

to be identical. The two Cu–O bonds in the plane defined by the Cu and N atoms are slightly shorter than the Cu–N bonds, as is usually the case. Both the Cu–O bond length of 1.967 ± 0.004 Å and the Cu–N bond length of 1.998 ± 0.004 Å are similar to the distances found in other complexes with both nitrogen and oxygen atoms coordinated to the copper atom.³ However, the Cu–O bonds to the second oxygen of each β -diketone ring are much longer, 2.296 ± 0.004 Å. Therefore, the four short–two long bond distortion of an octahedron is also found in this molecule. The bond lengths in the β -diketone moiety are given in Figure 1 and follow a pattern of alternating long and short bonds. The alternation of the bond lengths can easily be rationalized by the stronger interaction of one oxygen atom to the copper(II) ion.

Electron spin resonance studies were carried out on diluted solid samples of $\text{Cu}(\text{hfacac})_2 \cdot \text{bipy}$ in $\text{Zn}(\text{hfacac})_2 \cdot \text{bipy}$ which were prepared by cocrystallization of the two compounds from benzene. The optimum compromise between resolution and signal-to-noise ratio was found for a zinc:copper ratio in the solution of 50:1 although the final ratio in the solid was not determined.

The spectra of the diluted solid were recorded for both a finely powdered sample and a single crystal at several arbitrary orientations. Hyperfine interaction with one copper and two equivalent nitrogen nuclei was observed at each of the orientations of the single crystal. The spectrum of the powder at -150° was indicative of axial symmetry (about the O–Cu–O axis) at the copper atom. Observed parameters are $g_{\parallel} = 2.299 \pm 0.004$, $g_{\perp} = 2.056 \pm 0.004$; for Cu^{63} $A_{\parallel} = 151 \pm 2$ G; and for Cu^{65} $A_{\parallel} = 163 \pm 2$ G, $A_{\perp} = 26.6 \pm 1$ G. The difference between the isotopes of copper was not resolvable for the perpendicular features. The hyperfine splitting from two equivalent nitrogen nuclei was resolved on both the parallel ($A_N = 9.5 \pm 1$ G) and perpendicular ($A_N = 13.3 \pm 1$ G) features.

The measured g and A_{Cu} values are in accord with the values expected for a copper ion in a tetragonally distorted octahedral environment. However, whether the field is truly tetragonal or has some rhombic character could not be decided on the basis of the spectra obtained from the powdered sample. The anisotropy detected in the hyperfine splitting of the nitrogen nuclei deserves comment. Similar splittings have been observed for square-planar complexes,^{4,5} although in each case these splittings were isotropic, and for a tetrahedral copper(II) complex,⁶ where the splittings were also anisotropic. More extensive single-crystal studies are in progress to locate the principal direction of the nitrogen hyperfine tensor.

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(3) G. E. Gurr, *Acta Cryst.*, **B24**, 1511 (1968), and references therein.

(4) H. R. Gersmann and J. D. Swalen, *J. Chem. Phys.*, **36**, 3221 (1962).

(5) A. H. Maki and B. R. McGarvey, *ibid.*, **29**, 35 (1958).

(6) G. F. Kokoszka, C. W. Reiman, and H. C. Allen, Jr., *J. Phys. Chem.*, **71**, 121 (1967).

(7) Address all correspondence to this author.

M. V. Veidis, G. H. Schreiber
T. E. Gough, Gus J. Palenik⁷

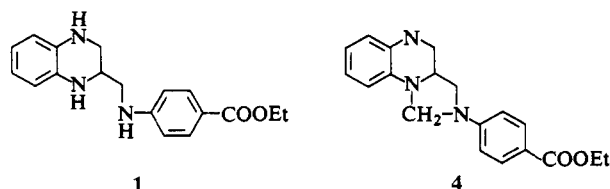
Department of Chemistry, University of Waterloo
Waterloo, Ontario, Canada

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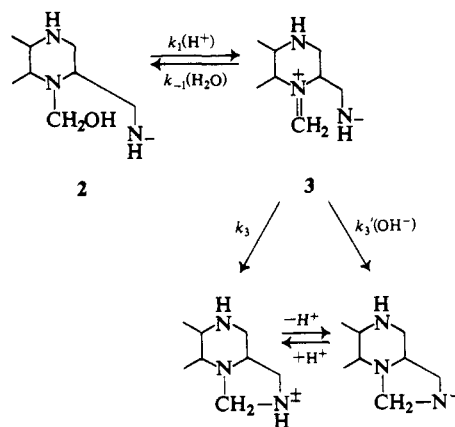
Kinetic Detection of the Imminium Cation in Formaldehyde–Amine Condensations in Neutral Aqueous Solution

Sir:

The intermediacy of the imminium cation in the Mannich condensations has been proposed by several investigators,^{1–3} although its presence has never been unequivocally established except in strong acid solutions.⁴ In our studies on the mechanism of action of tetrahydrofolic acid we have synthesized the model tetrahydroquinoxaline derivative **1** and investigated its condensation with formaldehyde to give **4**.⁵ The pH–rate profile for the



conversion of **1** to **4** in 50% v/v dioxane–water ($\mu = 0.2$, 25°) monitored by the increase in absorption at 310 m μ is exhibited in Figure 1. The first-order rate constants, k_{obsd} (reproducible within $\pm 5\%$), are obtained at kinetically saturating formaldehyde concentrations extrapolated to zero buffer concentration over the entire pH range studied; thus we conclude that **1** is in equilibrium with its respective carbinolamine **2**. The unique features of the pH–rate profile apparently arise from the conversion of carbinolamine to product. Although numerous investigations⁶ have demonstrated that dehydration of **2** proceeds almost entirely through hydronium ion catalysis (Brønsted $\alpha = 0.7$ – 0.9),⁶ this profile does not follow first-order acid-catalyzed dehydration. The kinetic results may only be explained in terms of a steady-state species, logically the imminium cation **3**, whose partitioning is subject to pH control. Two mechanisms are proposed which yield the requisite expression for k_{obsd} , I (below) or II (not illustrated), which neglects $k_3'(\text{OH}^-)$ but



(1) H. Hellmann and G. Opitz, *Angew. Chem.*, **68**, 265 (1959).

(2) S. V. Liebermann and E. C. Wagner, *J. Org. Chem.*, **14**, 1001 (1949).

(3) (a) T. F. Cummings and J. R. Shelton, *ibid.*, **25**, 419 (1960); (b) R. G. Kallen and W. P. Jencks, *J. Biol. Chem.*, **24**, 5851 (1966).

(4) J. DeLuis, Ph.D. Thesis, The Pennsylvania State University, 1964.

(5) All compounds reported gave satisfactory elemental analyses and their structures were consistent with the infrared, mass, nmr, and ultraviolet spectral data.

(6) K. Koehler, W. Sandstrom, and E. H. Cordes, *J. Am. Chem. Soc.*, **86**, 2413 (1964), and references therein.

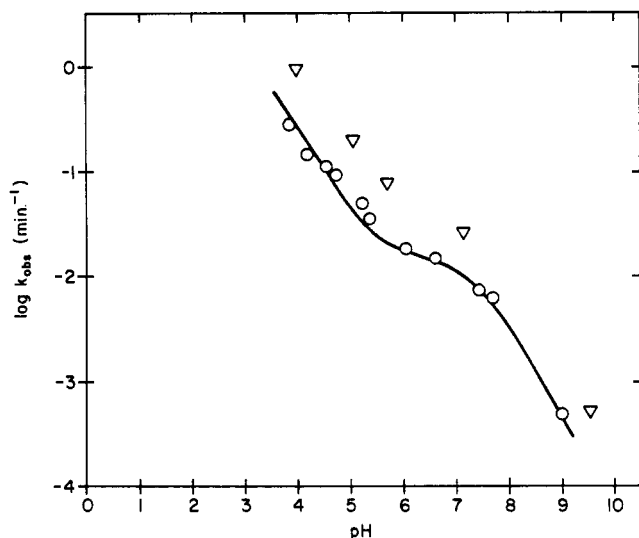


Figure 1. Plot of $\log k_{\text{obsd}}$ as a function of pH; (○) 50% v/v dioxane-water; (△) 20% v/v dioxane-water; $\mu = 0.2$, 25°. Solid line calculated from equation in text.

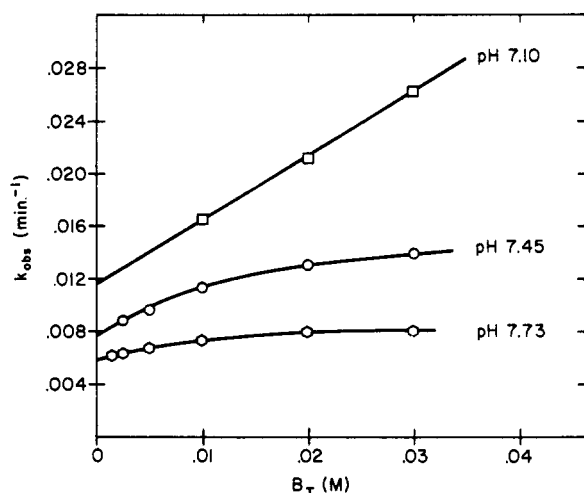


Figure 2. Plots of k_{obsd} vs. total phosphate buffer concentration ($\mu = 0.2$, 25°).

includes an additional uncatalyzed dehydration term, k_2 , and the associated $k_{-2}(\text{OH}^-)$ term.⁷ The appropriate equation for k_{obsd} as a function of pH is $k_{\text{obsd}} = [A(\text{H}^+) + B](\text{H}^+)/[(\text{H}^+) + C]$ and yields the theoretical curve of Figure 1. Limiting values of the above equation can be generated by assuming that (1) at $\text{pH} > 7.5$ $B \gg A(\text{H}^+)$ and $C \gg (\text{H}^+)$; (2) at $\text{pH} < 4.5$ $A(\text{H}^+) \gg B$ and $(\text{H}^+) \gg C$.⁸ The profile, therefore, arises from the near proximity of a kinetically generated titration curve of the form $A'(\text{H}^+)/[B' + (\text{H}^+)]$ and a hydronium term $A'(\text{H}^+)$ with the constants A' differing by a factor of

(7) (a) For mechanism I, $A = k_3 k_1 / (k_{-1} + k_3)$, $B = k_3' k_1 K_{\text{WD}} / (k_{-1} + k_3)$, $C = k_3' K_{\text{WD}} / (k_{-1} + k_3)$; mechanism II, $A = k_3 k_1 / (k_{-1} + k_3)$, $B = k_3 k_2 (k_{-1} + k_3)$, $C = k_{-2} K_{\text{WD}} / (k_{-1} + k_3)$. K_{WD} is defined as the autoprotolysis constant of 50% dioxane- H_2O . The above scheme as defined does not include the possibility that an alternative carbinolamine would also yield product. Thus the parameters A , B , and C may not be uniquely defined by these sets of rate constants. (b) An alternate description of k_{obsd} as a function of pH which yields a theoretical curve similar to the above except at $\text{pH} < 4$ is given by $\{[A'(\text{H}^+) + B](\text{H}^+)/[(\text{H}^+) + C]\} K_a / K_a + (\text{H}^+)$. The value of $\text{p}K_a \approx 3.76$ (the macroscopic $\text{p}K_a$ of the quinoxaline nitrogens) was determined spectrophotometrically.

(8) Reiterative calculations fix $-\log C$ as 7.45.

$\text{ca. } 3 \times 10^5$. The above assumptions are equivalent to allowing changes in the rate-determining step. Mechanism I may be analyzed in terms of rate-determining transitions from uncatalyzed to base-catalyzed ring closure and ultimately rate-determining dehydration of carbinolamine with increasing pH. A choice between the two schemes is problematic. Although there is ample chemical evidence for the lyate species catalysis employed in either sequence, the magnitude of the hydronium ion term in mechanism II demands a Brønsted α (0.4) considerably less than those generally observed with aromatic amines.⁹

The observed buffer catalysis (acetate, formate, and phosphate) can be rationalized by including general acid catalyzed dehydration of carbinolamine or general base catalysis of ring closure. Whereas k_{obsd} is linearly related to acetate and formate concentrations, a saturation phenomenon is encountered with phosphate buffer¹⁰ (Figure 2) which provides additional evidence for the existence of 3. Again this may be ascribed to a change in rate-determining step, in terms of mechanism I from general base catalysis of ring closure to hydronium ion catalysis of carbinolamine dehydration.

The demonstration of the imminium cation intermediate over this broad pH range implies that the duality of mechanism proposed for the Mannich condensation in acidic and basic media involving the imminium cation and carbinolamine as the respective reactive intermediates³ may not be general and gives insight into the mechanism of methylene transfer from tetrahydrofolic acid, a subject to be discussed in a forthcoming publication.

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(9) W. P. Jencks, *Progr. Phys. Org. Chem.*, **2**, 63 (1964).

(10) The unique behavior of phosphate buffer is not altered by changes in solvent (20% v/v dioxane- H_2O) or ionic strength.

Stephen J. Benkovic, Patricia A. Benkovic
David R. Comfort

Department of Chemistry, Pennsylvania State University
University Park, Pennsylvania 16802

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The Influence of Steric Inhibition of Resonance on Ion Intensities in Mass Spectra

Sir:

The recognition of quantitative correlations between structure and reactivity in substituted aromatic compounds in the 1930's¹ led to investigations of deviations from these correlations caused by nonbonded interactions between several substituents. For example, modification of the reactivities of the dimethylamino² and nitro³ groups by *ortho* substituents has been interpreted in terms of large deviations from coplanarity of the substituent and the ring, so that resonance effects of these substituents are greatly reduced.⁴

(1) L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1940, Chapter VII.

(2) F. H. Westheimer and R. P. Metcalf, *J. Am. Chem. Soc.*, **63**, 1339 (1941).

(3) W. C. Spitzer and G. W. Wheland, *ibid.*, **62**, 2995 (1940).