

Chemical Ionization Mass Spectrometry. XIV. Temperature Studies of Substituted 3-Methoxyphthalides

DANIEL P. WEEKS* AND F. H. FIELD

*Department of Chemistry, Seton Hall University, South Orange, New Jersey 07079,
and The Rockefeller University, New York, New York 10021*

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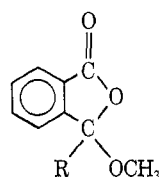
The temperature dependence of the methane chemical ionization mass spectra of six 3-methoxyphthalides substituted in the 3 position of the phthalide ring has been determined. The compounds studied are designated as 1-6 in the text. The major reactions occurring are loss of methanol from the protonated molecules or the loss of benzene and naphthalene from the phenyl- and α -naphthyl-substituted protonated molecules. Rate constants, activation enthalpies, and frequency factors are determined for the several decomposition reactions occurring. The rate constants for the loss of methanol decrease monotonically when the substituent on the 3 position is H, CH₃, C₂H₅, *i*-C₃H₇, and C₆H₅. The behavior of the α -naphthyl-substituted compound diverges from the trend. The results are basically in agreement with results previously reported in solution, and the gas-phase results are taken as a tentative corroboration of the postulate that in solution the acid-catalyzed decompositions of the several phthalides follow a unimolecular mechanism.

In the preceding¹ and subsequent papers² one of us (D. P. W.) reports the results of studies on the acid-catalyzed hydrolysis of 3-methoxyphthalides substituted in either the 3 position or in the 6 position of the phthalide ring. We report in this paper the results of a parallel chemical ionization study of a series of 3-methoxyphthalides substituted in the 3 position (1-6). The study was undertaken in the hope that the

ionization temperature studies to elucidate the physical organic chemistry of gaseous ionic systems.

Results

The mass spectra at three values of the ion source temperature for 3-ethyl-3-methoxyphthalide (3) using methane as reactant gas are given in Table I. Anal-



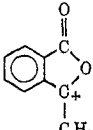
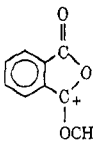
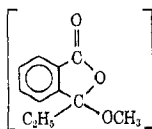
- 1, R = H 4, R = *i*-C₃H₇
 2, R = CH₃ 5, R = C₆H₅
 3, R = C₂H₅ 6, R = α -naphthyl

comparison of results obtained in gas phase and solution will serve the function of providing further knowledge about the factors influencing the gas-phase behavior and at the same time provide support for postulates made about the solution behavior.

In solution the rates of the acid-catalyzed aqueous solvolysis of compounds 1-4 decrease monotonically in the order H > CH₃ > C₂H₅ > *i*-C₃H₇. The rates for R = C₆H₅ and α -naphthyl are about equal to each other and in turn about equal to the rate for R = ethyl. It is postulated¹ that the solvolyses occur by A1 mechanisms and that the substituent effect results from the occurrence of a transition state hindered rotation which varies in amount with the physical size of the substituent. The exceptional behavior of the α -naphthyl substituted compound is attributed to the occurrence of hindered rotation in both the reactant and the transition state.

A general description of chemical ionization mass spectrometry has been written,³ and recent reports have appeared⁴⁻⁷ describing the use of chemical

TABLE I
CHEMICAL IONIZATION MASS SPECTRA OF
3-ETHYL-3-METHOXYPHthalIDE (3). CH₄ REACTANT^a

<i>m/e</i>	Ion	Rel intensity at		
		37°	124°	213°
105	PhC≡O ⁺	0.016	0.020	0.025
149	?	0.015	0.014	0.022
161		0.147	0.211	0.391
162	Isotope	0.016	0.031	0.045
163		0.026	0.030	0.043
193	 H ⁺	0.566	0.457	0.295
194	Isotope	0.081	0.068	0.043
221	(M + 29) ⁺	0.083	0.085	0.048
222	Isotope	0.018	0.021	0.011
233	(M + 41) ⁺	0.030	0.030	0.019

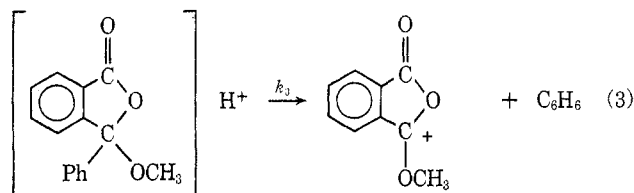
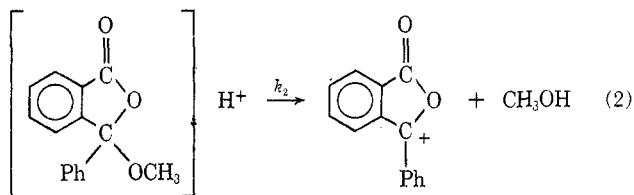
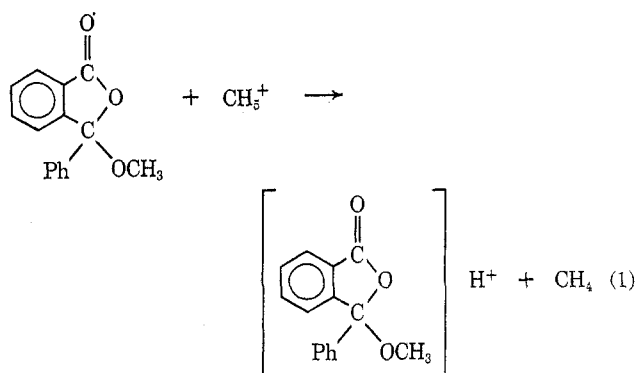
^a P_{CH₄} = 1.00 Torr. P_{phthalide} = 10⁻⁴ Torr. Mol wt, 192.

gous spectra are obtained when the substituent at the 3 position is H, CH₃, and *i*-C₃H₇. The spectra of 3-phenyl-3-methoxyphthalide at three temperatures using methane as reactant gas are given in Table II, and analogous spectra are obtained when the substituent at the 3 position is α -naphthyl. The most important difference between the two types of spectra is the fact that the phenyl and α -naphthyl substituted compounds lose the arene substituent from the 3 position to form the *m/e* 163 ion much more readily than the other

- (1) D. P. Weeks and J. P. Crane, *J. Org. Chem.*, **38**, 3375 (1973).
- (2) D. P. Weeks, J. Cella, and L. T. Chen, *J. Org. Chem.*, **38**, 3383 (1973).
- (3) F. H. Field, *Accounts Chem. Res.*, **1**, 42 (1968).
- (4) F. H. Field, *J. Amer. Chem. Soc.*, **91**, 2827 (1969).
- (5) F. H. Field, *J. Amer. Chem. Soc.*, **91**, 6334 (1969).
- (6) D. P. Weeks and F. H. Field, *J. Amer. Chem. Soc.*, **92**, 1600 (1970).
- (7) F. H. Field and D. P. Weeks, *J. Amer. Chem. Soc.*, **92**, 6521 (1970).

class of compounds loses alkyl or hydrogen to form m/e 163. For both types of compounds the $(M + 1)^+$ intensity is large at low temperatures and decreases as the temperature increases. On the other hand, the intensities of the ions formed by loss of methoxy (m/e 161 for 3, 209 for 5, and analogously for the other compounds) are relatively small at lower temperatures and increase as the temperature increases. For both types of compounds $(M + 29)^+$ and $(M + 41)^+$ ions are found, as is always the case with CH_4 chemical ionization, and in addition several other ions of small intensity appear in the spectra.

We envisage that the reactions occurring to produce the spectra involve the initial protonation of the molecule by a reactant ion from methane, and a certain fraction of these ions decompose to produce fragment ions. Thus, we write eq 1-3.

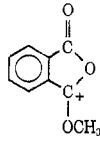
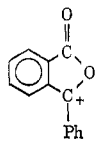
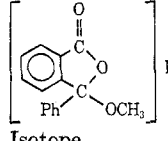


Note that, because these molecules contain several places at which a proton can be attached, we are of necessity quite noncommittal as to the actual point of attachment in eq 1-3. Obviously, however, the decomposition reactions 2 and 3 require that the proton be attached to (or migrate to) the methoxy and phenyl groups, respectively, at the time of the decompositions.

We have shown⁴ that values of the rate constants k_2 and k_3 can be calculated from the intensities of the reactant and product ions in reactions such as 2 and 3, that is, from the intensities of $(M + 1)^+$ and m/e 209 for reaction 2 and $(M + 1)^+$ and m/e 163 for reaction 3.

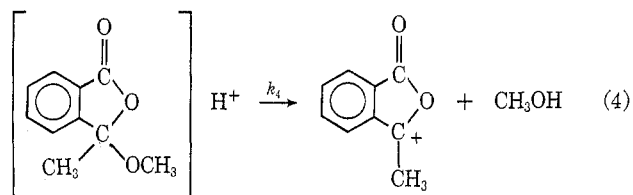
The values obtained for k_2 and k_3 depend upon temperature, and in fact the Arrhenius relationship is obeyed. This is the consequence of the fact that in the chemical ionization mass spectrometer the source pressure is high enough and sufficient collisions occur that the ion decomposition reactions such as 2 and 3 are thermally activated. The Arrhenius plot for the

TABLE II
CHEMICAL IONIZATION MASS SPECTRA OF
3-PHENYL-3-METHOXYPHthalIDE (5). CH_4 REACTANT^a

m/e	Ion	Rel intensity at		
		58°	127°	211°
105	$\text{PhC}\equiv\text{O}^+$	0.019	0.027	0.040
163		0.097	0.137	0.180
164	Isotope	0.015	0.015	0.020
196	?	0.015	0.020	0.018
197	?		0.016	0.016
209		0.099	0.130	0.180
210	Isotope	0.021	0.028	0.036
241		0.522	0.394	0.309
242	Isotope	0.091	0.075	0.055
263	$(M + 29)^+$	0.066	0.067	0.070
270	Isotope	0.016	0.019	0.013
281	$(M + 41)^+$	0.022	0.018	0.016

^a $P_{\text{CH}_4} = 1.00$ Torr. $P_{\text{phthalide}} \cong 10^{-4}$ Torr. Mol wt, 240.

loss of methanol from protonated 3-methyl-3-methoxyphthalide, *i.e.*, eq 4, is given as a typical example



in Figure 1. Activation enthalpies, frequency factors, and rate constants at 300° K for the reactions analogous to 2-4 which have been studied are given in Table III. For comparison we also include in Table III the rate constants at 298° K, activation enthalpies, and activation entropies for the analogous acid-catalyzed solvolysis reactions studied by Weeks and Crane.¹

Discussion

Of the three kinetic quantities given in Table III for the gas-phase reactions, the values of k_{300} are obtained by the most straightforward experimental measurements and are probably the most accurate and meaningful quantities. From Table III one observes that the k_{300} values for reactions involving compounds with $\text{R} = \text{H}, \text{CH}_3, \text{C}_2\text{H}_5,$ and $i\text{-C}_3\text{H}_7$ undergo a monotonic decrease from $1.20 \times 10^5 \text{ sec}^{-1}$ to $0.35 \times 10^5 \text{ sec}^{-1}$. The differences between adjacent values are small, but from an examination of the experimental data we are of the opinion that the differences are real. The rate constants for the acid-catalyzed aqueous solvolyses for these four compounds also diminish monotonically, although the magnitude of the change is much greater in the condensed-phase results than in the gas-phase results. If one carries the comparison

TABLE III
 RATE QUANTITIES BY CHEMICAL IONIZATION^a AND AQUEOUS SOLVOLYSIS^b

R	H	CH ₃	C ₂ H ₅	<i>i</i> -C ₃ H ₇	C ₆ H ₅	α -C ₁₀ H ₇
k_{300} , sec ⁻¹	1.20×10^6	0.66×10^6	0.44×10^6	0.35×10^6	0.26×10^6	0.44×10^6
ΔH^\ddagger , kcal/mol	3.5	3.8	3.2	2.8	2.9	2.3
A , sec ⁻¹	4.2×10^7	4.1×10^7	1.0×10^7	0.37×10^7	0.33×10^7	0.20×10^7

R	H	CH ₃	C ₂ H ₅	<i>i</i> -C ₃ H ₇	C ₆ H ₅	α -C ₁₀ H ₇
k_{298} , sec ⁻¹	153×10^{-4}	2.88×10^{-4}	0.65×10^{-4}	0.0116×10^{-4}	0.67×10^{-4}	0.446×10^{-4}
ΔH^\ddagger , kcal/mol	19.0	18.0	18.6	19.8	17.0	20.6
ΔS^\ddagger , cal/deg mol	-3.1	-14.4	-15.2	-19.2	-20.6	-9.2

R	Ph	α -C ₁₀ H ₇
k_{300} , sec ⁻¹		0.34×10^6
ΔH^\ddagger , kcal/mol		2.3
A , sec ⁻¹		0.16×10^7
		0.31×10^6
		2.5
		0.20×10^7

^a CH₄ reactant. $P_{\text{CH}_4} = 1.0$ Torr. ^b Reference 1.

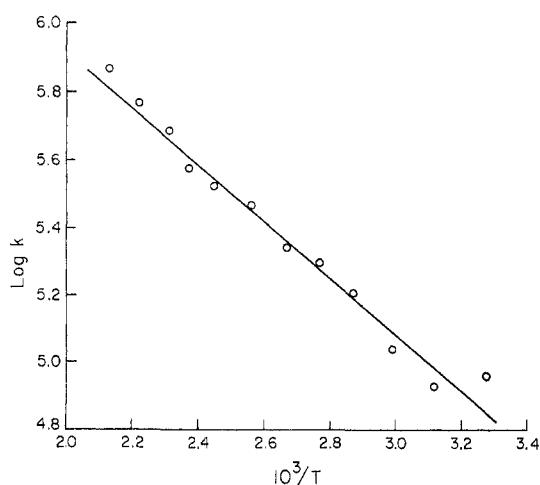


Figure 1.—Arrhenius plot for eq 4: CH₄ reactant, $P_{\text{CH}_4} = 1.00$ Torr.

between the gas-phase and solution results to the phenyl- and α -naphthyl-substituted compounds, one observes a divergence of behavior in that the decreasing trend is interrupted at the phenyl-substituted compound in solution but not at the α -naphthyl compound in the gas phase.

The A -factor values observed in the gas phase exhibit a monotonic decrease as the complexity of R increases, which is similar to the behavior observed in solution where ΔS^\ddagger becomes more negative in the series $R = \text{H}, \text{CH}_3, \text{C}_2\text{H}_5, i\text{-C}_3\text{H}_7, \text{and } \text{C}_6\text{H}_5$.

The amount of available information upon which one can base a judgment of the significance of the comparison found here between the gas-phase and solution results is very small. In total it consists of the previous findings from this laboratory that gas-phase and solution results agree well for the rates of decompositions of benzyl and *tert*-amyl acetate⁴ and for methoxymethyl acetate and formate⁶ but disagree for the decompositions of methylthiomethyl acetate and propionate.⁷ Thus, we are obliged to present the results of Table III without extensive comment. However, we think that the qualitative trends observed in the gas phase and in solution parallel each other to such an extent that the gas-phase results may be taken as a tentative corroboration of the postulates made¹ that the acid-catalyzed decompositions of the several phthalides follow a unimolecular mechanism. Beyond that, the rather small effect of the substituent upon the decomposition rates of the gas-phase reactions is surprising, but we can offer no explanation for the phenomenon. More systems must be studied to provide an understanding of the matter.

Experimental Section

The instrumentation and procedures of chemical ionization mass spectrometry have been described elsewhere.^{3,4}

The preparation of the compounds used in this study has been described by Weeks and Crane.¹

Registry No.—1, 4122-57-0; 2, 1077-59-4; 3, 40893-27-4; 4, 40893-28-5; 5, 7335-63-9; 6, 40893-29-6.