear sirup, $[\alpha]^{25D} - 64.5^\circ$ (*c* 2.6, ethanol). The amine, after crystallization from hexane in Dry Ice, had a m.p. of 67° and an $[\alpha]^{25D} - 69.5^\circ$ (*c* 3.7, ethanol) or $[\alpha]^{25D} - 89.5^\circ$ (*c* 0.9, dioxane).

Anal. Calcd. for C₂₀H₁₉N: C, 87.86; H, 7.01; N, 5.16. Found: C, 87.50, 87.58; H, 7.00, 6.97; N, 5.21, 5.06.

All mother liquors from the crystallizations in the above resolution were combined and concentrated to a small volume by evaporation in an air stream on the steam-bath. The residue was treated with excess sodium hydroxide and the amine was isolated as before; 67.3 g. (89% total amine recovery), $[\alpha]^{25D} + 30.4^\circ$ (*c* 2.2, ethanol). The recovered amine (67.1 g.) was dissolved in ethanol (100 ml.) and treated with a hot solution of (+)-tartaric acid (36.9 g.) in water (100 ml.). The resulting tartrate salt was collected and repeatedly recrystallized from a mixture of ethanol and water (1.2 ml. of each solvent per gram of salt). After six crystallizations the 46.8 g. of tartrate had $[\alpha]^{25D} + 47.5^\circ$ (*c* 1.5, pyridine). Two further crystallizations gave 41.5 g. of salt of identical rotation. Decomposition of the latter salt and that in its mother liquors (44.4 g. total) with excess sodium hydroxide, followed by usual extraction of the amine gave 26.0 g. (91%) of (+)-1,2,2-triphenylethylamine, $[\alpha]^{25D} + 65.4^\circ$ (*c* 3.2, ethanol). After two crystallizations from hexane the (+)-amine had a m.p. of 67–68°, and an $[\alpha]^{25D} + 74.6^\circ$. The unresolved amine in the combined mother liquors was recovered as usual, 39.2 g. (total amine recovery, 97.5%), $[\alpha]^{25D} + 5.7^\circ$ (*c* 5.2, ethanol).

(+)- and (-)-1,2,2-Triphenylethanol.—(-)-1,2,2-Triphenylethylamine, $[\alpha]^{25D} - 69.5^\circ$ (ethanol), was obtained by fractional crystallization of the (+)-camphor-10-sulfonic acid salt. The dextrorotatory enantiomer was obtained in slightly higher purity, $[\alpha]^{25D} + 74.6^\circ$ (ethanol), by recrystallization of the tartaric acid salt of the amine recovered from the mother liquors of the first resolution. When either enantiomeric amine was deaminated with nitrous acid under the conditions previously employed,⁶ the 1,2,2-triphenylethanol resulting was found to be optically active and to have the same sign of rotation as its amine precursor. Early attempts to resolve the *dl*-carbinol with alkaloids *via* its half-suc-

inate, half-phthalate, etc., were unsuccessful, so the carbinol obtained from deamination of the optically active amine and the acetate derived therefrom were subjected to fractional crystallization in a variety of solvents. It was found that samples of 1,2,2-triphenylethyl acetate, enriched in one optical isomer, could be further enriched to a constant optical rotatory power by fractional crystallization from ethyl alcohol, the racemic form of the acetate being considerably less soluble than either enantiomorph. In this way (-)-1,2,2-triphenylethyl acetate of $[\alpha]^{25D} - 60^\circ$, (+)-1,2,2-triphenylethyl acetate of $[\alpha]^{25D} + 61.4^\circ$, (-)-1,2,2-triphenylethanol of $[\alpha]^{25D} - 119^\circ$ (m.p. 82–83°) and (+)-1,2,2-triphenylethanol of $[\alpha]^{25D} + 122^\circ$ (m.p. 82–83°) were obtained.²²

Anal. Calcd. for C₂₀H₁₈O: C, 87.54; H, 6.62. Found (+)-isomer: C, 87.51, 87.47; H, 6.58, 6.64. Found (-)-isomer: C, 87.30; H, 6.65.

Enantiomeric 1,2,2-Triphenylethylammonium Chlorides.

—A sample of (+)-1,2,2-triphenylethylamine (9.9 g.) having $[\alpha]^{25D} + 59.3^\circ$ (*c* 3.5, ethanol) (80% optically pure) was dissolved in ethanol (20 ml.) containing water (15 ml.). The solution was treated with excess concentrated hydrochloric acid, and the resulting solid was filtered, washed and air-dried; 10.3 g. (92%). Purification was accomplished by vacuum sublimation at 210° (0.1 mm.). The sublimate was exposed to hydrogen chloride fumes,^{6a} then dried *in vacuo* prior to analysis, when it had a m.p. of approximately 270° (w. subl.) (Fisher block) and $[\alpha]^{25D} + 8.2^\circ$ (*c* 0.7, ethanol).

Anal. Calcd. for C₂₀H₂₀NCl: C, 77.59; H, 6.51. Found: C, 77.90; H, 6.61.

A sample of (-)-1,2,2-triphenylethylamine $[\alpha]^{25D} - 67.1^\circ$ (*c* 3.8, ethanol) (90% optically pure) was converted to its hydrochloride and purified in a similar fashion, m.p. ca. 270° (subl.), $[\alpha]^{25D} - 7.9^\circ$ (*c* 1.4; ethanol).

Anal. Calcd. for C₂₀H₂₀NCl: C, 77.59; H, 6.51. Found: C, 77.46; H, 6.51.

Given in Table IV are the physical constants and carbon and hydrogen analyses for several N-derivatives of (+)- or (-)-1,2,2-triphenylethylamine.

Deamination of Enantiomeric 1,2,2-Triphenylethylamines.—(-)-1,2,2-Triphenylethylammonium chloride (5.86 g.) was dissolved in hot water (290 ml.). The solution was cooled, filtered (Celite), treated with acetic acid (8.3 ml.) and chilled to 5–8°. A solution of sodium nitrite (12.5 g.) in water (125 ml.) was added dropwise with stirring to the amine solution over a period of five minutes. After being allowed to stand for 20 minutes at room temperature, the mixture was made alkaline with sodium hydroxide solution, and the insoluble carbinol product was recovered by four extractions with ether. The extract was dried over anhydrous sodium sulfate, decolorized by filtration through Norit and freed of solvent, leaving 5.30 g. (102%) of crude 1,2,2-triphenylethanol, $[\alpha]^{25D} - 41.3^\circ$ (*c* 3.2, ethanol). After seven crystallizations the 0.45 g. of product (dried *in vacuo* over phosphoric anhydride) had $[\alpha]^{25D} - 64.5^\circ$ (*c* 0.7-ethanol). As with the racemic carbinol, the partially resolved samples retained solvent of crystallization when taken from acetic acid. The above sample of carbinol, when merely air-dried, was analyzed.

Anal. Calcd. for C₂₀H₁₈O·C₂H₄O₂: C, 79.10; H, 6.64. Found: C, 79.41, H, 6.60.

When desiccated to constant weight *in vacuo* over sulfuric acid, the weight loss was 15.10% (calcd. for 1 mole CH₃-COOH of solvation, 17.95%), and the sample was analyzed.

Anal. Calcd. for C₂₀H₁₈O: C, 87.56; H, 6.61. Found: C, 86.92; H, 6.56.

(+)-1,2,2-Triphenylethylammonium chloride (10.5 g.) was deaminated as described in the previous section, proportional quantities of reagents being used. The crude carbinol obtained weighed 10.0 g. (107%) and had $[\alpha]^{25D} + 39.3^\circ$ (*c* 1.8, ethanol). On successive crystallization from acetic acid the rotation rose to +59.3° after desiccation.

(22) Since the completion of this work, *dl*-1,2,2-triphenylethyl hydrogen succinate has been resolved in two ways (Mrs. Joan B. Christie, unpublished work): (a) through the cinchonidine salts and (b) through the salts of (+)- and (-)-1,1-diphenyl-2-aminopropanol. The (+)-1,2,2-triphenylethanol obtained therefrom had $[\alpha]^{25D} + 123^\circ$, and the (-)-isomer an $[\alpha]^{25D} - 123^\circ$. Both enantiomers had m.p. 82–83°.

(20) Other experimental evidence has been explained by the intervention of carbonium ions which react to yield product more rapidly than they achieve rotational equilibrium; see, for example, B. M. Benjamin, H. J. Schaeffer and C. J. Collins, *THIS JOURNAL*, **79**, 6160 (1957); V. F. Raaen and C. J. Collins, *ibid.*, **80**, 1409 (1958). The work of P. Ballinger and P. B. D. de la Mare, *J. Chem. Soc.*, 1481 (1957), is also pertinent.

(21) We would like to emphasize the point made in an earlier paper (ref. 6, footnote 4) that although our present and past^{2–6} data clearly rule out the possibility that bridged ions are the cause of retention of configuration in the 1,2,2-triphenylethyl system, these data should not be taken as evidence contrary to bridged ions in other systems. The well-known studies of Winstein^{8,13} and of Cram,^{10,12,17a} in our opinion, offer evidence as conclusive as is possible for the soundness of the bridged ion concept.

TABLE IV

N-Acyl deriv. of 1,2,2-triphenylethylamine	M.p., °C.	[α] ²⁴⁻²⁶ _D	Formula	Carbon, %		Hydrogen, %		Nitrogen, %	
				Calcd.	Found	Calcd.	Found	Calcd.	Found
(+)-Acetyl ^a	235.5	+109.2 ^c	C ₂₂ H ₂₁ ON	83.78	83.70	6.71	6.47	4.44	4.44
(-)-Acetyl ^b	231.5-232	-104.2 ^c	C ₂₂ H ₂₁ ON	83.78	83.53	6.71	6.34	4.44	4.31
(-)-Propionyl ^b	164-165	-78.1 ^c	C ₂₃ H ₂₃ ON	83.85	83.22	7.04	7.12		
		-62.5 ^e			83.39		7.11		
(-)-Benzoyl ^b	231-232	-135.9 ^c	C ₂₇ H ₂₃ ON	85.91	86.35	6.14	6.20		
(-)-3,5-Dinitrobenzoyl ^b	186-187	-54.1 ^c	C ₂₇ H ₂₁ O ₅ N ₂	69.37	68.78	4.53	4.72		
(-)-Acid succinoyl ^b	184.5-185	-81.9 ^c	C ₂₂ H ₂₃ O ₃ N	75.70	75.49	6.52	6.35		
		-62.5 ^d	+1/2C ₂ H ₅ OH		75.28		6.15		
					75.38		6.26		
(-)- <i>p</i> -Toluenesulfonyl ^b	196-196.5	-107 ^e	C ₂₇ H ₂₅ O ₂ NS	75.90	76.03	5.90	5.96		

^a From (+)-1,2,2-triphenylethylamine. ^b From (-)-1,2,2-triphenylethylamine. ^c In dioxane. ^d In dilute ethanol containing 3% NaOH. ^e In acetone.

Anal. Calcd. for C₂₀H₁₈O: C, 87.56; H, 6.61. Found: C, 86.93; H, 6.37.

(+)- and (-)-1,2,2-Triphenylethyl-*p*-toluenesulfonates. —Owing to the difficulty, during the early stages of this work, of obtaining large amounts of completely resolved (+)- and (-)-1,2,2-triphenylethanol, the tosylates for the solvolytic reactions were prepared from partially racemic carbinol fractions. Three such samples were prepared, tosylates A, B and C, from carbinol samples whose [α]^{25D} were -52.0°; +58.2° and +51.6°, respectively (ethanol). The tosylate samples were prepared as described previously² for racemic tosylate and possessed melting points of 83-84°.

Anal. Calcd. for C₂₇H₂₄O₃S: C, 75.70; H, 5.65. Tosylate A: Found: C, 75.44, 75.47; H, 5.36, 5.40; [α]^{25D} + 8.0° (acetone). Tosylate B: Found: C, 75.28, 75.30; H, 5.45, 5.60. Tosylate C: Found: C, 75.28, 75.30; H, 5.45, 5.60; [α]^{25D} -6.7° (acetone).

Upon crystallization of these tosylates from acetone-hexane mixture, there was no change in optical rotation nor melting point of the samples. Finally, 5.0 g. of optically pure (-) carbinol²² of [α]^{25D} = 123° (ethanol) and m.p. 82-83°, was similarly converted² to 2.91 g. (48%) of (+)-1,2,2-triphenylethyl tosylate (m.p. 88-88.5° dec. and [α]^{25D} + 16.2° (c 1.47, acetone)).

Anal. Calcd. for C₂₇H₂₄O₃S: C, 75.70; H, 5.65. Found: C, 75.53, 75.65; H, 5.66, 5.59.

Hydrolysis of (+)-1,2,2-Triphenylethyl Tosylate.—One gram of the optically pure tosylate, [α]^{25D} + 16.2°, was dissolved in a mixture of acetone (30 ml.) and water (10 ml.). The solution was refluxed for 3.5 hours, diluted with water, and freed of acetone by warming in an air stream. The oily 1,2,2-triphenylethanol product was isolated by three extractions with ether. Vacuum rotary evaporation of the solvent yielded 0.66 g. (103%) of sirupy product, [α]^{25D} - 28.8° (c 1.11, ethanol). This specific rotation corresponds to a mixture of 62% (-) and 38% (+)-1,2,2-triphenylethanol.

Non-racemization of 1,2,2-Triphenylethanol under Hydrolysis Conditions.—To be certain that the above product was not further racemized under the reaction conditions producing it, the following experiment was performed. The above carbinol (0.64 g.) from the tosylate hydrolysis was dissolved in acetone (30 ml.) and water (10 ml.) and the solution was refluxed for 3.5 hours. Product isolation was accomplished as above, yielding 0.57 g. (89%) of sirupy carbinol having essentially identical rotation, [α]^{25D} - 28.5° (c 3.02, ethanol). This was crystallized from 2.5 ml. of acetic acid, drying the product for several days *in vacuo*, m.p. 82.5-84°.

Acetolysis of (+)-1,2,2-Triphenylethyl Tosylate.—Acetolysis was conducted under conditions previously described² for the acetolysis of 1,2,2-triphenylethyl-1-C¹⁴ tosylate. A mixture of 1.10 g. of (+)-tosylate of [α]^{25D} + 16.2°, in acetic acid (10 ml.) containing acetic anhydride (0.1 ml.) and anhydrous sodium acetate (0.25 g.) was heated on the steam-bath during 45 minutes. The mixture was treated with water until turbid and allowed to crystallize. The filtered product weighed 0.66 g. (82%) and had m.p. 152-153° and [α]^{25D} - 6.3° (c 1.577, dioxane). When this product was resubmitted to an identical reaction environment for a 45-minute period the 1,2,2-triphenylethyl acetate reisolated had m.p. 153-154° and [α]^{25D} - 3.7° (c 1.627, dioxane), agreeing within experimental error to the initially obtained acetate. The average of the above rotations corresponds to

that of a mixture containing 54% (-) and 46% (+)-1,2,2-triphenylethyl acetate.

This product was added to an ethereal suspension of lithium aluminum hydride in the manner previously described² to accomplish its deacetylation. The crude sirupy 1,2,2-triphenylethanol obtained (97%) had [α]^{25D} - 6.3° (c 3.973, ethanol), corresponding to a mixture of 53% (-) and 47% (+)-enantiomer. Crystallization of the sirup from 2.5 ml. of acetic acid afforded a solid product having m.p. 83-84.5° after extensive drying *in vacuo*.

Non-racemization of 1,2,2-Triphenylethyl Acetate under Acetolysis Conditions.—A mixture of (-)-1,2,2-triphenyl acetate (0.50 g., [α]^{25D} - 58.3°, m.p. 129-130°), sodium acetate (0.16 g.), *p*-toluenesulfonic acid hydrate (0.30 g.), acetic anhydride (0.23 ml.) and acetic acid (6.2 ml.), corresponding approximately to that prevailing after the above acetolysis, was heated on the steam-bath. After 45 minutes an aliquot of the solution was removed and added to excess water containing sodium sulfate. The precipitated acetate was filtered, washed and air-dried, m.p. 129-131.5°, [α]^{25D} - 54.4° (c 1.543, dioxane). The reaction mixture was heated for an additional 90 minutes, and the acetate was recovered as before, [α]^{25D} - 54.4° (c 2.377, dioxane).

The above experiment was duplicated exactly except that 2.4 g. (ca. 1400% excess) of sodium acetate and 12.4 ml. of acetic acid were employed instead of the previously indicated quantities. The acetate isolated after 45 minutes had m.p. 129-131.5° and [α]^{25D} - 54.4° (c 1.787, dioxane), while the acetate isolated after 135 minutes showed [α]^{25D} - 54.6° (c 1.793, dioxane). Thus no detectable racemization of 1,2,2-triphenylethyl acetate occurred under the acetolysis conditions which produced it from 1,2,2-triphenylethyl tosylate. Given in Table V is a summary of the data obtained upon hydrolysis and acetolysis of tosylates A, B and C (optically impure) and upon the tosylate of [α]^{25D} + 16.2°, obtained from optically pure carbinol of [α]^{25D} - 123°. The data obtained with tosylates which were not optically pure are listed in order to demonstrate the duplicability of the results.

Effect of Temperature on the Extent of Racemization During Deamination of (-)-1,2,2-Triphenylethylamine.—(-)-Amine of 98% optical purity (9.00 g.) was dissolved in warm acetic acid (16 ml.), giving 24 ml. of solution. Aliquots (8.00 ml.) of this solution were pipetted into three flasks containing concentrated hydrochloric acid (1.00 ml.) in water (170 ml.). Three solutions each containing sodium nitrite (7.3 g.) in water (73 ml.) were prepared. Each amine solution and nitrite solution was brought to the desired temperature, when the nitrite solution was added dropwise to the amine solution with magnetic stirring over a 5-minute period. Temperature prevailing during the three additions were -2°, 12.5° and 35-38°. Immediately after each addition was complete, excess sodium bicarbonate (13 g.) was stirred cautiously into the mixture, and the product was extracted twice into two 100 ml. portions of C.P. ether. The extracts were dried over anhydrous sodium sulfate (10 g.), filtered, and the solvent evaporated from each. Product yields were: 35-38°, 3.19 g.; 12.5°, 3.03 g.; -2°, 1.29 g. In the -2° experiment, a portion (1.56 g.) of the amine hydrochloride crystallized out at the low temperature, and was removed mechanically during processing of the reaction mixture. Each crude product was dissolved in 50 ml. of 55-85° ligroin, and the solutions were passed through 1 × 7-inch alumina columns in order to separate any hydrocarbon

TABLE V
 SUMMARY OF TOSYLATE SOLVOLYSIS DATA

Run	Rotation of starting carbinol	Rotation of tosylate	Hydrolysis carbinol		Acetolysis products			
			Rotation	Inverted, %	Rotation	Inverted, %	Rotation	Inverted, %
1	+ 51.6 ^{ab}	- 6.72 ^{oa}	+ 14.7 ^{ob}	36	+ 2.16 ^{oc}	..	+ 5.72 ^{ob}	46
2	+ 58.2 ^b	.....	+ 22.6 ^b	31	.....	..	+ 9.7 ^b	42
3	- 52.0 ^b	+ 8.0 ^a	- 14.7 ^b	36	.....	..	- 4.6 ^b	46
4	- 123.0 ^b	+ 16.2 ^a	- 28.8 ^b	38	- 5.0	46	- 6.3 ^b	47

^a Rotation observed in acetone. ^b Rotation observed in ethanol. ^c Rotation observed in glacial acetic acid.

by-products. Each column was then washed with three 75-ml. portions of ligroin, and the ligroin fractions were evaporated to dryness. The yields of non-adsorbed by-products for the three experiments were: 35–38°, 0.11 g.; 12.5°, 0.10 g.; -2°, 0.04 g. A blank evaporation of 100 ml. of the ligroin used gave no residue. Each alumina column was next eluted with three 75-ml. portions of ethanol, and the ethanol washings in each experiment were evaporated to dryness, last traces at 100° *in vacuo*. Yields and $[\alpha]^{25D}$ in ethanol of the recovered carbinol products corresponding to each temperature were: (1) 35–38°, 3.03 g., -32.8° (*c* 3.1); 12.5°, 2.99 g., -44.5° (*c* 4.1); -2°, 1.28 g., -60.0° (*c* 3.0). In similar experiments we obtained the results listed in Table I.

Deamination of (+)- and (-)-1,2,2-Triphenylethyl-1-C¹⁴-amine.—Racemic 1,2,2-triphenylethyl-1-C¹⁴-amine⁶ was resolved into (-)-amine of $[\alpha]^{25D} - 69.5^\circ$ and (+)-amine whose $[\alpha]^{25D} + 74.6^\circ$ (m.p. 67–68°) as described earlier in the Experimental section. The molar radioactivity of the free (-)-amine was 1.625 ± 0.023 mc./mole. The (-)-acetate derived therefrom had a molar radioactivity of 1.636 ± 0.013 mc./mole, and $[\alpha]^{25D} - 116^\circ$. In a typical experiment 6.0 g. of (-)-1,2,2-triphenylethylamine-1-C¹⁴ was dissolved in 10.7 cc. of glacial acetic acid, and to it was added 2 cc. of concentrated hydrochloric acid in 340 cc. of water. The flask containing the solution was placed in a water-bath at 36.6–37.2° for 90 minutes, then to it was added dropwise with stirring a solution of 14.6 g. of sodium nitrite in 146 cc. of water. The addition required 40 minutes. After the addition was complete, the mixture was stirred for 35 minutes, then removed from the bath and treated with 26 g. of sodium bicarbonate. The ether extract, washed well with water, was concentrated to dryness, and dissolved in hexane so that the total volume was 150 cc. A 12.5-cc. aliquot of this solution was concentrated and desiccated, yielding 547 mg. of crude, dry material, $[\alpha]^{24.5D} - 47.0^\circ$ (ethanol). The solution was allowed to stand overnight and from it crystallized a small amount of nearly racemic 1,2,2-triphenylethyl acetate, m.p. 158°. The entire sample from the 12.5-cc. aliquot was hereupon combined, deacetylated with lithium aluminum hydride and the carbinol product recovered. The $[\alpha]^{25.5D}$ of the recovered carbinol was -47.9°. The carbinol product (446 mg.) was dissolved in hexane and placed on a column of alumina. The column was washed with hexane until no more 1,1,2-triphenylethylene remained, then the carbinol (428 mg.) was removed with ethanol. The 428 mg. of 1,2,2-triphenylethanol was oxidized in 11 cc. of glacial acetic acid by adding to it 430 mg. of CrO₃ in 4 cc. of glacial acetic acid and 2.5 cc. of water. Both solutions had been chilled prior to mixing. After one hour the benzylidene phenyl ketone was isolated; 407 mg., m.p. 138°. This ketone was oxidized to benzophenone as described previously.⁶ The yield of 2,4-dinitrophenylhydrazone obtained therefrom was 369 mg. (68%). After being crystallized 3 times the derivative (m.p. 240–242°) had a radioactivity assay of 0.3220 ± 0.002 mc./mole, corresponding to 19.7% rearrangement of the carbon-14 label. This value is too low to be compatible with the percentages scrambling (Table II and *vide infra*) of the racemic and of the resolved carbinols isolated from the same mixture. This anomaly was subsequently shown to be due to two causes: (a) the presence of varying but small percentages of unreacted amine in the non-crystalline deamination product and (b) fractionation of the racemic carbinol during chromatography. Our inability to remove the last traces of unreacted amine from the crude product undoubtedly contributes to the variability of the observed rotations of the deamination products. These same considerations do not apply to the data of Tables II and III, or to our prior^{2–6} radiochemical results, which were obtained upon rigorously purified products.

The remaining 137.5 cc. of hexane solution of the original deamination product was concentrated to dryness, dissolved in 110 cc. of 95% ethanol, and allowed to stand overnight, yielding 422 mg. of tan crystals, m.p. 150°. After one crystallization from ethanol, 298 mg. of 1,2,2-triphenylethyl acetate was obtained whose m.p. and mixed m.p. with authentic racemic material was 158°, $[\alpha]^{25D} - 2.6^\circ$. After conversion to 1,2,2-triphenylethanol by deacetylation with lithium aluminum hydride, the recovered carbinol (257 mg.) had $[\alpha]^{25D} - 10.7^\circ$. This carbinol was oxidized to ketone (244 mg.) thence to benzophenone which was converted to 222 mg. (71%) of 2,4-dinitrophenylhydrazone. After three crystallizations from dioxane, the 2,4-dinitrophenylhydrazone had m.p. 240° and a radioactivity assay of 0.2109 ± 0.0005 mc./mole, corresponding to 12.9% rearrangement of the carbon-14 label.

The filtrate from which the 422 mg. of 1,2,2-triphenylethyl acetate was obtained was concentrated, then diluted to 100 cc. in a volumetric flask with hexane. A 25-cc. sample was placed on a column of alumina then washed with hexane until no more 1,1,2-triphenylethylene could be obtained. On concentration of the hexane solution there was obtained 48 mg. of olefin (3.5%) which crystallized when scratched with a spatula. The olefin fraction was dissolved in 4 cc. of glacial acetic acid, then oxidized with 50 mg. of CrO₃. The benzophenone isolated therefrom was converted to 40.0 mg. of 2,4-dinitrophenylhydrazone which, after one crystallization from dioxane-ethanol, had a radioactivity assay of 0.6007 ± 0.0007 mc./mole, corresponding to 36.8% carbon-14 rearrangement.

The remaining 75 cc. of hexane solution mentioned in the preceding paragraph was subjected to chromatography on alumina. After the olefin had been removed with hexane, the column was eluted with benzene-hexane and finally with benzene, yielding an additional 200 mg. of 1,2,2-triphenylethyl acetate. (From the weight of this sample of acetate, plus the 422 mg. obtained previously, it can be estimated that the total yield of 1,2,2-triphenylethyl acetate obtained in the deamination of 1,2,2-triphenylethylamine represents about 8% of the product.) After the acetate had been removed, there was obtained in the benzene eluent 431 mg. of 1,2,2-triphenylethanol of $[\alpha]^{25D} - 83^\circ$; the sample was dissolved in hexane, placed on a column of alumina. The column was washed with benzene to yield an initial fraction of 97.5 mg. of carbinol whose $[\alpha]^{25D} - 91.8^\circ$, and whose benzophenone oxidation fragment (102 mg. of 2,4-dinitrophenylhydrazone) had a radioactivity assay of 0.3375 ± 0.0015 mc./mole, corresponding to 20.68% rearrangement of the carbon-14 label.

The two alumina columns above were washed thoroughly with ethanol, and the resultant carbinol fractions therefrom were combined with all remaining carbinol fractions from the deamination. The 3.62 g. of carbinol so obtained was converted to 1,2,2-triphenylethyl acetate, and crystallized fractionally from ethanol. In this way there was obtained 603 mg. of acetate of $[\alpha]^{25D} - 59^\circ$, m.p. 122° (hot-bank), m.p. 128–129° (capillary). This was deacetylated with lithium aluminum hydride to yield 446 mg. of 1,2,2-triphenylethanol, $[\alpha]^{24.7D} - 118^\circ$. The 446 mg. of carbinol was oxidized as usual, and the purified benzophenone 2,4-dinitrophenylhydrazone had a radioactivity assay of 0.3367 ± 0.0015 mc./mole, corresponding to 20.62% rearrangement of the carbon-14 label. Another fraction of 1,2,2-triphenylethyl acetate (383 mg., $[\alpha]^{25D} - 1.72^\circ$) was converted to 1,2,2-triphenylethanol (322 mg., $[\alpha]^{25D} - 5.4^\circ$). Oxidation⁶ of this material yielded benzophenone whose 2,4-dinitrophenylhydrazone, when purified, had a radioactivity assay of 0.4008 ± 0.0008 mc./mole, corresponding to 24.52% carbon-14 rearrangement. Finally there was obtained 957 mg. of essentially racemic 1,2,2-triphenylethyl acetate, $[\alpha]^{25D} - 0.24^\circ$, which was converted to 800 mg. of carbinol by

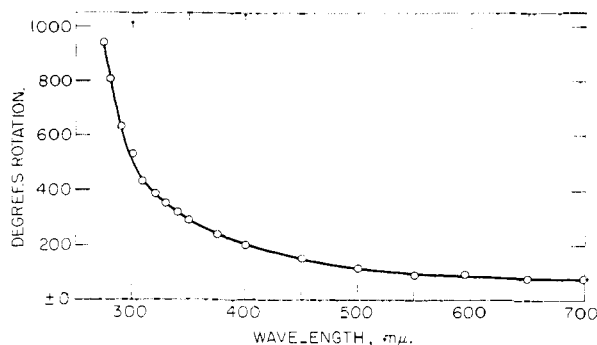


Fig. 2.—Optical rotary dispersion curve, (+)-N-acetyl-1,2,2-triphenylethylamine in methanol at 26° (c 0.0885).

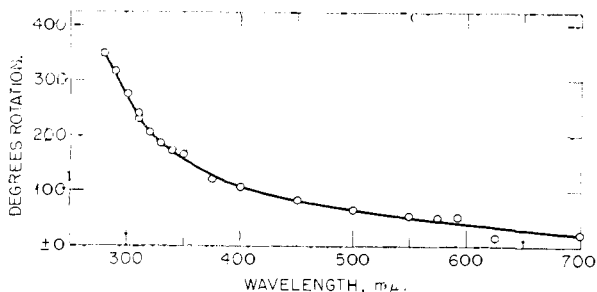


Fig. 3.—Optical rotary dispersion curve, (+)-1,2,2-triphenylethyl acetate in methanol at 26° (c 0.0845).

treatment with lithium aluminum hydride. After two crystallizations from acetic acid there was obtained 477 mg. of 1,2,2-triphenylethanol, m.p. 86°, whose benzophenone oxidation fragment, as the purified 2,4-dinitrophenylhydrazone, had a radioactivity assay of 0.3975 ± 0.0050 mc./mole, which corresponds to a rearrangement of the carbon-14 label of 24.5%.

Stability of 1,2,2-Triphenylethanol-1- C^{14} Under Conditions of the Deamination.—A sample of 1,2,2-triphenylethanol-1- C^{14} (2.12 mc./mole, 300 mg.) was dissolved in 5 cc. of acetic acid, then treated with 10 cc. of water containing 0.04 cc. of concentrated HCl. The solution was cooled to -2° and 0.2 g. of $NaNO_2$ in 4 cc. of H_2O was added. The mixture was stirred at -2° for 30 minutes, and then worked up as a normal deamination product. Oxidation of the carbinol with CrO_3 to benzhydryl phenyl ketone was followed by degradation⁶ of this ketone to benzophenone. The 2,4-dinitrophenylhydrazone obtained therefrom was non-radioactive.

Non-racemization of (-)-1,2,2-Triphenylethanol under Conditions of the Deamination.—A 505-mg. sample of (-)-1,2,2-triphenylethanol, $[\alpha]^{25D} -122^\circ$ (ethanol), m.p. 82–83°, was treated with 1 cc. of glacial acetic acid, 28 cc. of water and 0.2 cc. of concd. HCl. The mixture was heated to 80° and to it was added 1.2 g. of $NaNO_2$ in 12 cc. of water. After 40 minutes the carbinol was reisolated as a yellow sirup, which crystallized on standing; yield 488 mg., $[\alpha]^{25D} -121^\circ$.

Configurational Relationship of (+)-1,2,2-Triphenylethylamine and (+)-1,2,2-Triphenylethanol.—Presumptive evidence of like configuration of (+)-1,2,2-triphenylethylamine and of (+)-1,2,2-triphenylethanol is to be found in the optical rotary dispersion curves²³ (Figs. 2 and 3). Additional presumptive evidence is given in Figs. 4 and 5, respectively, representing the solid-liquid phase relationships^{15c} of (+)-1,2,2-triphenylethyl acetate with (+)- and (-)-N-acetyl-1,2,2-triphenylethylamine. Although there is no evidence of eutectic or quasi-racemate formation, the *solidi* are characteristically different, sufficient to allow the tentative conclusion that the two derivatives of positive sign possess the same configuration. Finally, 1.3 g. of N-acetyl-1,2,2-triphenylethylamine (m.p. 230°, $[\alpha]^{25D} +108^\circ$) was added with stirring at 0° to 500 cc. of carbon tetrachlo-

(23) The optical rotary dispersion data were kindly furnished by Professor Carl Djerassi.

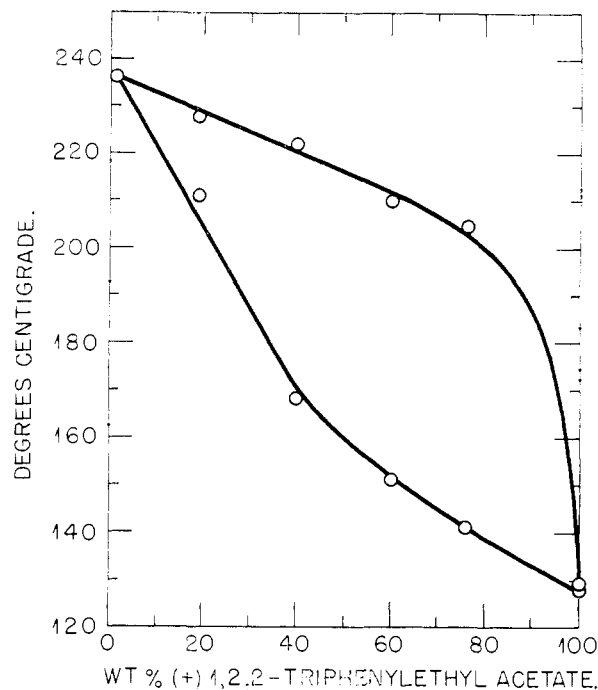


Fig. 4.—Solid-liquid phase diagram of (+)-1,2,2-triphenylethyl acetate with (+)-N-acetyl-1,2,2-triphenylethylamine.

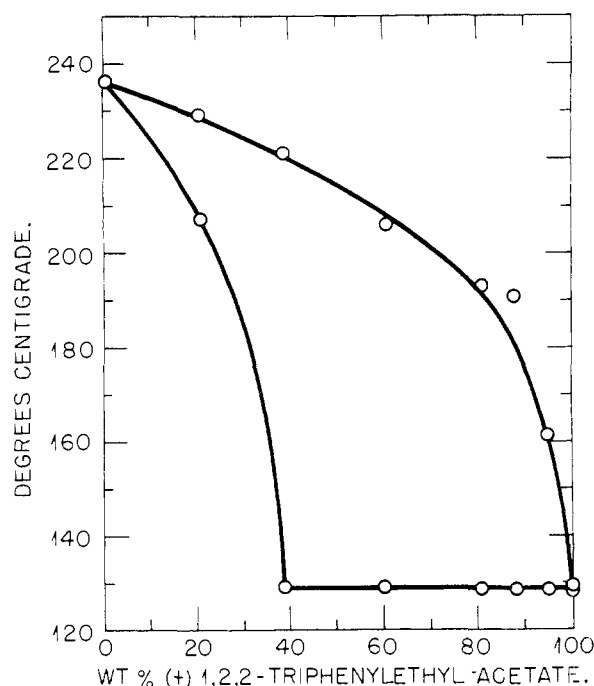


Fig. 5.—Solid-liquid phase diagram of (+)-1,2,2-triphenylethyl acetate with (-)-N-acetyl-1,2,2-triphenylethylamine.

ride containing 8 g. of $N_2O_4^{17a,b}$ and 12 g. of anhydrous sodium acetate. After 2 hours the mixture was poured over ice, after which the organic layer was separated, washed with sodium carbonate, water and then dried over magnesium sulfate. Unreacted N-acetyl-1,2,2-triphenylethylamine (0.7 g.) was recovered during the work-up. The dried carbon tetrachloride solution was heated under gentle reflux overnight, cooled and shaken with 5% sodium hy-

droxide solution, water, and finally dried over magnesium sulfate and evaporated. The solid material was taken up in hot 95% ethanol once the solution was treated with Norit and filtered. In this way 160 mg. of (+)-1,2,2-triphenylethyl acetate was isolated, m.p. 140°, $[\alpha]_{25}^{D} +26^{\circ}$ (dioxane). Still more N-acetyl-1,2,2-triphenylethylamine remained in the alcoholic mother liquors. The identity of the (+)-1,2,2-triphenylethyl acetate was established by deacetylation to (+)-1,2,2-triphenylethanol, followed by oxidation of the carbinol to benzhydryl phenyl ketone. The

ketone was oxidized⁶ with nitric-acetic acid to α -phenylbenzoin which was oxidized with chromic acid to benzophenone and benzoic acid.²⁴

(24) The preparation of the N-nitrosoacyl-1,2,2-triphenylethylamine and its subsequent thermal decomposition were carried out by Mrs. Joan B. Christie. Further details will be published at a later date.

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Studies on the Mechanism of Oxime and Semicarbazone Formation¹

BY WILLIAM P. JENCKS

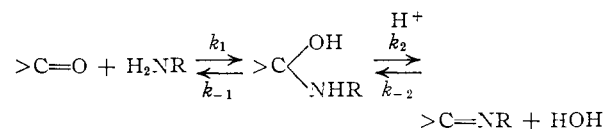
RECEIVED JUNE 23, 1958

At neutral pH hydroxylamine and semicarbazide react rapidly with a number of aldehydes and ketones to form addition compounds which lack the ultraviolet and infrared absorption of the original carbonyl compound. These addition compounds undergo a slow, acid-catalyzed dehydration to form oxime or semicarbazone. The decrease in the rate of oxime formation at acid pH appears to be due to a transition to a rate-limiting attack of free nitrogen base on the carbonyl compound and is not dependent on general acid catalysis. Dehydration of the addition complex, addition of water to the oxime or semicarbazone and addition of semicarbazide to the carbonyl group are subject to both specific and general acid catalysis, while the addition of the stronger base, hydroxylamine, to the carbonyl group is specific acid-catalyzed to only a small extent.

The classical experiments of Barrett and Lapworth,² Olander,³ Conant and Bartlett,⁴ and Westheimer⁵ demonstrated that the reactions of carbonyl compounds with such nitrogen bases as hydroxylamine and semicarbazide exhibit striking maxima in their pH-rate profiles. These pH optima have been attributed to the opposing effects of general acid catalysis and the decrease in the concentration of attacking free nitrogen base due to conversion to the conjugate acid at low pH.^{4,6}

The observation that hydroxylamine reacts rapidly with *p*-nitrophenyl esters at neutral pH without significant acid catalysis (to give a mixture of O- and N-substituted products)⁷ suggested that in the relatively slow, acid-catalyzed reaction of hydroxylamine with aldehydes and ketones the addition of nitrogen base to the carbonyl group might not be the rate-limiting step. The kinetics of oxime and semicarbazone formation have accordingly been studied by following the changes in the ultraviolet absorption of a number of carbonyl compounds in aqueous solution after the addition of the appropriate nitrogen base. It has been found that at neutral pH the attack of nitrogen base on the carbonyl compound is fast, so that the over-all rate is dependent on the equilibrium concentration of a non-absorbing addition compound and on the rate of its acid-catalyzed dehydration. The pH-rate maxima for oxime formation appear to be the result of a transition to a rate-limiting attack of free

nitrogen base on the carbonyl compound at acid pH and are not dependent on general acid catalysis.



Experimental

Materials.—Benzaldehyde and furfural were redistilled and stored at -15° ; solutions in water, containing 10^{-4} M ethylenediaminetetraacetic acid (EDTA) to retard heavy metal catalyzed decomposition, were made up just before use. Solutions of nitrogen bases were prepared from the solid or from stock solutions of the hydrochloride and were neutralized to the desired pH with NaOH just before use; 10^{-4} M EDTA was added to alkaline solutions. Glass-distilled water was used throughout.

Ultraviolet measurements were made on a Cary model 14 recording spectrophotometer, a Beckman model DU spectrophotometer or a Zeiss model PMQ II spectrophotometer. Infrared spectra were obtained with a Perkin-Elmer model 21 spectrophotometer using calcium fluoride cells. Solutions of hydroxylamine in D_2O were prepared by dissolving $\text{NH}_2\text{OH}\cdot\text{HCl}$ and NaOH in D_2O , evaporating to dryness, making up 4 M solutions in D_2O and neutralizing just before use.

Kinetic measurements were made on Beckman or Zeiss spectrophotometers with jacketed cell compartments through which was circulated water from a thermostat at $25.0 \pm 0.1^{\circ}$. Dilute solutions of the reactants were equilibrated in the thermostat before mixing. Readings were taken beginning 10 to 15 seconds after the start of the reaction and continued, usually with about 10 readings, until the reaction had proceeded to completion. All kinetic determinations were carried out with the concentration of nitrogen base greatly in excess of that of the aldehyde or ketone so that pseudo first-order kinetics were obtained. The results were plotted on semi-logarithmic graph paper, the half-times determined graphically, and the first-order rate constants obtained from the formula $k_1 = 0.693/t_{1/2}$. Rates were followed at a wave length, as indicated in the experimental data, suitable for measurement of product appearance or, after the initial rapid drop, of starting material disappearance; in several cases rate constants were determined under both conditions and found to be identical. The pH values reported are the apparent pH as measured with the glass electrode of the Beckman model G pH meter.

(1) Publication #14 of the Graduate Department of Biochemistry, Brandeis University. Presented at the 134th National Meeting of the American Chemical Society in Chicago, September, 1958.

(2) E. Barrett and A. Lapworth, *J. Chem. Soc.*, **93**, 85 (1908); cf. also S. F. Acree and J. M. Johnson, *Am. Chem. J.*, **38**, 308 (1907); D. G. Knorre and N. M. Emanuel, *Doklady Akad. Sci. S.S.S.R.*, **91**, 1163 (1953) (*C. A.*, **49**, 12936 (1955)).

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(6) L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1940, p. 331.

(7) W. P. Jencks, *THIS JOURNAL*, **80**, 4581 (1958), **80**, 4585 (1958).