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THE ACID-CATALYZED HYDROLYSIS OF PHOSPHINATES. II.
THE MECHANISM OF HYDROLYSIS OF METHYL DIALKYLPHOSPHINATES.

Khamis A. Abbas[1] and Robert D. Cook*

Department of Chemistry, American University of Beirut, Beirut, Lebanon.

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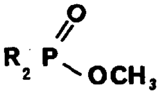
In an earlier communication[2] relative rate data and activation parameters for the hydrolysis of methyl dimethyl-(I), diethyl-(II), and diisopropylphosphinates (III) in D_2SO_4-D_2O have been reported. Bunnett, Edwards et al.[3] have also reported data on the hydrolysis of methyl methylarylphosphinates in perchloric acid solution. Both papers suggested an A-2 mechanism for the hydrolysis and suggested that attack of water most likely takes place on phosphorus, although no evidence was presented to support this conclusion. We have now finished our study of the hydrolysis[4] of compounds I-IV, and we offer evidence that the most probable mechanism for hydrolysis of these methyl esters is an $A_{al}2$ mechanism (i.e., attack of water on carbon and not on phosphorus).



I R = CH_3-; II R = CH_3CH_2-

III R = $(CH_3)_2CH$-; IV R = $(CH_3)_3C$-

The pH-rate profiles for all four esters (Figure I) are bell-shaped, which in itself is an indication that water is involved in the rate-determining step. The rate data was treated using the Bunnett[5] w and w* approaches, as well as the Bunnett-Olsen[6] ϕ and Yates r-value methods for determining the part water plays, if any, in the reaction. The results of these treatments, as well as the pKa's of the substrates and the entropies of activation of the reaction, are given in Table I.

The equations used for w, w*, ϕ_r and r are the appropriate equations for the conditions of the reaction, where the substrate is appreciably protonated. The results indicate that indeed water is involved in the reaction, either as a nucleophile or as a nucleophile and proton transfer agent. The w, ϕ_r and r values indicate that the more highly solvated the ester (smaller M-value[9]), the less water is needed in the rate-determining step. The entropies of activation also support an A-2 mechanism[8].

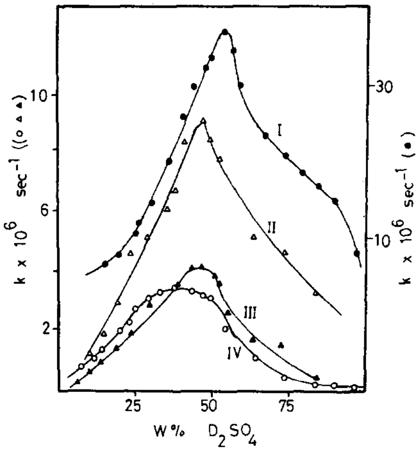


Figure I. pH-rate profiles for compounds I-IV.

The suggestion that attack of water takes place on carbon is strongly supported by the relative rate data in Table II. The alkaline hydrolysis of phosphinates[10] is extremely sensitive to the substituent on phosphorus, as one would expect for attack on tetrahedral phosphorus. However, the acid-catalyzed hydrolysis of phosphinates is relatively insensitive to the substituent on phosphorus; even less sensitive to substituent then the attack of hydroxide[11] or water[12] on trigonal carbon. These results strongly suggest an $A_{al}2$ mechanism for the phosphinate esters. This conclusion is also supported by the results on the acid-catalyzed hydrolysis of phosphonates[13] and phosphates[14] where C-O bond cleavage has been observed.

Table I

Data From the Acid-Catalyzed Hydrolysis of Methyl Dialkylphosphinates in D_2SO_4-D_2O at 75°C

Compound	w^a	w^{*a}	ϕ_r^{a}	r^a	$\Delta S^{\ddagger b}$	pKa^c	M^c
I	2.28	-0.94	0.09	0.31	-18±3	-3.14	0.49
II	3.00	-0.18	0.32	0.99	-24±3	-3.56	0.51
III	3.19	-0.04	0.35	1.12	-20±3	-3.29	0.51
IV	3.52	-0.17	0.56	1.99	-19±3	-3.11	0.62

[a] Values taken from the plot[15] of the kinetic data in the acidity range of 25-55 weight-percent D_2SO_4.

[b] From the acid strength where the esters are half-protonated and the values are for 75°C.

[c] Obtained from the least squares analysis of a plot of log SD^+/S versus D_o, where the slope = M and intercept = MpKa. The value M represents the deviation of the substrate from Hammett basicity; reference 9.

Table II

Relative Rates of Ester Hydrolysis

Reaction	R = Methyl	Ethyl	Isopropyl	tert-Butyl
$R_2POOCH_3 + D^{+a}$	3.6	1.5	0.8	1
$R_2POOCH_3 + D^{+b}$	11	2.7	1.3	1
$R_2POOCH_3 + D^{+c}$	11	2.5	1.2	1
$R_2POOCH_3 + D^{+d}$	40	9	3	1
$R_2PCOCH_3 + {}^-OH^e$	1700	33	1	
$RCOOC_2H_5 + {}^-OH^f$	95	45	10	1
$RCOOH + H^{+g}$	40	33	11	1

[a] This work; $D_o = -1$; T = 75°C; the k_{obs} for $((CH_3)_3C)_2PO_2CH_3 = 1.86 \times 10^{-6}$.

[b] This work; the relative k_{max} at 75°C; the k_{obs} for $((CH_3)_3C)_2PO_2CH_3 = 3.41 \times 10^{-6}$.

[c] This work; D_o = pKa, at 75°C; the k_{obs} for $((CH_3)_3C)_2PO_2CH_3 = 3.05 \times 10^{-6}$.

[d] This work; $D_o = -5.8$ at 75°C; the k_{obs} for $((CH_3)_3C)_2PO_2CH_3 = 5.5 \times 10^{-7}$.

[e] 60% Dimethoxyethane-water at 75°C; reference 10.

[f] 88% Ethanol at 30°C; reference 11.

[g] Esterification by C_2H_5OH in HCl at 14.3°C; reference 12.

References

1. Taken in part from the Ph.D. dissertation of K.A. Abbas. The research was supported by funds from the Arts and Sciences Research Committee of the American University of Beirut.

2. R.D. Cook and K.A. Abbas, Tetrahedron Letters, 519 (1973).

3. J.F. Bunnett, J.O. Edwards, D.V. Wells, H.J. Brass and R. Curci, J. Org. Chem., 38, 2703 (1973).

4. The rates of reaction were studied in D_2SO_4-D_2O solution and were followed by n.m.r. The methyl group of the ester and the product, methanol, are separated by approximately 20 Hz. The ratios of unhydrolyzed ester to hydrolyzed ester were determined by multiple integration (10-16 times). All correlations were done using D_o values (E. Hogfeldt and J. Bigeleisen, J. Amer. Chem. Soc., 82, 15 (1960) and J. Sierra, M. Ojeda and P.A.H. Wyatt, J. Chem. Soc. B, 1570 (1970)), and the values are corrected for temperature (P. Tickle, A.G. Briggs and J.M. Wilson, ibid. B, 65 (1970)). The activity of water values are those for deuterium oxide at 20°C (J. Bus, H, Steinberg and Th. J. DeBoer, Rec. Trav. Chim., 87, 609 (1968)).

5. J.F. Bunnett, J. Amer. Chem. Soc., 83, 4956, 4968, 4973, 4978 (1961).

6. J.F. Bunnett and F.P. Olsen, Canad. J. Chem., 44, 1917 (1966).

7. K. Yates, Acc. Chem. Res., 4, 136 (1971).

8. L.L. Schaleger and F.A. Long, Advan. Phys. Org. Chem., 1, 1 (1963).

9. P. Haake, R.D. Cook and G.H. Hurst, J. Amer. Chem. Soc., 89, 2650 (1967).

10. R.D. Cook, C.E. Diebert, W. Schwarz, P.C. Turley and P. Haake, ibid., 95, 8088 (1973).

11. C.K. Ingold, Structure and Mechanism in Inorganic Chemistry, 2nd Edition, Cornell University Press, Ithaca, (1969) p. 1135.

12. Reference 11, p. 1158.

13. P.W.C. Barnard, C.A. Burton, D.R. Llewellyn, C.A. Vernon and V.A. Welch, J. Chem. Soc., 2670 (1961).

14. L. Keay, Canad. J. Chem., 43, 2637 (1965).

15. The correlation coefficients of the plots for w, ϕ_r and r were generally quite good, i.e., above 0.95, with seven of the plots above 0.99. However the correlation coefficients for w* were generally poor, except for ester I where it was 0.995. It is not unexpected to have poor correlation coefficients for lines the slopes of which are very small.