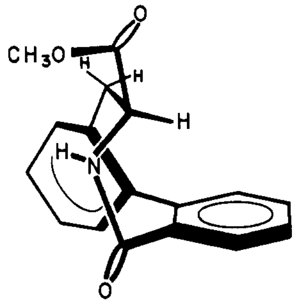

S−S$_{eq}$ isomer

VIII

substrate as present in an equilibrated dioxane solution were: $K_m = 1.6 \times 10^{-3}$ and $V_{max} = 72$ μmol of CT/(min mg).[16] Atropisomerism and conformational asymmetry of a precisely definable nature in a substrate molecule are therefore recognized by CT. It is worthwhile emphasizing the fact that different conformations of VI are stabilized in the crystalline state (VII) and in solution (VIII), respectively. A careful comparison of molecular models leads to the conclusion that Hein and Niemann's substrate D-1-keto-3-carbomethoxy-1,2,3,4-tetrahydroisoquinoline and conformer VIII are related as a key is to its lock only when the ester function of the former is axially orientated in the CT-bound state, thus confirming earlier hypotheses,[2-5] while casting doubt on other interpretations,[1,6] including speculations on the absolute conformation of enzyme-bound $BzPheOCH_3$.[1] Other recent observations[19] with flexible substrates appear consistent with the conformational pattern set by the S,S_{eq} substrate VIII.

Table I. Relative Velocities of the Conformational Change VII → VIII[a] and Activation Energies[b]

Solvent	$t_{1/2}$ min,[c] VII → VIII	Equilibrium composition,[d] VII:VIII	$\Delta H^{\ddagger}$, kcal[e]
Dioxane	62	46:54	19 ± 0.5
Chloroform[f]	44[f]	<1:>99[f]	
Water–dioxane	488	64:36	29 ± 0.5

[a] In three solvents at 25° as measured by ORD at 252 mμ. [b] In two solvents. [c] Time required for 50% decrease in amplitude at 252 mμ relative to the equilibrium amplitude. [d] Obtained at $t_{1/2} \times 10$; after this time no detectable change at 252 mμ occurred. [e] From perfectly linear Arrhenius plots covering the temperature range 15–35° in the ORD cell. [f] Af 30.2° instead of 25°.

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(16) For D-1-keto-3-carbomethoxy-1,2,3,4-tetrahydroisoquinoline[17] and L-$BzPheOCH_3$[18] the respective values are: $K_m = 5.3 \times 10^{-4}$ *M*, $V_{max} = 54.5$ μmol of CT/(min mg) and $K_m = 4.6 \times 10^{-3}$ *M*, $V_{max} = 90$ μmol of CT/(min mg).

(17) G. Hein, R. B. McGriff, and C. Nieman, *J. Am. Chem. Soc.*, **82**, 1830 (1960).

(18) J. E. Snoke and H. Neurath, *Arch. Biochem.*, **21**, 351 (1949).

(19) S. G. Cohen and A. Milovanović, *ibid.*, **90**, 3495 (1968).

(20) Holder of a National Research Council of Canada predoctoral scholarship, 1966–1968.

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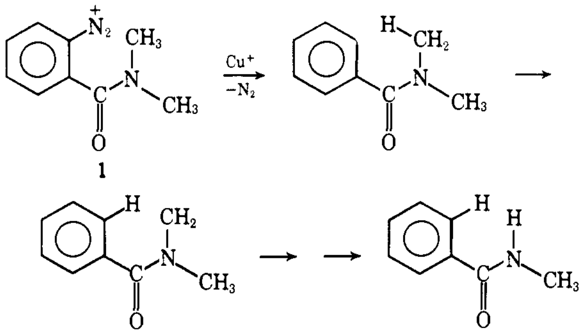
The Competition between Bond Rotations and Intramolecular Hydrogen Atom Transfer as Studied by the Use of Isotope Effects[1]

Sir:

The diazonium ion **1** derived from *o*-amino-N,N-dimethylbenzamide has the distinction of decomposing thermally to produce an aryl cation which undergoes a 1,5-*hydride ion* transfer while under the same conditions, but in the presence of copper compounds, the decomposition produces an aryl radical which undergoes a 1,5-*hydrogen atom* transfer.[2] The latter process which ultimately produces N-methylbenzamide is outlined in eq 1. We now wish to report a comparison of isotope effects for these two types of hydrogen transfer and to illustrate a novel use of isotope effect data in the study of a rapid chemical reaction in competition with a conformational change.



(1)

Since these hydrogen transfers are rapid reactions occurring subsequent to the rate-determining steps, isotope effects must be determined by a competition method. When the diazonium ion **1**, labeled with three deuterium atoms in one of the methyl groups, is decomposed in water in the presence of cuprous oxide, the transfer of deuterium occurs to almost the same extent as that of hydrogen; the product isotope ratio, defined as the ratio of ring-undeuterated to ring-deuterated N-methylbenzamide, is 1.1. This would indeed be a unique case of a carbon–hydrogen bond cleavage if the virtual absence of isotopic discrimination were due to the lack of an isotope effect.[3] A far more likely explanation is that the rate of hydrogen atom transfer is much greater than that of rotation about the carbonyl C–N bond. It is this rotation which would equilibrate the two species (**2a** and **2b**) which are capable of undergoing the transfer. Since the two are not in equilibrium, the former would transfer only a hydrogen atom and the latter only a deuterium atom.[4] This bond rotation is known to be unusually slow in N,N-dimethylbenzamide itself, presumably due to the double bond character of this bond.[5]

This concept was tested by performing the radical decomposition of (1) the diazonium ion in which the

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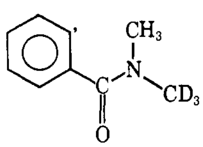
(1) This investigation was supported by Grant GP 7262 from the National Science Foundation.

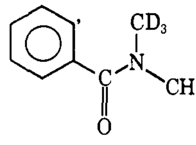
(2) A. H. Lewin, A. H. Dinwoodie, and T. Cohen, *Tetrahedron*, **22**, 1527 (1966).

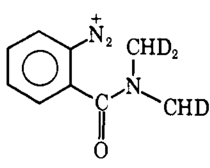
(3) K. Wiberg, *Chem. Rev.*, **55**, 713 (1955); L. Melander, "Isotope Effects on Reaction Rates," The Ronald Press, New York, N. Y., 1960, Chapters 4 and 6; K. Wiberg and E. L. Motell, *Tetrahedron*, **19**, 2009 (1963); A. F. Trotman-Dickenson, *Advan. Free Radical Chem.*, **1**, (1965).

(4) The slight excess of hydrogen transferred can easily be accounted for by a slight degree of incomplete deuteration combined with an isotope effect. See below.

(5) M. T. Rogers and J. C. Woodbrey, *J. Phys. Chem.*, **66**, 540 (1962); L. W. Reeves, *Advan. Phys. Org. Chem.*, **3**, 252 (1965); R. C. Neuman, Jr., D. N. Roark, and V. Jonas, *J. Am. Chem. Soc.*, **89**, 3412 (1967).


2a


2b


3

methyl groups were randomly labeled with deuterium to the extent of about 50% and (2) the ion **3** which was specifically labeled to the extent of about 93% with two deuterium atoms in each methyl group. In the former case the product isotope ratio was 5.1 and in the latter case it was 4.1. When the latter value is corrected for the degree of deuteration, the calculated isotope effect is 7.6.[6] It is thus clear that the lack of isotopic discrimination in the compound bearing one deuterated and one undeuterated methyl group is due to a hydrogen transfer which is very rapid compared to rotation about the carbonyl C–N bond. In view of the product isotope ratio of 4.1 in the case of **3**, it is also clear that the rate of this transfer is much less than that of rotation about the methyl C–N bond; if the relative rates were reversed, the maximum product isotope ratio would be 2.0.[7]

Unfortunately, the rate of hydrogen transfer is not well defined by these limits alone since the two rates of bond rotation in this case might differ by a factor of 10^{12} or greater. However, this work suggests a novel technique for studying such rapid reactions, and we are in the process of applying this general principle to other systems. In a subsequent paper we will show by the use of somewhat similar experiments that the transfer is probably also more rapid than rotation about the C–C bond between the ring and the carbonyl group.

The assertion[2] that the thermal decomposition involves an entirely different type of hydrogen transfer (a hydride transfer is strongly indicated[2,8]) from the catalyzed decomposition is strongly supported by the finding that the product isotope ratio in the thermal reaction under the same conditions is 1.4 for both the randomly labeled sample and the dideuteriomethyl compound **3**. The cause of these isotope ratios in the cationic process is now under investigation.

Acknowledgment. We thank the National Institutes of Health for providing the LKB 9000 combined gas chromatograph-mass spectrometer which was used for the deuterium analysis of the products. We also thank Mr. John Naworal for recording the mass spectra.

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(6) The value of 5.1 obtained for the randomly labeled sample must be corrected for the fact that finite percentages of the methyl groups will be completely deuterated and completely undeuterated. The calculated isotope effect is thus extremely sensitive to the exact extent of deuteration and of randomness of the label. Since the degree of deuteration was determined by nmr integration, it is not sufficiently accurate to yield a meaningful isotope effect.

(7) This value could be attained if, in the decomposition product of **3**, the aryl carbon atom bearing the odd electron were equidistant from two of the three methyl hydrogen atoms just prior to transfer. One-third of the time only deuterium atoms would flank this carbon atom and a deuterium atom would always be transferred. Two-thirds of the time there would be a choice of hydrogen or deuterium transfer and, assuming an infinite isotope effect, only hydrogen would be transferred.

(8) T. Cohen, R. M. Moran, and G. Sowinski, *J. Org. Chem.*, **26**, 1 (1961); T. Cohen, A. H. Dinwoodie, and L. D. McKeever, *ibid.*, **27**, 3385 (1962); T. Cohen and J. Lipowitz, *J. Am. Chem. Soc.*, **86**, 2514 (1964); T. Cohen and J. Lipowitz, *Tetrahedron Letters*, 3721 (1964).

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The Occurrence of Mixed Tetrahaloaluminate Ions Shown by Aluminum-27 Nuclear Magnetic Resonance Spectroscopy

Sir:

The existence of the tetrahaloaluminate ions $AlCl_4^-$ and $AlBr_4^-$ has been known for many years, and the tetrahedral structure of $AlCl_4^-$ in the solid state has been verified by X-ray crystallography.[1] The occurrence of these ions as intermediates essential to the functioning of Al_2Cl_6 and Al_2Br_6 in certain Friedel–Crafts catalyst systems has generated considerable activity in this area of aluminum chemistry.[2] While the existence of AlI_4^- has been reported by several workers,[3,4] it has never been characterized. In spite of the current interest in redistribution and exchange reactions generally,[5] no mixed tetrahaloaluminate ion of the type $AlX_nY_{4-n}^-$, where X and Y are different halogens, has yet been reported. By dissolving Al_2I_6 and $(n\text{-}C_3H_4)_4N^+I$ in anhydrous CH_2Cl_2 functioning both as solvent and as chloride ion source, we have prepared a solution[6] containing all five theoretically possible $AlCl_nI_{4-n}^-$ ions ($0 \leq n \leq 4$). These have been identified by the characteristic ^{27}Al nmr line generated by each ion. The spectrum for this solution, taken at 15.1 MHz and 27°, is shown in Figure 1a and spectral parameters are listed in Table I.

Table I. ^{27}Al Chemical Shifts[a] and Line Widths for Tetrahaloaluminate Ions

Anion	Shift, ppm	Line width, Hz
AlI_4^-	$+27.0 \pm 0.2$	23.9 ± 2.2
AlI_3Cl^-	-21.7 ± 0.4	46.0 ± 0.8
$AlI_2Cl_2^-$	-59.4 ± 0.3	57.6 ± 4.6
$AlICl_3^-$	-86.2 ± 0.3	42.0
$AlCl_4^-$	-102.4 ± 0.5	15.1 ± 0.5
AlI_2ClBr^-	-47.7	
$AlBr_2ICl^-$	-69.3	
$AlCl_2BrI^-$	*Ca.* -79	

[a] Chemical shifts relative to external aqueous acidic $Al(H_2O)_6^{3+}$; positive shifts indicate signals on the high-field side of the reference.

The lines at −102 and +27 ppm have been assigned to $AlCl_4^-$ from AlI_4^-, respectively, on the basis of ^{27}Al spectra obtained from separate solutions containing only the single AlX_4^- ion. The other three signals have been assigned by interpolation on the assumption that successive substitution of I^- for Cl^- in AlI_4^- causes a monotonic upfield shift in the resonance line of the resulting $AlCl_nI_{4-n}^-$ ion. These assignments are supported by the line widths given in Table I. The AlI_4^- and $AlCl_4^-$ ions with T_d symmetry give rise to the narrowest lines. The AlI_3Cl^- and $AlICl_3^-$ ions with

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(1) N. C. Baenziger, *Acta Cryst.*, **4**, 216 (1951).

(2) M. Baaz and V. Gutmann, "Friedel-Crafts and Related Reactions," Vol. 1, G. Olah, Ed., Interscience Publishers, New York, N. Y., 1963, pp 367–397.

(3) I. Zlotowski, A. Polaczek, and H. Wincel, *Nukleonika*, **6**, 415 (1961); *Chem. Abstr.*, **61**, 2689*g* (1964).

(4) I. Zlotowski and A. Polaczek, *Nucleonika*, **6**, 229 (1961); *Chem. Abstr.*, **59**, 6022*h* (1963).

(5) J. C. Lockhart, *Chem. Rev.*, **65**, 131 (1965).

(6) In this solution, as well as in those discussed below, the aluminum concentration was in the range 0.5–1.0 *M*. The molar ratio of tetraalkylammonium halide to aluminum trihalide ([MX]/[AlX₃]) lay in the range 1.1–1.9. Values for this ratio of less than unity give rise to solutions whose ^{27}Al nmr spectra consist of a single, time-averaged line, the position and line width of which indicate rapid exchange of halide ions at the aluminum atom.