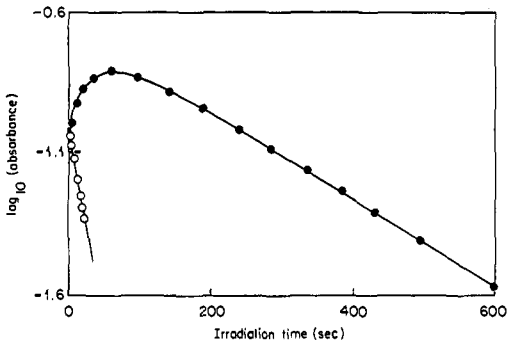


Figure 1. The time dependence of absorbance at the diazirine λ_{max} (362 nm) of 3-phenyl-3*H*-diazirine solutions in hexane, in the absence, a (●), and presence, b (○), of 0.1 *M* acetic acid.

some diazoacetamides[7] and is likely for alkyl diazirines.[8] Irradiation of 3-phenyl-3*H*- and of 3-(*p*-tolyl)-3*H*-diazirine[9] resulted in loss of the characteristic fine structure of the diazirine absorption band centered around 370 nm (Figure 2a,b). There was an initial rapid increase in absorbance at this wavelength followed by a slower decrease (see Figure 1a). New absorption bands at around 275 nm (see Figure 2b) and 490 nm appeared on irradiation, these bands being identical with those of the authentic diazo compounds.[10] When the irradiation of low (0.2 m*M*) concentrations of diazirine was carried out in the presence of 0.1 *M* acetic acid, the decrease in absorbance of the diazirine band was cleanly first order (Figure 1b). Successive uv spectra of the irradiated diazirine showed an isosbestic point under these conditions. However, when a solution of diazirine that had been irradiated for 2 min (see Figures 1a and 2b) was then treated with acetic acid, the diazo compound bands were eliminated as expected, but the absorbance increase at around 370 nm was maintained (Figure 2c). Consequently, the absorbance increase shown in Figure 1a cannot be attributed to a diazo compound and a second intermediate (X), that is insensitive to acid in the dark and has an absorbance maximum in the 340–380-nm region, is therefore implicated. Confirmation of the existence of more than one intermediate was provided by a general method of algebraic analysis of the spectral changes at different wavelengths, devised by Albery.[11] Brief irradiation of authentic phenyldiazomethane did not produce material absorbing in the 340–380-nm region, indicating that formation of the diazirine or of X from the diazo compound is unfavorable under these conditions.

The photolytic decomposition of diazirine is not all *via* the diazo compound. This was demonstrated by nmr examination of the product mixture, which gives the ratio of substituted benzyl acetate (derived from acid-trapped diazo compound) to aryl heptanes (the insertion products of the aryl carbene in hexane) as a function of added acetic acid concentration. The proportion of acetate rose to a maximum value at about

(7) R. A. Franich, G. Lowe, and J. Parker, *J. Chem. Soc., Perkin Trans. 1*, 2034(1972).
(8) H. M. Frey, *Advan. Photochem.*, **4**, 225(1966).
(9) In hexane solution (0.1–2 m*M*), with a medium-pressure mercury lamp and Pyrex filter, at room temperature.
(10) The photoisomerization of 3-(*p*-tolyl)-3*H*-diazirine was also followed by the appearance and decay of the ir band at 2060 cm^{-1} in CCl_4 (diazo N=N stretch).
(11) Dr. W. J. Albery, private communication.

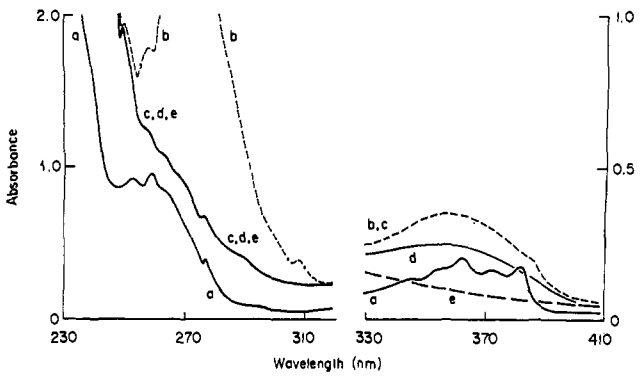


Figure 2. Ultraviolet spectra of a, 3-phenyl-3*H*-diazirine (0.6 m*M* in hexane); b, spectrum a after irradiation for 2 min; c, spectrum b after addition of acetic acid (to 0.25 *M*); d, spectrum c after further irradiation for 75 sec; and e, spectrum c after further irradiation for 5 min.

0.1 *M* acetic acid and was not significantly increased by using higher acid concentrations up to 1 *M*. At the maximum, about 70% of 3-(*p*-anisyl)-3*H*-diazirine and about 50% of 3-(*p*-tolyl)-3*H*-diazirine was converted to acetate (*via* the diazo compound). Since in the presence of acid the formation of X was spectroscopically undetectable (Figure 1b), the acid-insensitive route to carbene (and thence to aryl heptane) is likely to involve the direct photochemical fragmentation of the diazirine. The nature of X is uncertain. One possibility is 7α*H*-indazole which could be formed by ring expansion of the diazirine and which has been postulated as a carbene precursor in the gas-phase pyrolysis of 1*H*-indazole.[12] 3-Phenyl-3-chloro- and 3-(*p*-anisyl)-3-chlorodiazirines[13] show no evidence of formation of any intermediate on photolysis at room temperature. The presence of acetic acid has no effect on the spectral changes and α-chlorobenzyl acetates cannot be detected.

The 3-aryl-3*H*-diazirines reported here have considerable promise in the field of photogenerated labeling reagents, since they admirably fulfill the main criteria of chemical stability and appropriate photolability.

Acknowledgment. We thank the Science Research Council for a Research Studentship (to R. A. G. S.).

(12) W. D. Crow, R. Lea, and M. N. Paddon-Row, *Tetrahedron Lett.*, 2235 (1972).
(13) W. A. Graham, *J. Amer. Chem. Soc.*, **87**, 4396 (1965).

Richard A. G. Smith, Jeremy R. Knowles*
The Dyson Perrins Laboratory, University of Oxford
Oxford, England
Received April 2, 1973

Still Another Change in Rate-Determining Step for a Simple Carbonyl Addition Reaction. Evidence for a Kinetically Significant Proton Transfer Step in Acid-Catalyzed *O*-Methyloxime Formation[1]

Sir:

We wish to report the observation of two breaks on the acid limb of the pH–rate profile for *O*-methyloxime formation from *p*-chlorobenzaldehyde, which indicates the existence of *two* changes in rate-determining step

(1) Supported by a grant from the National Institute of Child Health and Human Development of the National Institutes of Health (HD 01247). Publication No. 905 from the Graduate Department of Biochemistry, Brandeis University.

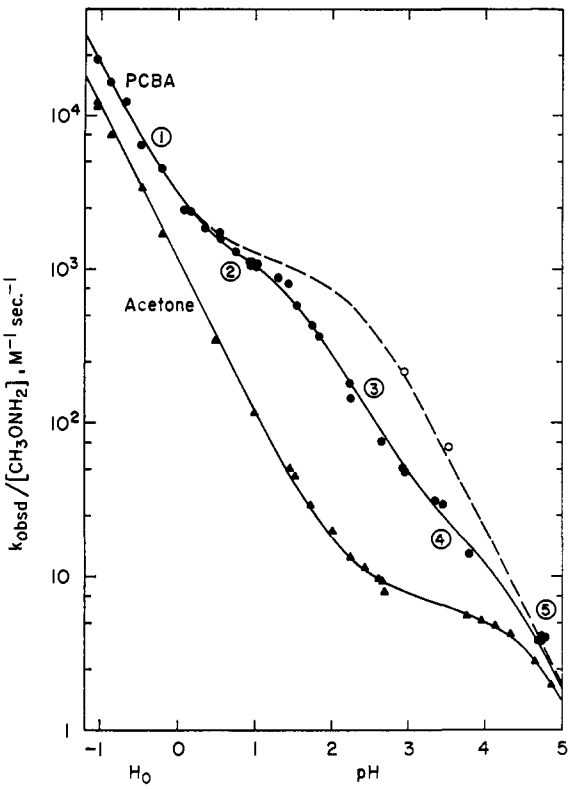


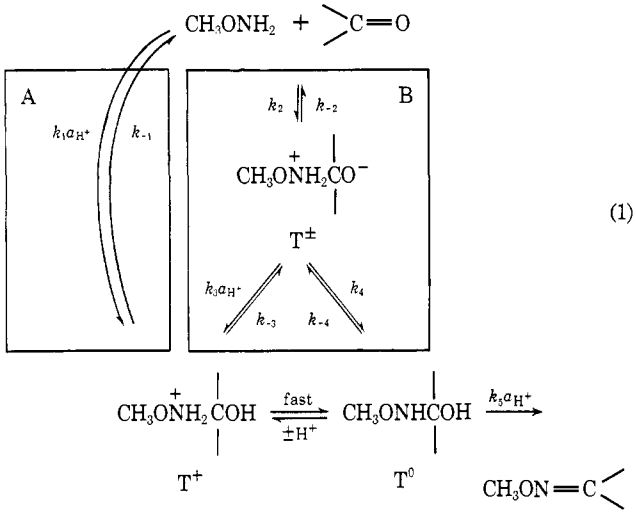
Figure 1. Dependence on pH of the second-order rate constants, corrected for catalysis by buffers and methoxyammonium ion, for *O*-methyloxime formation from *p*-chlorobenzaldehyde (●) and acetone (▲) in aqueous solution at 25°. The open symbols (○) represent the limiting rate constants (for rate-determining dehydration) for the reaction of *p*-chlorobenzaldehyde at high concentrations of formate buffer. The solid line for *p*-chlorobenzaldehyde is theoretical for the mechanism of eq 2 and 2a and the rate constants of Table I. The broken line is theoretical for a simple two-step mechanism (eq 2) with $k_{at}' = (k_1a_{H^+} + k_2)$. The line for acetone is theoretical for $k_{at}' = 1100a_{H^+} + 6.7\ M^{-1}$ sec^{-1} and $K_{ad}k_3 = 2.2 \times 10^6\ M^{-2}$ sec^{-1}.

for the reaction in this pH region. The observed dependence on pH of the rate is consistent with a dual mechanism for the attack step, involving a stepwise process for carbon–nitrogen bond formation and proton transfer to a dipolar intermediate, which occurs concurrently with "concerted" catalysis of the attack step by the hydronium ion.

The pH–rate profile for the reaction of methoxyamine free base with *p*-chlorobenzaldehyde, corrected for catalysis by buffers and methoxyammonium ion, is given by the solid circles in Figure 1. The limiting rate constants at low and high pH correspond to rate-determining acid-catalyzed attack of the amine and dehydration of the carbinolamine intermediate, respectively.[2] In the intermediate pH range (pH 1.5–4.0) the observed rate constants fall approximately two- to fourfold below the pH–rate profile (broken line) required by the steady-state rate law for a mechanism involving a single change in rate-determining step from attack to dehydration at pH ~2.0. In contrast, the pH–rate profile for *O*-methyloxime formation from acetone (Figure 1, solid triangles) exhibits only one break, at pH ~4.0; *i.e.*, the second break observed with *p*-chlorobenzaldehyde is not a result of some property of methoxyamine unrelated to the specific reaction studied.

The observation of two breaks in the pH–rate profile for *O*-methyloxime formation from *p*-chlorobenzaldehyde requires that there be two changes in rate-determining step and three kinetically significant steps in the reaction. Since there are only two processes in this reaction that involve making or breaking of bonds to carbon, the third step must involve a proton transfer process.

A mechanism consistent with the observed pH–rate profile for *p*-chlorobenzaldehyde is shown in eq 1.



(1)

According to this mechanism there are two concurrent pathways for the addition process: pathway A (the left-hand side of eq 1), which involves only one kinetically significant step, and pathway B (the right-hand side of eq 1), which involves two kinetically significant steps and undergoes a change in rate-determining step as a function of pH. At low pH (region **1** of the pH–rate profile) the reaction proceeds predominantly by the hydronium ion catalyzed mechanism of pathway A, whereas at higher pH (regions **2**, **3**, and **4** of the pH–rate profile) the predominant mechanism involves the stepwise pathway B. The change from pathway A to pathway B with increasing pH occurs because the rate-determining step for pathway B at low pH (region **2**) is the uncatalyzed attack of the nucleophile, k_2, and this process becomes faster than $k_1a_{H^+}$, for pathway A, as a_{H^+} is decreased. The negative break in the pH–rate profile at pH ~1 corresponds to a change from a neutral to a cationic transition state for pathway B and requires that a hydronium ion catalyzed step subsequent to the uncatalyzed carbon–nitrogen bond formation, k_2, must become rate determining for this pathway. The predominant rate determining processes in regions **3** and **4** of the pH–rate profile are catalysis of proton transfer by the hydronium ion (k_3) and water (k_4), respectively. At still higher pH (region **5**), or at high buffer concentrations (Figure 1, open circles), a second change in rate-determining step occurs. This break corresponds to the normal transition from rate-determining formation to dehydration of the carbinolamine[2,3] and is observed for both *p*-chlorobenzaldehyde and acetone.

(2) W. P. Jencks, *J. Amer. Chem. Soc.*, **81**, 475 (1959); J. E. Reimann and W. P. Jencks, *ibid.*, **88**, 3973 (1966); W. P. Jencks, *Progr. Phys. Org. Chem.*, **2**, 63 (1964).

(3) At high amine concentrations, rapid preequilibrium formation of the carbinolamine intermediate is observable spectrophotometrically at pH 7.0–7.2, from the initial decrease in absorbance of *p*-chlorobenzaldehyde at 260 nm in the presence of 0.02–0.27 *M* methoxyamine.

In order for the proton transfer steps k_3 and k_4 to be rate determining for pathway B at pH >1, the initial product of uncatalyzed methoxyamine attack, $T^{\pm}$, must revert rapidly to starting materials (with a lifetime of $\sim 10^{-9}$ sec) unless it is trapped by proton transfer.[4] As the pH is decreased, the acid-catalyzed proton transfer to $T^{\pm}$, $k_3 a_{H^+}$, becomes faster than the uncatalyzed attack and expulsion of methoxyamine and the rate for the reaction should eventually level off, with a rate constant equal to k_2, unless another mechanism for the addition reaction becomes available. This additional mechanism is provided by the hydronium ion catalyzed pathway A. The detailed mechanism for this pathway may involve either a proton transfer that is in some sense "concerted" with carbon–nitrogen bond formation, by analogy with the proposed mechanism for semicarbazone,[5] thiosemicarbazone,[6] and methylthiosemicarbazone[7] formation, or an attack of the nucleophile on the fully protonated aldehyde.

The steady-state rate law for the overall reaction is given by eq 2 and 2a, where K_{ad} is the equilibrium constant for formation of the neutral carbinolamine. The apparent rate constant, k_{at}', for carbinolamine formation is the sum of the rate constants for pathways A and B for the addition step described above. Experimentally, k_{at}' is obtained by correction of the observed second-order rate constant at any given pH for the contribution of the dehydration step,[6] $K_{ad}k_5 a_{H^+}$. Individual rate constants determined from the dependence on hydrogen ion activity of the observed rate constant for *O*-methyloxime formation are given in Table I.

$$k_{obsd} = \frac{k_{at}' K_{ad} k_5 a_{H^+}}{k_{at}' + K_{ad} k_5 a_{H^+}} \quad (2)$$

$$k_{at}' = k_1 a_{H^+} + \frac{k_2(k_4 + k_3 a_{H^+})}{k_{-2} + k_4 + k_3 a_{H^+}} \quad (2a)$$

Table I. Kinetic Constants for *O*-Methyloxime Formation from *p*-Chlorobenzaldehyde in Aqueous Solution at 25°[a]

K_{ad} (M^{-1})	13.4 ± 0.6[b]
k_1 (M^{-2} sec^{-1})[c]	2070
k_2 (M^{-1} sec^{-1})	1150
k_3k_2/k_{-2} (M^{-2} sec^{-1})[d]	4.0×10^4
k_4k_2/k_{-2} (M^{-1} sec^{-1})	25 ± 5
$K_{ad}k_5$ (M^{-2} sec^{-1})[d]	2.1×10^5

[a] Rate constants are for the processes defined in eq 1. Ionic strength was 1.0 *M* (KCl) except at high acid concentrations. [b] S. Rosenberg, unpublished observation. [c] Rate constant based on antilog ($-H_0$) (M. A. Paul and F. A. Long, *Chem. Rev.*, **57**, 1 (1957)), at HCl concentrations ≥1.0 *M*. [d] Based on hydronium ion activity.

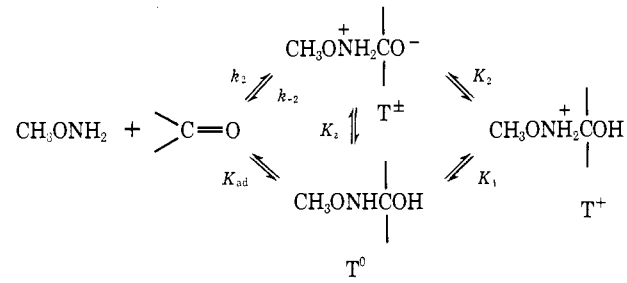
The solid line of Figure 1 for *p*-chlorobenzaldehyde, calculated[8] from these constants, is in good agreement with the experimental points.

Support for the proposed mechanism is provided by calculation of the rate constants k_3 and k_4 from the kinetic data of Table I and an estimated equilibrium constant,[9] k_2/k_{-2}, of 4×10^{-6} M^{-1} for the formation of $T^{\pm}$ from starting materials. The estimated values of $k_3 = 10^{10}$ M^{-1} sec^{-1} and $k_4 = 6 \times 10^6$ sec^{-1} are consistent with the expected rate constants for a thermodynamically favorable diffusion controlled proton transfer[12] and a solvent-mediated "proton switch" of the zwitterionic intermediate,[13] respectively.

Acknowledgment. We wish to express our gratitude to Professor William P. Jencks for valuable discussions and comments.

(4) J. M. Sayer and W. P. Jencks, *J. Amer. Chem. Soc.*, **94**, 3262 (1972); M. I. Page and W. P. Jencks, *ibid.*, **94**, 8828 (1972).
(5) E. H. Cordes and W. P. Jencks, *ibid.*, **84**, 4319 (1962).
(6) J. M. Sayer and W. P. Jencks, *ibid.*, **91**, 6353 (1969).
(7) J. M. Sayer and W. P. Jencks, *ibid.*, in press.
(8) We wish to thank Mr. Steven Rosenberg for assistance with this calculation.

(9) This equilibrium constant is equal to $K_{ad}K_z$, where K_{ad} is the measured equilibrium constant for formation of the neutral carbinolamine and K_z is the equilibrium constant for conversion of T^0 to $T^{\pm}$



A value for K_z of 3×10^{-7} is calculated from values of 2.0 and 8.5 for pK_1 and pK_2, respectively, estimated from $pK_a = 4.88$ for *N,O*-dimethylhydroxylammonium ion,[10] $pK_a = 10.0$ for the hydroxyl group[11] of $CH_3N^+H_2CH_2OH$, and structure–reactivity correlations.[7]

(10) N. Gravitz and W. P. Jencks, *J. Amer Chem. Soc.*, submitted for publication.
(11) J. Hine, J. C. Craig, Jr., J. G. Underwood, II, and F. A. Via, *J. Amer. Chem. Soc.*, **92**, 5194 (1970).
(12) M. Eigen, *Angew. Chem., Int. Ed. Engl.*, **3**, 1 (1964).
(13) Z. Luz and S. Meiboom, *J. Amer. Chem. Soc.*, **85**, 3923 (1963); R. E. Barnett and W. P. Jencks, *ibid.*, **91**, 2358 (1969); E. Grunwald and D.-W. Fong, *ibid.*, **94**, 7371 (1972); G. Maass and F. Peters, *Angew. Chem., Int. Ed. Engl.*, 11, 428 (1972).

Samuel M. Silver, Jane M. Sayer*
Graduate Department of Biochemistry, Brandeis University
Waltham, Massachusetts 02154
Received April 12, 1973

Photoelectron Spectroscopy and the Anodic Fragmentation of Adamantane Derivatives

Sir:

We wish to report an unusual, new anodic fragmentation reaction of an aliphatic ketone and the first use of photoelectron spectroscopy in understanding electrochemical phenomena.

It has been previously demonstrated[1] that the anodic oxidation of adamantane (**1**) at platinum in acetonitrile produces *N*-(1-adamantyl)acetamide (**2**). This oxidation involves initial electron transfer from the hydrocarbon to the electrode. The cation radical produced in this reaction then loses a proton and an electron forming the 1-adamantyl cation. This cation is finally converted to amide **2** in analogy with the Ritter reaction.

Anodic oxidations of several adamantane derivatives have now been undertaken and we report here on 1-acetyladamantane (**3**) and 1-carbomethoxyadamantane (**4**). Ester **4** was potentiostatically oxidized at 2.45 V *vs.* Ag|0.1 *M* $AgNO_3$ in damp acetonitrile. The current decayed from 180 mA down to the background level of 3 mA over a 3-hr period. Work-up by concentration of the anolyte and extraction with ether provided 1-

(1) V. R. Koch and L. L. Miller, *Tetrahedron Lett.*, 693 (1973).