calculated ρ^0(or ρ^n)-values by assuming that for certain substituents σ^0 (or ρ^n) was equivalent to the normal Hammett σ. Then knowing ρ^0 or ρ^n for a particular reaction they were able to calculate σ^0- or σ^n-values for other substituents. Finally, best values were obtained by statistical averaging. Taft was very careful in his choice of reactions, to avoid resonance complications, and used only data pertaining to compounds which had at least one insulating methylene group between the reaction center and the ring. Also, in setting up his master ρ^0-values he very wisely used data from *meta*-substituted compounds only. Wepster, however, was not so cautious. In many of his "resonance free" reaction series, the reaction center was in direct conjugation with the ring, and he also used some data from *para*-substituted compounds (especially for the groups p-NO_2 and p-COMe) in setting up his master ρ-values. Taft found these two substituents to require two σ^0-values, one for hydroxylic and one for nonhydroxylic solvents. Wepster did, in fact, find that second-order resonance effects ("saturation" effects) were operating in some of his reaction series, particularly those involving anilinium ion formation, and he does say that the best σ^n-values would probably be obtained from systems with an insulating bridge between benzene ring and reaction center. In his reference 17 he actually gives modified σ^n-values for the groups p-F, p-Cl, and p-Br which are almost identical with Taft's σ^0-values.

As the Taft approach appears to be sounder theoretically and his σ^0-values for nonhydroxylic solvents correlate well with experimental results obtained in the vapor phase, we conclude that these values give a good quantitative measure of the relative polar effects of *meta*- and *para*-substituted phenyl groups.

Some compounds were studied in the present work and in the pyrolysis of ethyl aryl carbonates (paper IX), for which σ^0-values were not previously available. It was possible to assign the following σ^0-values by substitution in the equation $\log k/k_0 = \rho\sigma^0$ [14]: p-Ph, +0.08; p-t-Bu, −0.18; 3,4-C_4H_4(β-naphthyl), +0.15.

It should be added that Norman and co-workers[15] recently made an almost duplicate approach to the problem using much of the same reaction rate and equilibrium data as did Taft. Their handling of this data was slightly different though, and, like Wepster, they did not notice any solvent effects. The Norman values, designated σ_G do not correlate the present data as well as do Taft's, the deviation being very marked in the case of m-NO_2. Interestingly, Norman and coworkers also drew attention to the danger of using the substituents p-NO_2 and p-COMe in setting up master ρ-values. They say this is likely to lead to anomalies because of second-order resonance effects.

In view of what has been said previously, it is a little surprising that the pyrolysis of alkyl benzoates proves to be a reaction which shows a resonance-free σ^0 correlation, as there is no insulating methylene bridge between reaction center and the ring, especially as the transition state involves a degree of charge separation formally similar to that in the benzoate anion. A similar anomaly is observed in the case of ion-pair formation between substituted benzoic acids and 1,3-biphenylguanidine in benzene solution.[4,16] Evidently the difference in resonance stabilization between the ground state and the transition state (or between reactant and product in the cases of equilibria) only becomes important when the carboxylate anion is fully developed; with incipient species the "resonance effect" is apparently negligible.

Acknowledgment.—This work was supported in part by the United States Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command, under Grant No. AF-AFOSR 62-268. Acknowledgment is made also to the donors of the Petroleum Research Fund, administered by the American Chemical Society, and to the Utah State University Division of University Research for partial support of this research.

We are grateful to Mr. D. V. White and Mr. V. R. Rice for assistance with synthetic work.

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(14) σ^0 for p-Ph was obtained from phenyl ethyl carbonate data only; σ^0 for p-t-Bu and β-naphthyl were obtained by averaging the values from the two studies: G. G. Smith, D. A. K. Jones, and R. Taylor, Paper IX, *J. Org Chem.*, **28**, 3547 (1963).

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Another Example of the Novel Conversion of a Phosphonate to a Phosphate

B. H. ALEXANDER, L. S. HAFNER, M. V. GARRISON, AND J. E. BROWN

Walter Reed Army Institute of Research, Washington, D. C.[1a]

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Treatment of diethyl α-(N-alkylamino)benzylphosphonates with thionyl chloride, p-nitrophenol, and triethylamine causes conversion to the triethylamine salt of di-p-nitrophenyl hydrogen phosphate. The products of conversion were compared with compounds of known structure obtained by another preparation and found to be identical. New N-alkylaminophosphonourethans and α-N-alkylaminophosphonates are also reported.

As part of a continuous program looking toward the synthesis of a more specific organophosphorus enzyme inhibitors,[1b] a number of new phosphonate esters have been prepared (Table I). However, the desired phosphonate was I, and its synthesis was attempted *via* the well known route shown on p. 3500, col. 1.

The product of the reaction was not I, but rather II, and, the isolation of this triethylamine salt of di-p-nitrophenyl hydrogen phosphate in fair yield is another of the few known examples of the conversion of phosphonate to a phosphate.

Other such rearrangements known to us are Perkow's[2] rearrangement reaction between trialkyl phos-

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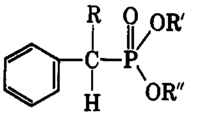
(1) (a) This manuscript does not indorse nor recommend any instruments or products as may be named herein; (b) E. L. Becker, T. R. Fukuto, B. Boone, D. C. Canham, and E. Boger, *Biochem. J.*, **8**, 72 (1963).

(2) W. Perkow, *Ber.*, **87**, 755 (1954); W. Perkow, K. Utterich, and F. Meyer, *Naturwiss.*, **39**, 353 (1952).

TABLE I

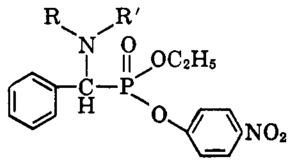
PHYSICAL CONSTANTS ON NEW *N*-ALKYLAMINOBENZYLPHOSPHONATES



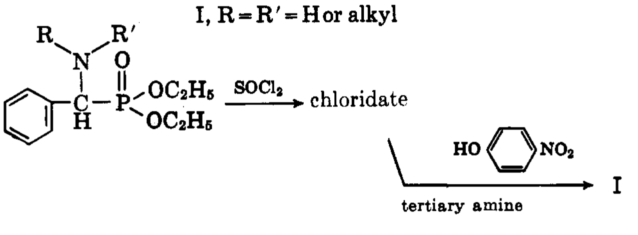
VI

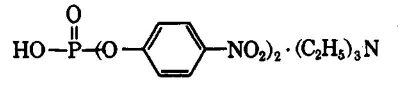
No.	Empirical formula	R	R′, R″	M.p. or b.p. (mm.), °C.	n^{25}D	Yield, %	Analyses C Calcd.	Analyses C Found	Analyses H Calcd.	Analyses H Found	Analyses N Calcd.	Analyses N Found	Analyses P Calcd.	Analyses P Found
1	$C_{13}H_{22}NO_3P$	$-\overset{H}{N}-C_2H_5$	$-C_2H_5$	132 (0.90)	1.4926	67	57.6	57.3	8.2	8.3	5.2	5.3	11.4	11.6
2	$C_{14}H_{24}NO_3P$	$-\overset{H}{N}-C_3H_7$	$-C_2H_5$	118 (0.05)	1.4866	65	58.9	58.7	8.5	8.4	4.9	5.0	10.9	10.7
3	$C_{12}H_{20}NO_3P$	$-\overset{H}{N}-CH_3$	$-C_2H_5$	38–39, 106 (0.11)	1.4971	67	56.0	56.5	7.8	7.8	5.5	5.2	12.0	12.1
4	$C_{15}H_{24}NO_5P$	$-\overset{CH_3}{N}-\underset{O}{\overset{}{C}}-OC_2H_5$	$-C_2H_5$	180 (2.70)	1.4936	76	54.7	54.7	7.4	7.5	4.3	4.3	9.4	9.1
5	$C_{16}H_{26}NO_5P$	$-\underset{C_2H_5}{N}-\overset{O}{C}-OC_2H_5$	$-C_2H_5$	156 (0.40)	1.4906	78	56.0	55.6	7.6	7.5	4.1	4.1	9.0	8.6
6	$C_{20}H_{26}NO_3P$ characterized as acid below	$-\underset{C_2H_5}{N}-\overset{O}{C}-C_6H_5$	$-C_2H_5$	Molecular still	1.5415	67								
7	$C_{16}H_{18}NO_4P$	$-\overset{C_2H_5}{N}-\underset{O}{C}-C_6H_5$	-H	163–165		77[a]	60.2	59.7	5.7	5.3	4.4	4.6	9.7	9.3
8	$C_{11}H_{18}NO_5P$	$-\underset{C_2H_5}{N}-\overset{O}{C}-CH_3$	-H	165–166		68[a]	51.4	51.5	6.3	6.3	5.4	5.9	12.0	11.5

[a] Crude yield.



I, R = R′ = H or alkyl





II

phite and chloral to yield a phosphate; Barthel's[3] conversion of a phosphonate (III) to the phosphate insecticide "dipterex" (IV) (this is shown below),

$$\underset{\text{III}}{(CH_3O)_2\overset{O}{\overset{\|}{P}}-\overset{H}{\underset{OH}{C}}-CCl_3} \xrightarrow{OH^-} \underset{\text{IV}}{(CH_3O)_2\overset{O}{\overset{\|}{P}}-O-\overset{H}{C}=C-Cl_2}$$

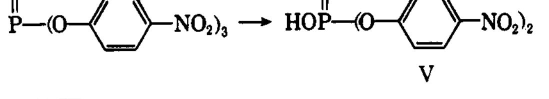
which is similar to the work reported by Lorenz, *et al.*[4]; the preparation of diethyl 1-cyanoethylphosphate from diethyl 1-cyano-1-hydroxyethylphosphonate by Hall and Stephens[5]; and finally the rearrangement of α-hydroxyalkylphosphonates into isomeric phosphates reported by Kukhtin, *et al.*[6]

The unknown was assigned configuration II and evidence for this structure is as follows.

The derived empirical formula shows a ratio of three nitrogens to one phosphorus atom as one would expect.

The unknown was hydrolyzed in 48% hydrobromic acid, and the isolated salt was identified as triethylamine hydrobromide by melting point and infrared data. Triethylamine hydrochloride was isolated similarly from the use of hydrochloric acid.

On treatment of the unknown with aqueous dilute hydrochloric acid and ether, di-*p*-nitrophenyl hydrogen phosphate (V), a known compound was isolated. V was prepared previously by Stansly,[7] and Moffatt and



V

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[3] W. F. Barthel, B. H. Alexander, P. A. Giang, and S. A. Hall, *J. Am. Chem. Soc.*, **77**, 2424 (1955).

[4] W. Lorenz, A. Henglein, and G. Schrader, *ibid.*, **77**, 2554 (1955).

[5] L. A. R. Hall and C. W. Stephens, *ibid.*, **78**, 2565 (1956); L. A. R. Hall, C. W. Stephens, and J. J. Drysdale, *ibid.*, **79**, 1768 (1957).

[6] Y. A. Kukhtin, V. S. Abramov, and K. M. Orekhova, *Dokl. Akad. Nauk SSSR*, **128**, 1198 (1959); *Chem. Abstr.*, **54**, 7536 (1960).

[7] P. G. Stansly, *J. Org. Chem.*, **23**, 148 (1958).

Khorana[8] from tri-*p*-nitrophenyl phosphate. Dr. Stansly and Dr. Moffatt supplied us with authentic samples of V which were identical with our isolated di-*p*-nitrophenyl hydrogen phosphate. Their V was then treated with triethylamine and the resultant product was the same as our unknown di-*p*-nitrophenyl hydrogen phosphate triethylamine salt (II) according to mixture melting point and infrared data.

$$\text{V} + (C_2H_5)_3N \xrightarrow[\text{acetonitrile}]{\text{ether}} \text{II}$$

The intermediates (Table I, 1, 2, and 3) were prepared from freshly distilled diethyl hydrogen phosphite and the appropriate *N*-benzylidene alkylamine by the procedures of Fields,[9] and Murray and Gallaway[10] in fair yields.

Other new compounds are reported in Table I. The urethans were prepared in good yield by the procedure of Medved and Kabachnik[11] by treating the *N*-alkylaminophosphonates[9] with ethyl chloroformate and pyridine in dry benzene. As expected, the ethoxy groups, as well as the carbamate radical of these new urethans, were stable to the usual chlorinating agents such as thionyl chloride[12] and oxalyl chloride.

The benzoate and phosphonic acids found in Table I were prepared according to the usual procedures.

Experimental

Diethyl α-(*N*-Alkylamino)benzylphosphonates (Table I).—The methyl, ethyl, and propylamino were prepared similarly. Only the preparation of the diethyl α-(*N*-propylamino)benzylphosphonate is given in detail. A mole of freshly distilled diethyl hydrogen phosphite was added with stirring, carefully, over a period of 10 min. to a mole of freshly distilled *N*-benzylidenepropylamine[9,10] in a water bath at 25°. When all had been added, maintaining the temperature below 70°, the exothermic reaction mixture was stirred for 0.5 hr. and then heated and kept between 50–70° for 3 hr. After standing overnight at room temperature, the solution was distilled.

***N*-Alkyl-*N*-(α-benzyldiethylphosphonate)urethans (Table I).**—A typical preparation is that of the *N*-methyl-*N*-(α-benzyldiethylphosphonate)urethan. Diethyl α-(*N*-methylamino)benzylphosphonate, distilled ethyl chloroformate, and pyridine reacted according to literature directions.[11]

Di-*p*-nitrophenyl Hydrogen Phosphate Triethylamine Salt (II). A.—Approximately 36 ml. of distilled thionyl chloride was placed in a 500-ml. flask equipped with a mechanical stirrer, air condenser, drying tube, and dropping funnel. At 0° and while stirring, 0.2 mole of diethyl α-(*N*-alkylamino)benzylphosphonate (Table I, methyl, ethyl, or propyl) was added. After the addition, the solution was kept at 58° for 3 hr. with stirring. The excess thionyl chloride was removed *in vacuo;* then 250 ml. of dry xylene and 0.2 mole of dried *p*-nitrophenol were added. The mixture was cooled to 0°; 96 ml. of triethylamine was added slowly with stirring, and the mixture was allowed to stand for 18 hr. at 25°. It was heated to 95° (air condenser replaced with water condenser), stirred and kept at this temperature for 2 hr. The mixture was filtered hot, and the residue was triturated with a small amount of cold water; the resultant crystals after filtering were washed with cold water and finally with benzene. Yield of crude product was 21 g.; per cent yields varied from 17–32%. Crystallization from ligroin and ethanol produced crystals melting at 154–156°.

Anal. Calcd. for $C_{18}H_{24}N_3O_8P$: C, 48.98; H, 5.48; N, 9.52; P, 7.02. Found: C, 48.87; H, 5.63; N, 9.40; P, 7.20.

B.—Di-*p*-nitrophenyl hydrogen phosphate (0.1 g.) supplied by Stansly[7] and Moffatt[8] was mixed with 0.5 ml. of triethylamine and 2 ml. of acetonitrile. The solution which resulted on warming was allowed to stand several hours; ether was then added and the mixture filtered. The crystals, after recrystallization from ethanol and ethyl ether, melted at 153–155°. A mixture melting point with the crystals from method A melted at 154–156°; its infrared spectrum was also identical with the one obtained from the crystals synthesized previously.

C.—The reaction conditions employed in procedure A were used, and the reagents were the same except that diethyl hydrogen phosphite was used instead of the diethyl α-(*N*-alkylamino)benzylphosphonate (Table I). After filtering the hot reaction mixture (unlike the runs in A there was no water-insoluble product in the precipitated triethylamine hydrochloride), the filtrate was kept at 5° and crystallization occurred. The recovered crystals, 2% yield, melted at 153–155°, and the mixture melting point with the crystals from A was not depressed.

Determination of the Molecular Weight of II.—A known weight of approximately 30 mg. of II was dissolved in acetone and diluted to a final volume of 10 ml. In duplicates, exactly 0.5 ml. of this solution, 1 ml. of 1 *N* sodium hydroxide, 0.5 ml. of pure acetone, and 3 ml. of distilled water were sealed in a glass ampoule. The ampoule was kept at 100° for 2 hr., cooled, and its contents acidified with 1 ml. of 1 *N* hydrochloric acid. The solution was then diluted to 100 ml. with 0.06 *M* phosphate buffer, and the absorbance was ascertained in a Beckman DU spectrophotometer and compared with a *p*-nitrophenol standard curve.

Anal. Calcd. for $C_{18}H_{24}N_3O_8P$: mol. wt., 441. Found: mol. wt., 436.

Isolation of Triethylamine Hydrochloride from II.—II (5 g.) was heated in aqueous sodium hydroxide, and the gas given off was collected in aqueous hydrochloric acid. The isolated crystalline amine salt melted at 254–256° with decomposition; a mixture melting point with a sample of authentic triethylamine hydrochloride was not raised or depressed. The infrared spectra of the two salts were also similar.

Isolation of Triethylamine Hydrobromide and *p*-Nitrophenol from II.—II (5 g.) was refluxed in 48% hydrobromic acid for 6 hr. After removal of the excess hydrobromic acid, the residue was worked up in the usual way by ether extraction.

p-Nitrophenol melting at 112–114° as well as triethylamine hydrobromide melting at 250–251° was isolated; mixture melting points of each with authentic samples were not changed.

Neutralization of II.—II (3.6 g.) was added to 2 ml. of concentrated hydrochloric acid in 15 ml. of water and ether was added. The mixture was shaken, and the layers were separated. The ether layer yielded 1.1 g. of V melting at 174–176°, and a mixture melting point with an authentic sample of di-*p*-nitrophenyl hydrogen phosphate was not depressed. The water layer produced 0.6 g. of triethylamine hydrochloride.

V reacted with sodium hydroxide and a yellow solid was produced which on recrystallization from water melted at 317–319° dec. The resultant compound was identified as sodium di-*p*-nitrophenylphosphate when, after treatment with hydrochloric acid, V was isolated in high yield.

Anal. Calcd. for $C_{12}H_8N_2O_8PNa$: C, 39.79; H, 2.20; N, 7.74; P, 8.56. Found: C, 39.61; H, 2.53; N, 7.78; P, 7.51.

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