ORGANIC AND BIOLOGICAL CHEMISTRY

[CONTRIBUTION NO. 2185, FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY, AND FROM THE MCPHERSON CHEMICAL LABORATORY, THE OHIO STATE UNIVERSITY]

Basicity Constants and Rates of Hydration of Some Imines[1]

BY GABRIEL J. BUIST AND HOWARD J. LUCAS[2]

RECEIVED FEBRUARY 21, 1957

The K_b values of a number of imines and their N-ethyl derivatives lie in the range 0.8 to 4.7 $\times 10^{-6}$ with the exception of *trans*-N-ethyl-2,3-iminobutane for which the value of 27 $\times 10^{-6}$ is inexplicably high. The perchloric acid-catalyzed rates of hydration of imines increase in the order: 1,2-iminoethane, 1,2-iminopropane and 1,2-imino-2-methylpropane. The order is consistent with predominantly SN2 mechanism at a primary carbon atom, mixed SN1 and SN2 mechanisms at a secondary carbon atom and predominantly SN1 mechanism at a tertiary carbon atom.

Introduction

Dissociation constants have been measured for 1,2-iminoethane,[3-6] 1,2-iminobutane,[6] 1,2-imino-2-methylpropane[6] and N-methyl-1,2-iminoethane.[7] Schatz and Clapp[8] have determined the rates of reaction and the nature of the products of reaction of 1,2-imino-2-methylpropane with aqueous hydrochloric acid, 1 and 6 *N*. They showed that reaction takes place by two mechanisms. In 1 *N* acid roughly $^1/_4$ to $^1/_3$ of the imine reacts by an SN1 mechanism with the intermediate carbonium ion reacting mainly with water to form 1-amino-2-methyl-2-propanol and less importantly with chloride ion to form 1-amino-2-chloro-2-methylpropane. The rest of the imine reacts by an SN2 mechanism in which there is a bimolecular reaction with chloride ion to form 1-chloro-2-amino-2-methylpropane. In 6 *N* hydrochloric acid the reaction is predominantly (*ca.* 85%) SN2, and the main product is 1-chloro-2-amino-2-methylpropane.

In the present work the effect of both C- and N-alkyl substituents on the basicity and on the perchloric acid-catalyzed rate of hydration of 1,2-iminoethane in aqueous solution was determined.

Calculation of K_a.—The dissociation constant, K_a, of the iminium ion, ImH^+, is calculated with eq. 1, where brackets indicate activities, f, an activity coefficient, M, molarity of added acid, v, volume of added acid, v_t, total volume of acid required to reach the end-point, and v_0 is the initial volume of the imine solution. It is assumed that

$$K_a = \frac{[H^+]f_{Im}\left\{\frac{M(v_t - v)}{v_0 + v} - \frac{[OH^-]}{f_{OH^-}} + \frac{[H^+]}{f_{H^+}}\right\}}{f_{ImH^+}\frac{M_v}{v_0 + v} + [OH^-] - [H^+]} \quad (1)$$

the activity coefficient of the uncharged species is unity and the activity coefficients of the hydroxyl and hydrogen ions are equal and under the conditions prevailing are so small that they also can be taken as unity, eq. 2. When $[H^+]$ and $[OH^-]$

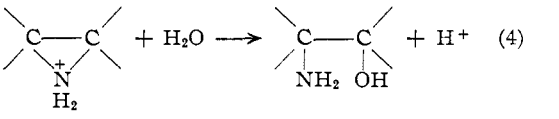
$$f_{H^+} = f_{OH^-} = 1 \quad (2)$$

are negligible, as they are in most cases, eq. 1 is simplified to eq. 3.

$$K_a = [H^+](v_t - v)/(v)f_{ImH^+} \quad (3)$$

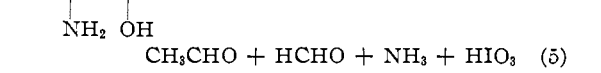
At the beginning of each titration $[OH^-]$ is appreciable. Equation 1 is used until about 30% of the acid has been added, when $[OH^-]$ becomes negligible. Then eq. 3 is used throughout except when close to the equivalence point in the cases of 1,2-iminoethane and N-ethyl-1,2-iminoethane. Here eq. 1 is necessary. When required, $[OH^-]$ is calculated from the values of K_w in I.C.T.[9] The activity coefficient, f_{ImH^+}, is calculated from the ionic strength, μ, by the use of the Debye–Hückel equation, $-\log f_{ImH^+} = 0.50\sqrt{\mu}$. Half-way through the titration μ = *ca.* 0.001 *M* in all cases and $\log f_{ImH^+}$ is −0.016.

Hydration.—Hydration of iminoalkanes leads to the formation of aminoalkanols, eq. 4. The reaction has been followed by determining the re-



(4)

sulting α-amino alcohol by periodate oxidation in slightly alkaline solution, as shown in eq. 5 for 2-amino-1-propanol. An excess of periodate is taken



(5)

and the periodate remaining after the oxidation is determined by titrating the iodine liberated from neutral potassium iodide against standard sodium arsenite. In this reaction periodate is reduced to iodate.[10]

The periodate method for the amino alcohol has the advantage that the experiment can be carried out in quite dilute solution (0.002 *M* or less) of imine, thus minimizing polymerization which is

(1) This research has been made possible by support extended to the California Institute of Technology by the Office of Ordnance Research under Contract No. DA-04-495-Ord-410.

(2) To whom requests for reprints should be sent.

(3) H. C. Brown and M. Gerstein, THIS JOURNAL, **72**, 2926 (1950). These authors determined the dissociation constants of complexes of trimethylboron with a number of cyclic imines, including 1,2-iminoethane.

(4) W. G. Barb, *J. Chem. Soc.*, 2564 (1955).

(5) E. J. Shepherd and J. A. Kitchener, *ibid.*, 2448 (1956).

(6) C. E. O'Rourke, L. B. Clapp and J. O. Edwards, THIS JOURNAL, **78**, 2159 (1956).

(7) S. Searles, M. Tamres, F. Block and L. A. Quarterman, *ibid.*, **78**, 4917 (1956).

(8) V. B. Schatz and L. B. Clapp, *ibid.*, **77**, 5113 (1955).

(9) "International Critical Tables," Vol. VI, McGraw-Hill Book Co., Inc., New York, N. Y., 1929, p. 152.

(10) F. P. Treadwell and W. T. Hall, "Analytical Chemistry," Vol. II, 9th ed., John Wiley and Sons, Inc., New York, N. Y., 1942, p. 602.

liable to occur in concentrated solutions containing acid.[11]

Calculation of the Rate Constant.—A plot of log imine concentration *versus* time t should be linear as required for a first-order (in these cases pseudo first-order) reaction and have a slope of $-k/2.303$. The imine concentration is calculated according to eq. 6, where $[Im_t]$ is the concentration of imine at time, t, As_t and As_∞ are the millimoles of sodium

$$[Im_t] = \frac{As_t - As_\infty}{v} \qquad (6)$$

arsenite required for the titrations at times t and infinity, respectively, and v is the volume of the solution. Plots of log $[Im_t]$ against t were linear in all cases. Values of k were obtained from the slopes of these plots by multiplying by 2.303.

Experimental

Imines.—Some of the imines, *viz.*, 1,2-iminobutane, *cis*- and *trans*-2,3-iminobutane, N-ethyl-1,2-iminobutane and *cis*- and *trans*-N-ethyl-2,3-iminobutane, were available from other researches.[12] The other imines were prepared by the method of Wenker[13] from aminoalcohols. To obtain 1,2-imino-2-methylpropane, it is necessary to use 2-amino-2-methyl-1-propanol.[14] Each imine was dried with metallic sodium and distilled from it just before use. Its purity was calculated from titration with perchloric acid in the pK_b determination.

Titration Method.—Aqueous solutions of the imines were made quite dilute (0.002 M) to minimize polymerization, and measurements were made at room temperature to minimize hydration, which is negligible under these conditions. All solutions were made with carbon dioxide-free distilled water.

To a weighed 25-ml. flask partially filled with water was added from a syringe an approximately known volume of imine. The flask was again weighed and filled to the mark. A 5.00-ml. portion of the solution was diluted to 250.0 ml., and 100.0 ml. of the new solution was introduced into a beaker fitted with glass electrode, calomel reference electrode, stirrer and thermometer. A stream of CO_2-free nitrogen was passed constantly over the solution. The pH was read on a Beckman model G pH meter which had been standardized by placing the electrodes in Beckman pH 4 buffer. The meter was checked by using Beckman pH 7 buffer; the correct pH value was obtained. Portions of 0.02 M perchloric acid were added from a buret and the pH was read after each addition of acid. The titration was continued until the end-point (inflection point) was just passed. This point easily was determined by inspection within ±0.01 ml.

TABLE I

TITRATION OF L(−)-2,3-IMINOBUTANE

Imine, initial: 0.002050 mole/l. by weighing; 0.002045 mole/l. by titration.

Acid added, ml.	pH	pK_a	Acid added, ml.	pH	pK_a
0.00	10.02	(8.73)	6.01	8.43	8.71
1.00	9.55	(8.71) 8.64	7.00	8.20	8.70
2.00	9.23	(8.69) 8.67	8.02	7.88	8.72
3.00	9.01	(8.71) 8.70	9.01	6.98	8.68 ± 0.05
4.00	8.81	(8.70) 8.70	9.10	6.64	
4.28	8.77	8.71	9.14	6.47	
4.50	8.72	8.70	9.17	6.03	
4.76	8.69	8.72	9.21	5.40	
5.01	8.63	8.71	9.25	4.99	
5.50	8.54	8.71	9.30	4.74	

(11) G. D. Jones, *et al.*, *J. Org. Chem.*, **9**, 125 (1944); **9**, 484 (1944).

(12) R. Ghirardelli and H. J. Lucas, THIS JOURNAL, **79**, 734 (1957).

(13) H. Wenker, *ibid.*, **57**, 2328 (1935).

(14) We are indebted to the Commerical Solvents Corporation, Terre Haute, Ind., for this material.

A Typical Titration.—Data are shown in Table I for the titration of L(−)-*trans*-2,3-iminobutane. The equivalence point by inspection is 9.19 ml. The values in brackets are obtained with eq. 1, all others with eq. 3. The mean of all points from 1.00 to 8.02 ml., excluding 8.64 and 8.67, is 8.71, uncorrected for the activity coefficient of the iminium ion. The corrected value of pK_a of L(−)-*trans*-2,3-iminobutane is 8.69.

Hydration Method.—An approximately known volume of imine was added from a syringe to a weighed, 25-ml. volumetric flask partially filled with water. In the case of 1,2-iminoethane and 1,2-iminopropane 1.0 ml. of 0.10 M sodium hydroxide was included to prevent polymerization of the imine. The flask was reweighed and filled to the mark with water. A 5.00-ml. portion of this solution was taken and diluted to 250.0 ml. with water, including the required amount of perchloric acid solution. Aliquots, 10.0 ml. each, were sealed in test-tubes. The tubes were suspended in a thermostat at 64.9° and left for various lengths of time before removal and analysis. About five tubes were left in the thermostat for ten half-lives to serve as infinity samples.

Analysis for Amino Alcohol.—Since different amino alcohols are oxidized at different rates and the rates of oxidation of an amino alcohol depend upon the pH, it is important to standardize the procedure and to determine the time necessary for completion of the oxidation. All oxidations were carried out in neutral solution and at room temperature with one exception, that of the amino alcohol from 1,2-imino-2-methylpropane. This was oxidized at 35°.

For each analysis, 5.00 ml. of 0.0045 M periodic acid was pipetted into a stout glass bottle. A tube was quenched in acetone–Dry Ice, cleaned, put into the bottle and crushed. The solution was brought to slight alkalinity to phenolphthalein with 0.5 M sodium carbonate. When oxidation was complete, sufficient 0.5 M hydrochloric acid was added to discharge the color and this was followed by 2 ml. of 2 M potassium iodide. The liberated iodine was titrated after 2 minutes against 0.002 M sodium arsenite with starch as the indicator. The infinity samples were handled in exactly the same way.

Under the controlled conditions the analyses were satisfactory, although it has been reported that ethanolamine consumes more than 1 mole of periodate.[15] The number of moles of periodate consumed per mole of 1-amino-2-propanol reached a steady value of 1.010. Also, excellent agreement was obtained in independent runs between the initial concentration of imines by weight and the concentration of aminoalcohol at infinity, as determined by oxidation. In the case of *trans*-2,3-iminobutane the respective values were 2.001 and 2.005 × 10^{-3} M, and in the case of 1,2-imino-2-methylpropane they were 3.98 and 3.97 × 10^{-3} M.

Infrared spectra were measured for 1,2-iminopropane, 1,2-iminobutane, 1,2-imino-2-methylpropane, *cis*-2,3-iminobutane, L(−)-*trans*-2,3-iminobutane, N-ethyl-2,3-iminobutane, *cis*-N-ethyl-2,3-iminobutane and L(+)-*trans*-N-ethyl-2,3-iminobutane. There are two differences between the N-H and N-Et compounds. The former show the N-H stretching band of secondary amines[16] at 3220–3300 cm.$^{-1}$ (3.05–3.25 mμ), and the latter show a band at 1175–1185 cm.$^{-1}$ (8.45–8.5 mμ).

Discussion

Basicity Constants.—In Table II are listed the values of pK_a of the iminium ion and pK_b and K_b × 10^{-6} of the imine, as determined on a number of imines. These are weaker bases than ammonia and aliphatic amines, a relationship first noted by Brown and co-workers[3] and substantiated by others.[4-7] The pK_a of ethylenimine is 7.98, whereas for ammonia[17] it is 9.5 and for dimethyl-

(15) P. Fleury, J. Courtols and M. Grandchamp, *Bull. soc. chim.*, 88 (1949).

(16) L. J. Bellamy, "The Infrared Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1954, p. 213.

(17) H. C. Brown, D. H. McDaniel and O. Haflinger, in "Determination of Organic Structures by Physical Methods," ed. by A. E. Braude and F. C. Nachod, Academic Press, Inc., New York, N. Y., 1955, p. 573.

TABLE II

BASICITY CONSTANTS OF SOME IMINES

Name	B.p., °C.	Mm.	Purity, %	Iminium ion, pK_a	Imine pK_b	Imine $K_b \times 10^6$	Temp., °C.
1,2-Iminoethane	54.9–55.0	744	100.0	7.98[a]	6.11[b]	0.78[c]	22
1,2-Iminobutane	87.7–88.1	739	98.9	8.29	5.70[d]	1.99[e]	25
cis-2,3-Iminobutane	81.1–81.5	739	97.6	8.72	5.34	4.6	23
trans-2,3-Iminobutane	73.8–73.9	739	99.8	8.69	5.33	4.7	24
1,2-Imino-2-methylpropane	70.2–70.4	741	99.8	8.61	5.38[f]	4.2[g]	23
N-Ethyl derivative of							
1,2-Iminoethane	50.2–50.7	739	99.3	7.93	6.09	0.81	24
1,2-Iminobutane	90.2–90.5	743	98.3	8.18	5.81	1.55	24–25
cis-2,3-Iminobutane	80.7	744	99.3	8.56	5.43	3.7	24–25
trans-2,3-Iminobutane	90.0–90.1	745	99.0	9.47	4.59	26.7	23

[a] Lit.[5,7] 7.88, 8.04. [b] Lit.[4,6] 6.045–6.155, 5.99. [c] Lit.[4,6,7] 0.7–0.9, 1.0, 1.1 × 10^{-6}. [d] Lit.[6] 5.69. [e] Lit.[6] 2.0 × 10^{-6}. [f] Lit.[6] 5.36. [g] Lit.[6] 4.3 × 10^{-6}.

amine,[18] 10.7. This may be explained by the concept of "I-strain" put forward by Brown.[19] Protonation of tercovalent nitrogen tends to make the bond angles of the nitrogen atom tetrahedral, causing more strain in the imine with its bond angles of approximately 60° than in a secondary amine with its bond angles of approximately 90°. Thus an imine is a weaker base than ammonia or the corresponding secondary amine. An alternative explanation[7,20] is that the ethylenimine ring has partial aromatic character (this is supported by other work)[21] and that the unshared electrons on the nitrogen are made less readily available for covalent bond formation with a proton.

Alkyl substituents on carbon increase the basicity of ethyleneimine, in accordance with the inductive effect of these substituents, but substitution on the nitrogen atom decreases the basicity (with the exception of *trans*-2,3-iminobutane). But the decrease is not so great as that found in going from a secondary to a tertiary amine, *e.g.*, compare diethylamine,[18] pK_a 11.1, and triethylamine,[18] pK_a 10.75, with *cis*-2,3-iminobutane, pK_a 8.72, and N-ethyl-*cis*-2,3-iminobutane, pK_a 8.56. According to Brown's concept of "B-strain"[19] the decrease is a result of crowding caused by the additional group. Since in the imines two of the groups are tied back, the effect is not expected to be so great as with the amines. However, this explanation has been shown to be inconsistent with the relative basicities of primary, secondary and tertiary amines in aprotic solvents, and another explanation has been put forward, namely, that the introduction of a third alkyl group on nitrogen reduces the solvation of the iminium ion in aqueous solution and hence its stability.[22] This could apply equally well to the imines; it has been pointed out that the smaller decrease observed with imines could be due to greater ease of solvation of the iminium ion when two of the groups are tied back.[7]

(18) N. A. Lange, "Handbook of Chemistry," 8th ed., Handbook Publishers, Inc., Sandusky, Ohio, 1956, p. 1203.

(19) H. C. Brown, H. Bartholomay, Jr., and M. D. Taylor, THIS JOURNAL, **66**, 435 (1944).

(20) N. H. Cromwell, N. G. Barker, R. A. Wankel, P. J. Vanderhorst, F. W. Olson and J. H. Anglin, Jr., *ibid.*, **73**, 1044 (1951); N. H. Cromwell and M. A. Graff, *J. Org. Chem.*, **17**, 414 (1952).

(21) H. S. Gutowsky, R. L. Rutledge, M. Tamres and S. Searles, THIS JOURNAL, **76**, 4242 (1954).

(22) R. P. Bell and A. F. Trotman-Dickenson, *J. Chem. Soc.*, 1288 (1949); A. F. Trotman-Dickenson, *ibid.*, 1293 (1949); R. P. Bell and J. W. Bayles, *ibid.*, 1518 (1952).

The relatively high basicity of N-ethyl-*trans*-2,3-iminobutane is anomalous. A second titration gave duplicate results. The values of pK_a calculated in the 0–30% titration range did not differ by more than 0.03 pH unit from 9.49, and those in the 81–97% range dropped from 9.45 to 9.37 ± 0.03 pH units. The reasonably constant values seem to indicate that contamination by a much stronger base is not an important factor.

Rates of Hydration.—Values of the rate constants are shown in Table III. The results should

TABLE III

RATE CONSTANTS OF THE HYDRATION OF IMINES AT 64.9°

Name	Initial concn., $M \times 10^3$ By wt.	By anal., ∞	Perchloric acid, M	$k_1 \times 10^3$ min.$^{-1}$
1,2-Iminoethane	1.993	1.984	0.0408	6.3 ± 0.4
1,2-Iminopropane	2.020	2.027	.0408	7.0 ± .2
1,2-Iminobutane	2.102	2.086	.00926	4.27 ± .15
		1.91	.00926	4.23 ± .08
		2.05	.0948	4.10 ± .08
cis-2,3-Iminobutane		1.98	.0382	6.9 ± .2
trans-2,3-Iminobutane		2.16	.0382	4.9 ± .2
1,2-Imino-2-methylpropane		3.52	.0408	37 ± 4

be regarded as provisional only since in most cases only one run was made and in one case the accuracy was poor. The best results were obtained with 1,2-iminobutane. For this compound there was no significant change in rate over a tenfold change in acid concentration. This suggests that the imine is completely protonated under both conditions. This is in accord with the pK_a value of 8.29 at 25°. Since the pK_a values of the other imines fall in the range, 7.9–8.8, they likewise would be completely protonated.

There is an increased rate of reaction in the order, 1,2-iminoethane < 1,2-iminopropane < 1,2-imino-2-methylpropane. This is the order that would be expected if the reactions were truly first order and proceeded *via* an open carbonium ion.[23] It is known[8] that 1,2-imino-2-methylpropane reacts in 1 *N* hydrochloric acid by both SN1 and SN2 mechanisms, the latter involving chloride ion. Since

(23) S. Winstein and R. B. Henderson in "Heterocyclic Compounds," Vol. I, edited by R. C. Elderfield, John Wiley and Sons, Inc., New York, N. Y., 1950, p. 37. They point out that the rate sequence in the opening of oxide rings by such a mechanism would be tertiary > secondary > primary.

perchlorate ion is not nucleophilic, this imine probably reacts almost entirely by SN1 in dilute perchloric acid. 1,2-Iminoethane probably reacts only by SN2. The other imines would react by a combination of SN1 and SN2. The relative rates of these acid-catalyzed hydrations of imines can be accounted for on the basis of a transition from SN1 to SN2 mechanism as in the case of epoxides[24] and the assumption that reaction is predominantly SN2 at a primary carbon atom, a mixture of SN1 and SN2 at a secondary carbon atom and predominantly SN1 at a tertiary carbon atom.

The SN2 rate at a primary carbon atom could well be approximately equal to the combined SN1 and SN2 rates at a secondary carbon atom and definitely slower than the SN1 rate at a tertiary carbon atom. Thus 1,2-imino-2-methylpropane would be the fastest reacting and the others would vary, depending on the different contributions of SN1 and SN2 reactions at secondary carbon atoms.

Although the steric results of the opening of the rings of L(+)-N-ethyl-2,3-iminobutane by ammonia and ethylamine and of L(−)-2,3-iminobutane by ethylamine are in all cases inversions of configurations,[12] an SN1 mechanism even under basic conditions is not ruled out because in the transition state the carbonium carbon atom is shielded by the departing nitrogen atom from attack by a nucleophilic amine molecule on the same side of the carbon atom. Thus inversion of configuration is not incompatible with SN1 mechanism, but on the other hand retention of configuration cannot occur in an SN2 reaction. Actually L(+)-*trans*-N-ethyl-2,3-iminobutane with aqueous ethylamine[12] gave 99.5% *meso*-2,3-bis-(ethylamino)-butane and 0.5% L(+)-2,3-bis-(ethylamino)-butane. The active product must result from an SN1 reaction, and a frontal attack on a carbonium ion would seem to be the only way in which it could be formed. Here the conditions are quite unfavorable for frontal attack on the carbonium ion, owing to the presence of the two ethyl groups, one on the imine nitrogen, the other on the attacking amine nitrogen atom. The fact that some frontal attack took place points to a significant contribution of SN1 in the weakly basic medium. This would be enhanced under the much more favorable conditions of acid-catalyzed hydration, as in the case of epoxides.[25] Therefore it is reasonable to expect that in acid solution there would be a mixture of SN1 and SN2 reactions at the two secondary carbon atoms of this imine.

(24) C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, p. 344.

(25) Reference 23, p. 38.

PASADENA, CALIFORNIA

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

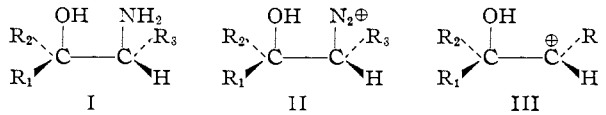
Molecular Rearrangements. XI. The Deamination of 1,1-Diphenyl-2-amino-1-propanol[1]

BY BEN M. BENJAMIN, HOWARD J. SCHAEFFER AND CLAIR J. COLLINS

RECEIVED MAY 11, 1957

It has been shown that the addition of phenylmagnesium bromide and of *p*-tolylmagnesium bromide to α-aminopropiophenone are 98–99% sterospecific. The rearrangement, in the presence of nitrous acid, of (+)- or (−)-1,1-diphenyl-2-aminopropanol (IV) stereospecifically labeled in only one of the two phenyls, has been shown to produce α-phenylpropiophenone (VII) which has undergone approximately 88% inversion (with 12% retention) at the migration terminus. These results are in agreement with those of McKenzie, Roger and Wills.[4a] The product from the deamination of (+)-IV was resolved into a (−)-fraction [$[\alpha]^{24}D$ −210°] and a very nearly racemic [$[\alpha]^{24}D$ −1.6°] fraction. Degradation of these two fractions followed by radioactivity assay of the degradation products disclosed that migration of the labeled phenyl resulted in inversion to produce (−)-VII, whereas migration of the unlabeled phenyl resulted in retention to produce (+)-VII. The deamination of labeled 2-amino-1,1,2-triphenylethanol also has been studied. The results of the present research are explained in terms of open carbonium ion intermediates whose rotation about the C-C$^+$ bond is restricted and whose phenyl groups migrate solely through *trans*-transition states.

In the rearrangement with nitrous acid of amino alcohols of general structure I, it often has been assumed: (1) that the ion II is first formed, followed



I II III

by a one-stage migration of R_1 or R_2; (2) that the rate of rotation about the bond connecting the two central carbon atoms is very fast compared to rearrangement; and (3) that the steric factor, called the "*cis*-effect" by Curtin,[2] "is a function only of the difference in free energy between the two transition states for the rearrangement step and is independent of the relative populations of the conformations of the initial molecule."[3] An alternate possibility involves the formation, from II, of ion III. The relative proportions, then, of products formed will depend upon the populations of the conformations of ion III which will allow migration of R_1 or R_2; this, in turn, will depend upon the rate

(1) (a) This paper is based upon work performed at Oak Ridge National Laboratory, which is operated by Union Carbide Nuclear Co. for the Atomic Energy Commission. Paper X, W. A. Bonner and C. J. Collins, THIS JOURNAL, **78**, 5587 (1956); (b) portions of this research were presented at the International Conference on Radioisotopes in Scientific Research, Paris, France, Sept. 13, 1957.

(2) P. I. Pollak and D. Y. Curtin, THIS JOURNAL, **72**, 961 (1950); D. Y. Curtin and P. I. Pollak, *ibid.*, **73**, 992 (1951); D. Y. Curtin, E. E. Harris and P. I. Pollak, *ibid.*, **73**, 3453 (1951).

(3) (a) Quoted from D. Y. Curtin and M. C. Crew, *ibid.*, **77**, 355 (1955); (b) W. G. Dauben and K. S. Pitzer, Chapter 1, "Steric Effects in Organic Chemistry," edited by M. S. Newman, John Wiley and Sons, Inc., New York, N. Y., 1956, pp. 11, 44.