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Mechanism of Solvolysis Reactions of *O*-Methylbenzohydroximoyl Halides. Stereoelectronic Control in Formation of and Nucleophilic Addition to Nitrilium Ions[1]

James E. Johnson* and Sravanthi C. Cornell[2]

Department of Chemistry, Texas Woman's University, Denton, Texas 76204

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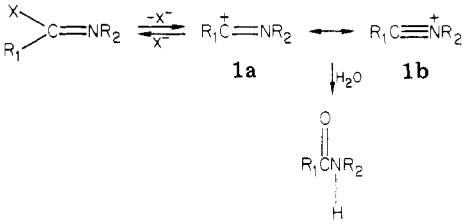
The hydrolysis reactions of the *Z* and *E* isomers of *O*-methylbenzohydroximoyl chloride (**3a** and **2**, respectively) have been investigated. The first-order rate constant for the hydrolysis of **3a** (1) shows common-ion rate depression, (2) decreases with decreasing concentration of sodium perchlorate, and (3) is independent of change in pH. Hydrolysis of the hydroximoyl bromide **3g** is 41 times faster than that of the chloride **3a**. The hydrolysis rates for six (*Z*)-hydroximoyl chlorides (**3a–f**) gave a Hammett correlation with σ^+ with a ρ value of −2.40. These observations are indicative of a hydrolysis mechanism involving rate-determining ionization of the hydroximoyl chloride to a nitrilium ion. Since the (*Z*)-hydroximoyl chloride **3a** undergoes hydrolysis about 470 times faster than the *E* isomer (**2**), it is concluded that there is a strong preference for the nitrogen lone pair to be trans to the leaving group in the transition state for nitrilium ion formation. The methanolysis of either **3a** or **2**, which gave only methyl (*Z*)-*O*-methylbenzohydroximate (**6**), demonstrates that nucleophilic addition to the nitrilium ion also proceeds in a trans fashion. Addition of chloride and bromide ion to the nitrilium ion generated by nitrosative deamination of *O*-methylbenzamidoxime (**8b**) was also investigated. Chloride ion was shown to react stereospecifically with the nitrilium ion to give **3a**.

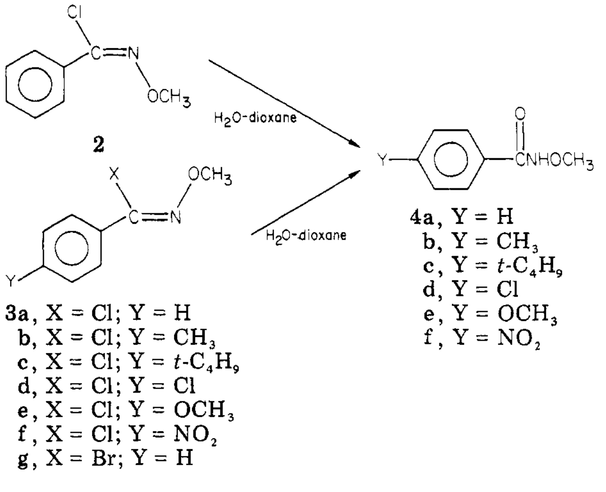
Nitrilium ions, which are represented by the resonance structures **1a** and **1b**, have been found to be intermediates in the hydrolysis of several functional groups (Scheme I) containing the carbon-nitrogen double bond (imines).[3,4] Nitrilium ions have also been reported[5,6] as intermediates in the reactions of diarylimidoyl chlorides with amines in aprotic solvents (benzene and acetonitrile). The nitrilium ions formed in these reactions were usually formed as ion pairs, but in one case[5] with a sterically hindered amine, the reaction proceeded through a free nitrilium ion. When the diarylimidoyl chlorides were substituted with electron-attracting groups, the reactions proceeded by a nucleophilic addition–elimination pathway. The stereochemical requirement for nitrilium ion formation has not been determined heretofore because the imine derivatives studied previously were not configurationally stable. We have reported previously on the remarkable configurational stability of the *E* and *Z* isomers of *O*-methylbenzohydroximoyl chlorides (**2** and **3**).[7-9] In this paper we describe our investigations of the solvolysis of these compounds.

The rates (Table I) of hydrolysis of *O*-methylbenzohydroximoyl halides (**2** and **3a–g**) were determined in degassed 3:1 (v/v) dioxane–water solutions at pH 7 in the presence of 0.10 M sodium perchlorate to maintain a constant ionic strength. In all cases studied, the reactions gave good first-order plots,[10] with the methyl benzohydroxamates (**4**) as the only reaction products (Scheme II).

Scheme I



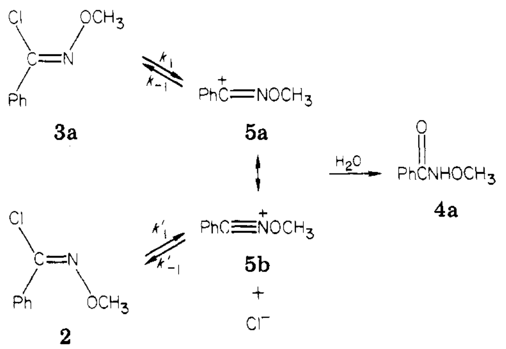
Scheme II



3a, X = Cl; Y = H
b, X = Cl; Y = CH_3
c, X = Cl; Y = *t*-C_4H_9
d, X = Cl; Y = Cl
e, X = Cl; Y = OCH_3
f, X = Cl; Y = NO_2
g, X = Br; Y = H

4a, Y = H
b, Y = CH_3
c, Y = *t*-C_4H_9
d, Y = Cl
e, Y = OCH_3
f, Y = NO_2

Scheme III



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[1] This work was initially reported at the Third IUPAC Conference on Physical Organic Chemistry, LaGrande Motte, France, Sept 10, 1976, Abstracts p 59.

[2] Taken from the Ph.D. Dissertation of S. C. Cornell, Texas Woman's University, July 1977; *Diss. Abstr.* **38/09B**, 4270 (1978).

[3] I. Ugi, F. Beck, and U. Fetzer, *Chem. Ber.*, **95**, 126 (1962).

[4] A. F. Hegarty, D. A. Cronin, and F. L. Scott, *J. Chem. Soc., Perkin Trans. 2*, 429 (1975), and earlier work from this laboratory (see ref 6 for a complete list of references).

[5] R. Ta-Shma and Z. Rappoport, *J. Am. Chem. Soc.*, **98**, 8460 (1976).

[6] R. Ta-Shma and Z. Rappoport, *J. Am. Chem. Soc.*, **99**, 1845 (1977), and references therein.

[7] J. E. Johnson, E. A. Nalley, and C. Weidig, *J. Am. Chem. Soc.*, **95**, 2051 (1973).

[8] J. E. Johnson, E. A. Nalley, Y. K. Kunz, and J. R. Springfield, *J. Org. Chem.*, **41**, 252 (1976).

[9] The *E–Z* configurational assignments made for the hydroximoyl halides reported in ref 7 and 8 must be reversed. The *O*-methyl-*p*-nitrobenzohydroximoyl chloride prepared by reaction of methyl *p*-nitrobenzohydroxamate with phosphorus pentachloride has been determined by X-ray crystallographic analysis to have the *Z* configuration: V. Bertolasi, M. Sacerdoti, and D. Tassi, *Cryst. Struct. Commun.*, **6**, 335 (1977).

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Table I. First-Order Rate Constants for Hydrolysis of *O*-Methylbenzohydroximoyl Halides 2 and 3 in Dioxane-Water[a]

compd	temp, °C	10^5k, s^{-1}
3a	120	5.50 ± 0.12
3a	120	5.52 ± 0.16[b]
3a	120	4.74 ± 0.11[c]
2	150	0.433 ± 0.026
2	155	0.759 ± 0.022
2	160	1.29 ± 0.06
2	120	0.0118[d]
3g	80	3.28 ± 0.09
3g	90	9.51 ± 0.28
3g	95	18.5 ± 0.4
3g	100	30.5 ± 2.8
3g	120	225[d]
3b	120	26.2 ± 0.7
3c	120	19.8 ± 1.6
3d	120	3.08 ± 0.04
3e	80	3.33 ± 0.08
3e	90	11.6 ± 0.1
3e	95	20.8 ± 0.4
3e	120	324[d]
3f	120	0.0545 ± 0.0013

[a] Unless otherwise noted all reactions were carried out at pH 7 in 0.10 M sodium perchlorate. [b] pH 11. [c] pH 3. [d] Calculated by extrapolation of a plot of ln (k/T) vs. $1/T$.

Table II. Effect of Salts on First-Order Rate Constants for Hydrolysis of *O*-Methylbenzohydroximoyl Chlorides 2 and 3a[a]

compd	temp, °C	concn of added salt(s), M	10^5k, s^{-1}
3a	120	0.1 ($NaClO_4$)	5.50 ± 0.12
3a	120	0.05 ($NaClO_4$) 0.05 (NaCl)	1.48 ± 0.03
3a	120	0.05 ($NaClO_4$)	4.56 ± 0.03
3a	120		3.56 ± 0.08
2	150	0.1 ($NaClO_4$)	0.433 ± 0.026
2	150	0.05 ($NaClO_4$) 0.05 (NaCl)	0.244 ± 0.012

[a] All reactions carried out at pH 7.

In order to study the effect of the leaving group on these reactions, the hydrolysis rates of (*Z*)-*O*-methylbenzohydroximoyl chloride (**3a**) and bromide (**3g**) were measured. The k_{Br}/k_{Cl} ratio of 41 is considerably larger than the k_{Br}/k_{Cl} ratio of 1.9 observed by us for bimolecular reactions of these compounds with methoxide ion.[7] The hydrolysis reactions of imidoyl halides and hydrazonoyl halides which proceed through nitrilium ion intermediates have been reported[6,11] to give k_{Br}/k_{Cl} ratios in the range of 30–440. Thus, a k_{Br}/k_{Cl} ratio of 41 observed in this work strongly supports a mechanism involving rate-limiting carbon–halogen bond cleavage to a nitrilium ion (Scheme III). The following additional evidence substantiates this proposal.

The *Z* isomer of *O*-methylbenzohydroximoyl chloride (**3a**) showed a 3.7-fold decrease in rate (at 120 °C) in the presence of 0.05 M chloride ion (Table II). This is a small effect when compared to the 25-fold decrease observed for *N*-arylbenzimidoyl chlorides when 0.01 M sodium perchlorate was replaced with 0.01 M sodium chloride, but a smaller common-ion rate depression has been observed in the hydrolysis of phenyl *N*-phenylchloroformimidate.[4] The observed rate depression indicates that in the hydrolysis of **3a** at least 73%[12,13] of **4a** is formed from the free nitrilium ion. The rate of hydrolysis of **3a** was found to decrease by a factor of 1.5 in going from 0.10 M sodium perchlorate to zero concentration of this salt which is consistent with a mechanism involving rate-determining formation of a charged intermediate.

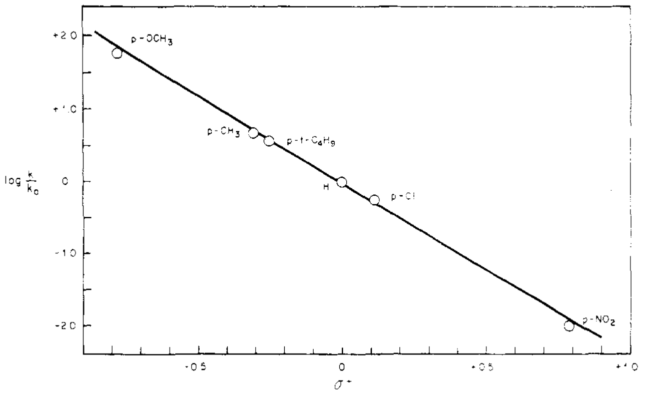

Figure 1. Hammett plot (σ^+) for hydrolysis of (*Z*)-*O*-methylbenzohydroximoyl chlorides (**3**) in 3:1 dioxane–water at 120 °C (pH 7 and 0.10 M sodium perchlorate).

A 1.8-fold decrease in rate (at 150 °C) was observed for the hydrolysis of the *E* isomer (**2**). The common-ion rate depression observed in this reaction will be discussed later in the paper.

The rates of hydrolysis of five para-substituted derivatives of (*Z*)-*O*-methylbenzohydroximoyl chloride (**3b–f**) were measured in order to determine the effect of substituents on this reaction. A better Hammett correlation (r = 0.999) was obtained with σ^+ (Figure 1) than with σ (r = 0.956). The ρ value with σ^+ of –2.40 ± 0.14 is similar to those values reported for the hydrolysis of imidoyl chlorides[4] and related systems[14–16] and is further evidence that the hydrolysis of *O*-methylhydroximoyl halides involves rate-determining ionization to a nitrilium ion. It is interesting that all of the Hammett correlations published[4,6,14–18] previously for nitrilium ion formation have been with σ or σ^* even though in most cases these correlations were with imines which would produce nitrilium ions where the positive charge on carbon could participate in through-resonance[19] with electron-donating para substituents (**1**, $R_1 = C_6H_4Y$). In fact, in one instance,[4] substituents capable of participating in through-resonance

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(10) In the first attempts to investigate the kinetic behavior of **3a** with samples containing oxygen, nonlinear first-order plots were obtained after 10% of the reaction had taken place. Furthermore, a small amount of benzonitrile was formed along with the expected hydrolysis product **4a**.

(11) F. L. Scott, D. A. Cronin, and J. K. O'Halloran, *J. Chem. Soc. C*, 2769 (1971).

(12) Calculated from the following equation: percentage of **4a** formed from free ion = $100(1 - k_d/k_t°)$, where k_d is the depressed rate constant in 0.05 M sodium chloride and 0.05 M sodium perchlorate and $k_t°$ is the undepressed rate constant in 0.10 M sodium perchlorate. This percentage represents a lower limit since it has not been determined if the common-ion rate depression observed for **3a** corresponds to a minimum value.

(13) (a) P. J. Stang, Z. Rappoport, M. Hanack, and L. R. Subramanian, "Vinyl Cations", Academic Press, New York, 1979; (b) S. Winstein, E. Clippinger, A. H. Fainberg, R. Heck, and G. C. Robinson, *J. Am. Chem. Soc.*, 78, 328 (1956); (c) S. Winstein, B. Appel, R. Baker, and A. Diaz, *Chem. Soc., Spec. Publ.*, No. 19, 109 (1965).

(14) J. Cronin, A. F. Hegarty, P. A. Casbell, and F. L. Scott, *J. Chem. Soc., Perkin Trans. 2*, 1708 (1973).

(15) A. F. Hegarty, J. O'Driscoll, J. K. O'Halloran, and F. L. Scott, *J. Chem. Soc., Perkin Trans. 2*, 1887 (1972).

(16) J. Donovan, J. Cronin, F. L. Scott, and A. F. Hegarty, *J. Chem. Soc., Perkin Trans. 2*, 1050 (1972).

(17) F. L. Scott, M. Cashman, and A. F. Hegarty, *J. Chem. Soc. B*, 1607 (1971).

(18) See, however, ref 6 where Ta-Shma and Rappoport calculated a ρ value of –1.2 from a Hammett plot with σ^+ for the hydrolysis of *N*-phenylbenzimidoyl chlorides using the data of Ugi and Beck (ref 3).

(19) L. P. Hammett, "Physical Organic Chemistry", 2nd ed., McGraw-Hill, New York, 1970, pp 357–358, 362–363.

Table III. Activation Parameters for Hydrolysis of *O*-Methylbenzohydroximoyl Halides

compd	$\Delta G^{\ddagger}$, kcal/mol (120 °C)	$\Delta H^{\ddagger}$, kcal/mol	$\Delta S^{\ddagger}$, eu
2	35.7	39	+8
3a	30.9		
3e	27.7	31	+8
3g	28.8	28	+1

were apparently omitted from the correlation so as to avoid this "complication". For purposes of comparison to previous work the ρ value calculated for the hydroximoyl chloride (**3a**–**f**, omitting **3e**) hydrolysis reactions with σ is -2.60 ($r = 0.990$). Hegarty and co-workers[4] found the ρ value for substituted phenyl attached to nitrogen ($\rho = -3.0$) in imidoyl chlorides to be substantially larger than the ρ value for substituted phenyl attached to carbon ($\rho \leq -2.0$). They attributed this difference to the greater importance of the octet-stabilized resonance structure **1b** vs. the nonoctet resonance structure **1a** of the nitrilium ion.

It is noteworthy that *O*-methylbenzohydroximoyl halides are quite resistant to nitrilium ion formation when compared to imidoyl halides and hydrazonoyl halides. Imidoyl halides and hydrazonoyl halides undergo relatively rapid hydrolysis at room temperature,[3,4] whereas the hydrolysis of hydroximoyl halides requires temperatures of 120 °C or more in order to obtain conveniently measured hydrolysis rates. It is likely that this low reactivity is due to a destabilization of the nitrilium ion by the electronegative methoxy group attached to nitrogen. Furthermore, it would be expected that the relative importance of resonance structure **5b** would be decreased with respect to **5a** by the inductive effect of the *N*-methoxy group. The increased importance of **5a** vs. **5b** would account for the rather high ρ value observed for the hydroximoyl chloride hydrolysis reactions as compared to imidoyl chlorides.

Finally, there was no significant change in first-order rate constants of **3a** with change in pH (Table I), which demonstrates that the hydrolysis is neither base nor acid catalyzed.

Since the formation of nitrilium ions as intermediates in these reactions has been established, the matter of the stereochemical requirement for nitrilium ion formation may be considered. It was found that the (*Z*)-hydroximoyl chloride reacted about 470 times faster than the *E* isomer. This rate difference is particularly significant when it is compared to the nearly identical bimolecular reaction rates of **3a** and **2** with methoxide ion.[7] It is conceivable, however, that most of the difference in activation energy ($\Delta\Delta G^{\ddagger} = 5$ kcal/mol, Table III) between the hydrolysis reactions of the (*Z*)- and (*E*)-hydroximoyl chlorides is due to a stability difference between the geometric isomers, with the *E* isomer being more stable than the *Z* isomer, rather than a difference in the energies of the transition states for nitrilium ion formation. This possibility is eliminated because, as we have reported earlier,[8,9] the *E* isomer undergoes acid-catalyzed isomerization to the more stable *Z* isomer. In this work it has been determined that the equilibrium concentrations of the *Z* and *E* isomers (**3a** and **2**) in a 0.2 M hydrochloric acid 3:1 (v/v) dioxane–water solution are about 99.5% *Z* to 0.5% *E* at 39.5 °C, which corresponds to a free-energy difference of ca. 3 kcal/mol between the two isomers. Thus, there is a free-energy difference of about 8 kcal/mol between the two transition states for nitrilium ion formation (Figure 2). We conclude, therefore, that there is a strong preference in the ionization process for the nitrogen lone pair to be trans to the leaving group. The stereoelectronic control[20,21] observed in this work is analogous to that found in the alkoxide-induced dehydrohalogenations of vinyl halides which proceed through vinyl carbanions ($E_{C=C}1cB$).[22,23] Vinyl carbanions are isoelectronic with imines and also show a preference for loss of halide ion trans to the unbonded electron pair.

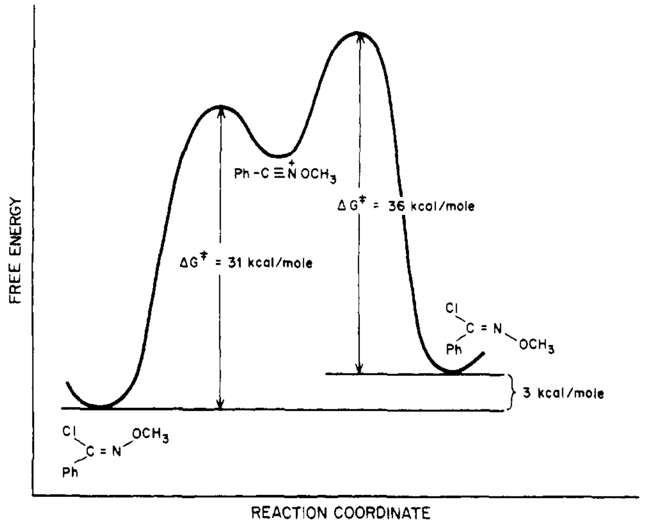
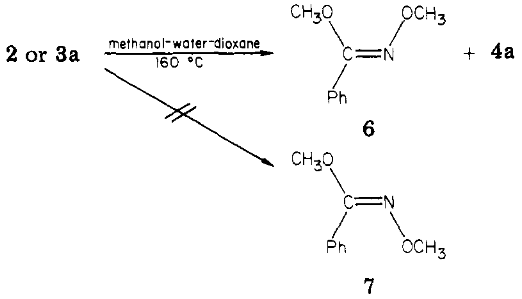


Figure 2. Free-energy profile for ionization of (*Z*)- and (*E*)-*O*-methylbenzohydroximoyl chlorides (**3a** and **2**) at 120 °C.

Scheme IV



On the basis of our observations, the principle of microscopic reversibility would require the addition of chloride ion to the nitrilium ion **5** to give predominately the *Z* isomer (**3a**). It would be expected that common-ion rate depression should be observed for the *Z*-hydroximoyl chloride (**3a**) if the hydrolysis produces a free nitrilium ion. The hydrolysis of the *E* chloride (**2**), however, should not show appreciable common-ion rate depression since return of chloride ion would give exclusively the *Z* chloride (**3a**) which hydrolyzes much faster than the *E* isomer (**2**); i.e., $k_1 \gg k'_1$ and $k_{-1} \gg k'_{-1}$ in Scheme III. Although we have no explanation to offer for the rather substantial rate depression (a 1.8-fold decrease) observed for the *E* chloride, a similar phenomenon has been reported by Rappoport and Atidia[24] in the acetolysis of *cis*- and *trans*-α-bromo-4,4′-dimethoxystilbenes. Since the principle of microscopic reversibility predicts that the nitrilium ion should react

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(20) P. Deslongchamps, *Heterocycles*, 7, 1271 (1977).

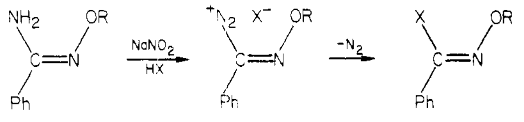
(21) The terminology "stereoelectronic control" has been used by Deslongchamps (ref 20) to describe selective elimination from tetrahedral intermediates when the leaving group is antiperiplanar to lone electron pairs on directly bonded heteroatoms. We have extended the usage of "stereoelectronic control" to include the increased rate of elimination by vinyl carbanions (ref 22 and 23) and imines (this work) when the lone electron pair is trans to the leaving group.

(22) (a) S. I. Miller and R. M. Noyes, *J. Am. Chem. Soc.*, 74, 629 (1952); (b) S. I. Miller and W. G. Lee, *ibid.*, 81, 6313 (1959).

(23) W. H. Saunders and A. F. Cockerill, "Mechanisms of Elimination Reactions", Wiley-Interscience, New York, 1973.

(24) (a) Z. Rappoport and M. Atidia, *Tetrahedron Lett.*, 4085 (1970); (b) *J. Chem. Soc., Perkin Trans. 2*, 2316 (1972).

Scheme V



8a, R = n-C_3H_7
b, R = CH_3
c, R = C_2H_5

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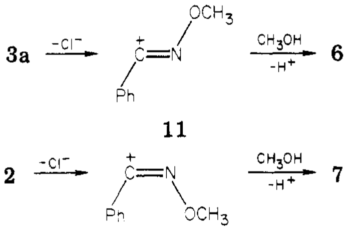
10a, R = n-C_3H_7; $X = O\overset{\overset{O}{\|}}{C}CH_3$
b, R = n-C_3H_7; X = Cl
c, R = C_2H_5; X = Cl
d, R = C_2H_5; X = Br

Scheme VI



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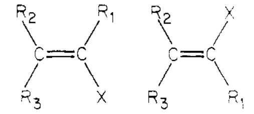
with chloride ion to give the Z chloride, it would be reasonable to expect that other nucleophiles would react with the nitrilium ion in a similar fashion. In order to test this proposal, the methanolysis of (Z)- and (E)-O-methylbenzohydroximoyl chlorides was investigated. It was found that both the (E)- and (Z)-hydroximoyl chlorides gave the same addition product, methyl (Z)-O-methylbenzohydroximate (**6**), which corresponds to trans addition to the nitrilium ion (Scheme IV). The E isomer of methyl O-methylbenzohydroximate (**7**) was found not to rearrange to **6** under the solvolysis reaction conditions.

These results are in agreement with the work of Hegarty and co-workers who have investigated the stereochemistry of nucleophilic addition to N-anilino- and N-alkoxynitrilium ions[25,26] and the structurally related nitrile oxides.[27,28] In the case of the N-alkoxynitrilium ion,[26] which was generated by nitrosative deamination of the amidoxime **8a** (Scheme V), an alternative mechanism was suggested for the stereospecific formation of **10a** and **10b**. This alternative involves attack by the nucleophile on a nonlinear nitrilium ion before it reaches its normal equilibrium state. A nonlinear nitrilium ion could not be eliminated as an intermediate because the configuration of the diazonium ion **9** is not known and amidoximes with structure **8** are configurationally unstable and exist only in the thermodynamically more stable E configuration.

It is possible that a nonlinear nitrilium ion (which in this case would be more properly called a azovinyl carbocation) could correspond to the equilibrium state if resonance stabilization by the nitrogen lone pair (resonance structure **5b**) were diminished and the main contribution to the resonance hybrid were from **5a**. In this case, however, assistance by the nitrogen lone pair in the ionization process should be insignificant, and the (Z)- and (E)-hydroximoyl chlorides (**3a** and **2**) should hydrolyze at similar rates. Furthermore, the ionization of **3a** and **2** should give two different nonlinear nitrilium ions (Scheme VI). It would be expected that nucleophilic attack by methanol on nitrilium ion **11** would give the (Z)-hydroximate (**6**), whereas **12** would give the (E)-hydroximate (**7**). The fact that the (Z)- and (E)-hydroximoyl chlorides ionize at much different rates, but give the same methanolysis product, indicates that a common intermediate, a linear nitrilium ion, is formed in these reactions. Although the results of the methanolysis experiments could be rationalized in terms of rapidly equilibrating bent ions (**11** ⇄ **12**), we argue that the initially formed ion must be linear in order for the nitrogen lone pair to have assisted in the ionization. Furthermore, if the initially formed ion is linear, it seems reasonable to assume the equilibrium state is a resonance-stabilized linear nitrilium ion and it is this ion, not a pair of rapidly equilibrating bent ions, that undergoes reaction with methanol.

It is interesting to compare the results obtained for the solvolysis of hydroximoyl halides with the observations made on the generation of vinyl cations through solvolysis of vinyl substrates.[13a] Differences in rates between E and Z isomers have been observed in the solvolysis of vinyl halides[29] but they are small (k_E/k_Z for **13a**/**14a** = 10.3) in comparison to hydroximoyl chlorides (k_Z/k_E for **3a**/**2** = 466). The higher solvolysis rate for the E vinyl iodide **13a** was explained by the greater relief of strain in the E isomer as the C-1 carbon undergoes a change in hybridization from sp^2 to sp during ionization. In the solvolysis of α-alkyl-substituted vinyl compounds (such as **13b** and **14b**) the E and Z isomers give different product distributions with an excess of inversion.[30,31] The inversion component in these reactions has been attributed to ion pairing which shields the side of the ion that is closest to the leaving group. In the solvolysis of α-aryl-substituted vinyl compounds[24,32] the E and Z isomers (**13c** and **14c**, for example) give the same E/Z product mixture, indicating the formation of a free vinyl cation which is either a linear ion or a pair of rapidly interconverting bent ions. The methanolysis of (E)- and (Z)-hydroximoyl chlorides **2** and **3a** is similar to the solvolysis of α-aryl vinyl compounds, with the exception that the nitrilium ion **5** reacts with methanol to give only one product, the (Z)-hydroximate (**6**).



13 **14**

a, X = I; R_1 = cyclopropyl; $R_2 = CH_3$; R_3 = H
b, $X = OSO_2CF_3$; $R_1 = R_2 = CH_3$; R_3 = H
c, X = Br; $R_1 = R_2$ = anisyl; $R_3 = C_6H_5$

In work similar to Hegarty's,[26] we have reinvestigated the nitrosative deamination of O-methylbenzamidoxime (**8b**) in the presence of chloride or bromide ion (Scheme V, X = Cl or Br). Nitrosative deaminations of **8b** and **8c** were reported in the early literature[33] to give the hy-

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[25] M. T. McCormack and A. F. Hegarty, *J. Chem. Soc., Perkin Trans. 2*, 1701 (1976).

[26] D. G. McCarthy and A. F. Hegarty, *J. Chem. Soc., Perkin Trans. 2*, 1080 (1977).

[27] K. J. Dignam, A. F. Hegarty, and P. L. Quain, *J. Chem. Soc., Perkin Trans. 2*, 1457 (1977).

[28] K. J. Dignam, A. F. Hegarty, and P. L. Quain, *J. Org. Chem.*, **43**, 388 (1978).

[29] D. R. Kelsey and R. G. Bergman, *J. Am. Chem. Soc.*, **93**, 1941 (1971).

[30] (a) R. H. Summerville and P. von R. Schleyer, *J. Am. Chem. Soc.*, **94**, 3629 (1972); (b) R. H. Summerville, C. A. Senkler, P. von R. Schleyer, T. E. Dueber, and P. J. Stang, *ibid.*, **96**, 1100 (1974); (c) R. H. Summerville and P. von R. Schleyer, *ibid.*, **96**, 1110 (1974).

[31] (a) T. C. Clarke, D. R. Kelsey, and R. G. Bergman, *J. Am. Chem. Soc.*, **94**, 3626 (1972); (b) T. C. Clarke and R. G. Bergman, *ibid.*, **94**, 3627 (1972).

[32] (a) Z. Rappoport, I. Schnabel, and P. Greenzaid, *J. Am. Chem. Soc.*, **98**, 7726 (1976); (b) Z. Rappoport and Y. Apeloig, *ibid.*, **97**, 836 (1975); (c) *ibid.*, **91**, 6734 (1969).

[33] F. Tieman and P. Kruger, *Chem. Ber.*, **17**, 1685 (1884); *ibid.*, **18**, 727 (1885); P. Kruger, *ibid.*, **18**, 1053 (1885); F. Tieman, *ibid.*, **24**, 3453 (1891).

droximoyl halides **3a**, **10c**, and **10d**, but the configurations of these products were not known and yields were not given. We have found that the deamination of **8b** in the presence of chloride ion gives a good yield (88%) of **3a**. The formation of **3a** is kinetically controlled since the *E* isomer (**2**) did not undergo isomerization when subjected to the deamination reaction conditions.[34] The deamination of **8b** in the presence of bromide ion gave a 51% yield of **3g** and is an improved method of preparation of this compound.[8]

In conclusion, the formation of linear nitrilium ions in the hydrolysis of *O*-methylbenzohydroximoyl halides has been established. Nitrilium ion formation is strongly favored when the nitrogen lone pair and the leaving group are trans to each other. It has been further demonstrated that the addition of nucleophiles to nitrilium ions proceeds so that the incoming nucleophile and the nitrogen lone pair are trans to each other.

Experimental Section

Materials. All inorganic chemicals were reagent grade. The dioxane was obtained from Burdick and Jackson (distilled in glass) and was used without further purification. The water used in this study was deionized and then distilled. The hydroximoyl chlorides **2** and **3a–f** were prepared according to published procedures.[8] The liquid hydroximoyl halides **2**, **3a–c**, and **3g** were purified by preparative gas–liquid chromatography followed by micromolecular distillation and the solids **3d–f** were purified by repetitive recrystallization.

Hydrolysis Product Analysis. The hydrolysis reaction products of the benzohydroximoyl halides were analyzed with a Model ALC-202 Waters Associates high-pressure liquid chromatograph fitted with an ultraviolet absorption detector. The analyses were carried out on a Waters Associates μ-Bondapack C18 column with a 7:3 (v/v) methanol–water solution as the mobile phase. In all cases studied, the hydrolysis products from the benzohydroximoyl halides were determined to be the corresponding methyl benzohydroxamates by comparison of high-pressure LC retention times with authentic samples.[8]

Kinetic Method. The solvent mixtures of 3:1 dioxane–water (v/v) were made up at room temperature. The solutions were buffered to pH 7, using 0.01 M potassium dihydrogen phosphate and 0.01 M sodium hydroxide and a constant ionic strength was maintained by the addition of sodium perchlorate (0.10 M). Solutions of the hydroximoyl halides were placed in tubes made from 5-mm o.d. Pyrex glass tubing and degassed on a vacuum line at $<10^{-3}$ torr by the freeze–thaw method. After three freeze–thaw cycles, the tubes were sealed and suspended in a constant-temperature bath (±0.1 °C). At least five samples were prepared for each kinetic run, and the hydrolysis reactions were followed to at least 60% of completion. The tubes were removed from the constant-temperature bath and immediately chilled in an ice bath. The samples were analyzed by measuring the high-pressure LC peak area ratios of the hydroximoyl halides and methyl hydroxamates. Normalization factors for the peak areas were determined by running samples containing known amounts of reactants and products. The rate constants and Hammett ρ values were calculated by the method of least-squares and the error limits were calculated at the 95% confidence level. Each rate constant in Tables I and II represents an average of at least two rate determinations and the reported error corresponds to the largest error limit in the averaged rate constants. The averaged rate constants differed from each other by no more than the largest error limit.

Methanolysis of (*Z*)-*O*-Methylbenzohydroximoyl Chloride (3a). The methanolysis of **3a** was carried out in a degassed 2:1:1 methanol–dioxane–water (v/v/v) solution at 160 °C. The solution was buffered to pH 7, using 0.01 M phosphate buffer. The methanolysis product was determined to be methyl (*Z*)-*O*-methylbenzohydroximate (**6**) by comparison of high-pressure LC retention times with authentic samples.[7,8] The methanolysis of **2** was carried out under identical reaction conditions. Both reactions were slow and were followed to about 10% of completion (which took 30 h in the case of the *E*-hydroximoyl chloride, **2**).

***O*-Methylbenzamidoxime (8b).** Dimethyl sulfate (12.7 g, 100 mmol) was added dropwise to a cold (0 °C) stirred solution of benzamidoxime[25] (12.9 g, 94.7 mmol) in a 0.70 N solution of sodium hydroxide (153 mL, 107 mmol). After the addition was completed, the reaction mixture was stirred and kept cold for 6 h. The **8b** which crystallized from the mixture was filtered and the aqueous solution was extracted with ether (4 × 50 mL). The ether extracts were dried over magnesium sulfate and evaporated to yield an oil which crystallized on cooling. The crystals were combined and recrystallized from ether–petroleum ether (bp 30–60 °C) to yield 11.5 g (81%) of **8b**: mp 54–55 °C (lit.[33] mp 57 °C); IR (Nujol) 3470, 3350, 1650 cm^{-1}; NMR ($CDCl_3$) δ 3.80 (s, 3, CH_3), 4.6 (br s, 2, NH_2), 7.2–7.7 (m, 5, aromatic H).

(*Z*)-*O*-Methylbenzohydroximoyl Chloride (3a). Nitrosative Deamination of 8b in Hydrochloric Acid. *O*-Methylbenzamidoxime (**8b**) was deaminated according to the procedure of Tieman and Kruger.[33] A solution of sodium nitrite (2.07 g, 30.0 mmol) in water (20 mL) was slowly added to a cold (0 °C) solution of **8b** (3.00 g, 20.0 mmol) in 2.0 N hydrochloric acid (24 mL, 48 mmol). The mixture was stirred and kept cool for about 30 min during which time an insoluble oil formed. The mixture was extracted several times with ether and the ether extracts were dried over magnesium sulfate. Evaporation of the ether produced a yellow oil which was distilled to give a colorless oil (2.98 g, 88%), bp 53–54 °C (0.1 torr). The NMR spectrum of this oil was identical with the NMR spectrum of an authentic sample of **3a** which had been prepared by the reaction of phosphorus pentachloride with methyl benzohydroxamate (**4a**).[8]

(*Z*)-*O*-Methylbenzohydroximoyl Bromide (3g). Nitrosative Deamination of 8b in Hydrobromic Acid. The deamination of **8b** (3.00 g) was carried out by the procedure described in the preceding experiment except that **8b** was dissolved in 2.0 N hydrobromic acid (25 mL, 50 mmol). The oil left after evaporation of the ether extracts was distilled to give a colorless oil (2.18 g, 51%), bp 65–66 °C (0.1 torr). The NMR spectrum of this oil was identical with the NMR spectrum of **3g** which had been prepared by the reaction of phosphorus tribromide with **4a**.[8]

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Registry No. **2**, 41071-34-5; **3a**, 41071-35-6; **3b**, 57139-33-0; **3c**, 57139-35-2; **3d**, 57139-34-1; **3e**, 57139-36-3; **3f**, 41071-37-8; **3g**, 57139-40-9; **6**, 41071-39-0; **8b**, 4424-16-2; benzamidoxime, 613-92-3.

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(34) The rearrangement of **2** to **3a** probably does not occur under the deamination reaction conditions because **2** (and **3a**) is insoluble in the reaction medium.