7% volume TFA and show opposite shifts to limits of about ±25 Hz only after the transition has started.

The superiority of the information contained in the chemical-shift behavior in ^{13}C nmr with respect to ^{1}H nmr for these systems is clearly indicated by these results. In the proton spectra only the α-CH and, when observable, the NH signals show significant shifts limited to the transition region. In the carbon spectra the chemical shifts seem to map in a very detailed way both the conformation and the solvation state of the polymer.

It is hopeful that the utilization of this information, qualitatively and quantitatively improved by experiments at higher resolution, coupled with the careful study of solvation effects in model systems may bring about a detailed understanding of the peptide–solvent interaction.

G. Boccalon, A. S. Verdini
SNAM Progetti SpA, Laboratori Ricerche di Base
Monterotondo, Rome, Italy
G. Giacometti*
Istituto di Chimica Fisica, Universita' di Padova
Padua, Italy
Received March 7, 1972

Isotopic Exchange of Molecular Hydrogen in Dimethyl Sulfoxide–Water Mixtures under Base Catalysis[1]

Sir:

The interaction between molecular hydrogen (or deuterium) and hydroxide ion in aqueous solution, leading to ortho–para conversion or isotopic exchange,[2] is conceptually one of the simplest of reactions, involving molecular species of only moderate complexity. It is of considerable interest theoretically as a possible model for proton-transfer processes. Also, the reaction could have utility in the production of D_2O,[3] although the rate of isotopic exchange in aqueous base is far too slow. Theory[4] predicts, however, that molecular hydrogen does *not* react with OH^- by rate-determining proton transfer, with formation of hydride ion, as might have been expected.[2] Instead, it is proposed[4] that formation of an addition complex $[HODD]^-$ is the rate-determining step in the overall exchange process.

We wish to report results on the isotopic exchange process which are pertinent to the theoretical and practical aspects referred to above. Our approach involves the use of dipolar media[5,6] and correlations with acidity functions applicable to reaction rates in strongly basic solutions.[7,8]

Isotopic exchange experiments were performed with Me_4NOH as base in a closed vessel containing the vigorously stirred DMSO–water solution saturated with D_2 at a partial pressure of 1 atm. The solubility of D_2 was estimated from measurements made with H_2 in these media; the H_2 solubility data have been reported.[9] Aliquots of gas were withdrawn periodically and analyzed mass spectrometrically for D_2, HD, and H_2. First-order rate constants were obtained from plots of log (mole per cent D_2) *vs.* time. The resulting vapor-phase data were converted to in-solution rate constants through multiplying by the factor (total moles of D_2 in the system)/(moles of D_2 dissolved in the liquid phase). Present results refer to 65°; data obtained at other temperatures, leading to activation parameters as a function of medium composition, will be reported subsequently.

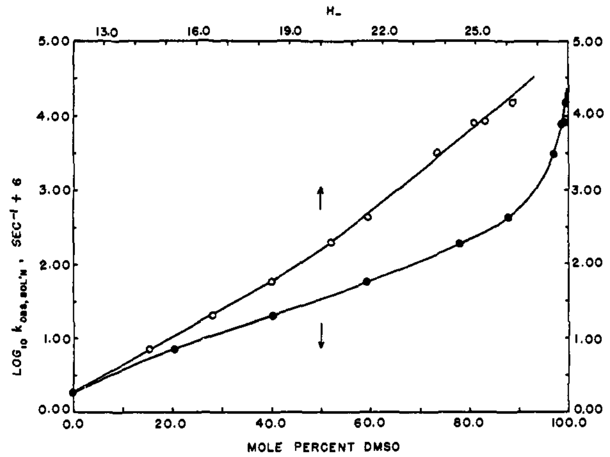


Figure 1. Dependence of the logarithm of the first-order, in-solution rate constants for D_2 exchange on medium composition (solid circles) and H_- (open circles) at 65°. The rate data have been extrapolated to a common base concentration, 0.011 M Me_4NOH. The value for pure water was calculated from the data of ref 2.

Our results on the rate of isotopic exchange as a function of medium composition are shown in Figure 1. It is seen that the rate of exchange increases by a factor of 10,000 as the medium composition is changed from purely aqueous to 99.5% DMSO. This increase in rate, although not particularly large for such a change in medium, is in accord with the generally observed enhanced reactivity of hydroxide ion in DMSO–water mixtures and is ascribed largely to progressive desolvation of hydroxide ion as the hydroxylic component is replaced by the poorly hydrogen-bonding DMSO.[5,6]

The plot of log (exchange rate) *vs.* H_-, the acidity function for the DMSO–water system, is somewhat curved, with an initial slope of 0.23 in the aqueous region increasing to 0.36 at the DMSO rich end. These slope values appear to be the smallest yet reported for an overall proton-transfer process. The slopes of log (rate)-H_- plots have recently been interpreted as signifying the degree of transfer of a proton from substrate to base.[10,11] Taking hydrogen isotope exchange in the CH_3SOCH_3-OH^--H_2O system, for example,[10] the observed slope of 0.93 was interpreted as indicating that the proton from CH_3SOCH_3 is practically completely transferred to hydroxide ion in the transition state. Thus the observed slope of 0.23–0.35 in the D_2-OH^- reaction is indicative of a very small degree of proton transfer from substrate to base in the rate-limiting tran-

---

(1) Hydrogen Exchange Studies. VII. For part VI, see E. Buncel, K. E. Russell, and J. Wood, *Chem. Commun.*, 252 (1968).

(2) J. M. Flournoy and W. K. Wilmarth, *J. Amer. Chem. Soc.*, **83**, 2257 (1961).

(3) H. K. Rae, Chemical Exchange Processes for Heavy Water, Atomic Energy of Canada Ltd. Report AECL-2555, 1966.

(4) C. D. Ritchie and H. F. King, *J. Amer. Chem. Soc.*, **90**, 833 (1968).

(5) A. J. Parker, *Quart Rev., Chem. Soc.*, **16**, 163 (1962); *Chem. Rev.*, **69**, 1 (1969).

(6) C. D. Ritchie in "Solute-Solvent Interactions," J. F. Coetzee and C. D. Ritchie, Ed., Marcel Dekker, New York, N. Y., 1969.

(7) W. D. Kollmeyer and D. J. Cram, *J. Amer. Chem. Soc.*, **90**, 1784 (1968).

(8) R. Rochester, *Quart. Rev., Chem. Soc.*, **20**, 511 (1966); "Acidity Functions," Academic Press, New York, N. Y., 1970.

(9) E. A. Symons, *Can. J. Chem.*, **49**, 3940 (1971).

(10) J. R. Jones and R. Stewart, *J. Chem. Soc. B*, 1173 (1967).

(11) A. Albagli, R. Stewart, and J. R. Jones, *ibid.*, 1509 (1970).

sition state. This is in accord with formation of an intermediate through addition of hydroxide ion to D_2 (eq 1)[12] and that this intermediate subsequently reacts

$$HO^- + D\text{-}D \xrightarrow{\text{slow}} [H\text{-}O\text{-}D\text{-}D]^- \qquad (1)$$

with water leading to isotopic exchange (eq 2).

$$[H\text{-}O\text{-}D\text{-}D]^- + HOH \xrightarrow{\text{fast}} HOD + H\text{-}D + HO^- \qquad (2)$$

The observed increasing slope of the log k-H_- plot with changing medium could be caused by varying solvation effects between reactants, transition state(s), and intermediate(s). It is also possible that the change of slope signifies a gradually changing mechanism, as would be the case if hydroxyl ion became gradually displaced by the dimsyl anion as the reactive basic species.[14,15] However, it is probable that the dimsyl anion could become important only when the DMSO content is very high.

Further information concerning the mechanism of the D_2-OH^- interaction will be obtained from studies now under way of kinetic isotope effects in the DMSO-water system. Also, measurements in other dipolar aprotic media such as hexamethylphosphoric triamide, which, in contrast to DMSO, does not contain exchangeable protons,[16] will aid in determining the role of the aprotic component in the D_2 exchange reaction.

[12] It has been proposed[13] that, for a process involving rate-determining addition of base to substrate, a more appropriate correlation is between log k and J_- where $J_- = H_- + \log a_{H_2O}$. In the present case this plot is also curved with an initial slope of 0.25 increasing to 0.53. Both types of plot have the underlying weakness that the indicators used to set up the acidity functions are generally quite different structurally from the reactants in the kinetic studies.

[13] K. Bowden and R. S. Cook, *J. Chem. Soc. B*, 1765 (1971).

[14] J. I. Brauman and N. J. Nelson, *J. Amer. Chem. Soc.*, **88**, 2332 (1966).

[15] E. Buncel, E. A. Symons, and A. W. Zabel, *Chem. Commun.*, 173 (1965).

[16] J. E. Hofmann, A. Schriesheim, and D. D. Rosenfeld, *J. Amer. Chem. Soc.*, **87**, 2523 (1965).

E. A. Symons
Whiteshell Nuclear Research Establishment
Atomic Energy of Canada Limited, Pinawa, Manitoba

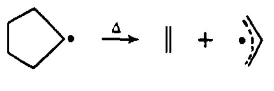
E. Buncel*
Department of Chemistry, Queen's University
Kingston, Ontario, Canada

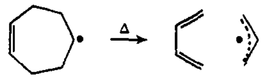
Received February 12, 1972

Stereochemistry of the Cleavage of the Cyclopentyl Radical

Sir:

The predictions of concertedness and of stereochemistry for cycloadditions involving neutral, cationic, or anionic π systems, as derived from orbital symmetry considerations, have thus far been borne out in each experimental test.[1] However, similar predictions for cycloadditions involving *radical* π systems are much more ambiguous in nature. Longuet-Higgins and Abrahamson in 1965 pointed out very succinctly that for electrocyclic reactions, and thus analogously for cycloadditions such as that shown below for the cyclopentyl radical, the ground state of the reactant correlates only with an *excited* state of the products.[2] Boche and Szeimies, on the other hand, have only recently claimed that, in the case of the cyclopropyl → allyl radical conversion, the need for crossing *can* be obviated and correlation may be made without the need for excited states.[3] The frontier orbital approach[4] does not really distinguish, as far as orbital symmetry is concerned, between this reaction and that involving the anion. This approach would predict *non*concertedness for the similar cleavage of the 4-cycloheptenyl radical,





while the Longuet-Higgins approach in comparing these two systems would be to predict that neither should be smoothly concerted, but that the cyclopentyl radical cleavage would have an energetically *more accessible* concerted pathway than would the cycloheptenyl radical cleavage.

Obviously the question remains as to *how important* these factors are which would superficially predict that *no* cycloadditions involving radical π systems are allowed.

Heretofore, no experimental measure of the concertedness of such reactions has been presented. We wish to report the results of a stereochemical study of the retrocycloaddition of a cyclopentyl radical system.

Bis(3,4-dimethylcyclopentyl)formyl peroxide (*cis*-**1**)[5] and its trans isomer, *trans*-**1**, were utilized as the precursors for generation of low concentrations of the *cis*- or *trans*-3,4-dimethylcyclopentyl radicals, *cis*-**2** or *trans*-**2**, in the gas phase.[6]

Scheme I outlines the general sequence of product formation in the pyrolysis of *cis*-**1**, while Table I presents the conditions and the results of all of the pyrolyses. Note that the relative yields of the products are greatly dependent upon the pyrolysis temperature and on the concentration of peroxide on the absorbant. The cleavage process is clearly enhanced relative to disproportionation processes by increasing temperature.

The necessity for such high temperatures to observe this reaction is most likely just a result of the very short contact times under our conditions, since the activation energy for this cleavage for the parent cyclopentyl radical has been determined to be about 37 kcal/mol.[7] *cis*- and *trans*-2-butene are found to be themselves

---

[1] R. B. Woodward and R. Hoffmann, "The Conservation of Orbital Symmetry," Verlag Chemie, Academic Press, Weinheim/Bergstr., Germany, 1970.

[2] H. C. Longuet-Higgins and E. W. Abrahamson, *J. Amer. Chem. Soc.*, **87**, 2045 (1965).

[3] G. Boche and G. Szeimies, *Angew. Chem., Int. Ed. Engl.*, **10**, 911, 912 (1971).

[4] K. Fukui and H. Fujimoto in "Mechanisms of Molecular Migrations," Vol. 2, B. S. Thyagarajan, Ed., Interscience, New York, N. Y., 1969, p 117.

[5] The isomer used was probably the all-syn species since the synthesis proceeded *via* a catalytic reduction of the ethyl ester of 3,4-dimethylcyclopent-3-ene carboxylic acid.

[6] In a typical run, 0.005 mol of **1** on Chromosorb P (10 g) was dropped in very small portions into a vertical Vycor tube, partially filled with small pieces of Vycor tubing, evacuated to ~0.5 mm pressure, and heated to 505°. The products were condensed in a series of traps, one at room temperature, and two successive traps cooled to −195°. Vacuum line techniques combined with glpc analyses produced estimates of product yields.

[7] R. Walsh, *Int. J. Chem. Kinet.*, **2**, 71 (1970), and references therein.