ene glycol column indicated the product to be a single compound.

Anal. Calcd. for $C_{12}H_{19}N$: C, 81.30; H, 10.80; N, 7.90. Found: C, 81.27; H, 10.69; N, 7.85.

The picrate, after two recrystallizations from absolute ethanol, melted at 131.5–132.5°.

Anal. Calcd. for $C_{18}H_{22}N_4O_7$: C, 53.20; H, 5.46; N, 13.79. Found: C, 53.26; H, 5.49; N, 13.94.

The Reaction between Dialkyl Phosphonates and Their Sodium Salts

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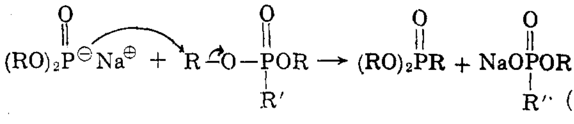
Sodium dialkylphosphonates having primary alkyl groups react with the parent dialkyl phosphonate *via* P-alkylation, to yield dialkyl alkylphosphonates and sodium alkyl phosphonates. The analogous reaction with *sec*-butyl esters is much slower and proceeds *via* O-alkylation, to yield tri-*sec*-butyl phosphite and sodium *sec*-butyl phosphonate.

Pelchowicz[1] and co-workers have recently described the reaction of sodium dialkyl phosphonates with dialkyl phosphonates shown in equation 1. Previously Petrov[2] and co-workers had reported a related reaction wherein R′ was primary alkyl. Concurrently in this laboratory the reaction has been applied successfully to the preparation of esters of butyl- and dodecylphosphonic acids. It was then hoped to use the reaction to prepare *sec*-alkylphosphonate esters. When one equivalent of sodium was treated with two equivalents of di-*sec*-butyl phosphonate in refluxing heptane, sodium mono-*sec*-butyl phosphonate was isolated in about 50% yield. This structure was established by the splitting of the phosphorus absorption in the nuclear magnetic resonance (n.m.r.) spectrum into a doublet (due to spin-spin coupling with the attached hydrogen), by comparison of the infrared spectrum with that of an authentic sample, and by elemental analyses. Identification and isolation of the other products was not achieved because they codistilled with the solvents during work-up.



$$(RO)_2\overset{\overset{O}{\|}}{P}{}^{\ominus}Na^{\oplus} + R\text{–}O\text{–}\underset{\underset{R'}{|}}{\overset{\overset{O}{\|}}{P}}OR \rightarrow (RO)_2\overset{\overset{O}{\|}}{P}R + NaO\underset{\underset{R''}{|}}{\overset{\overset{O}{\|}}{P}}OR \quad (1)$$

(R = primary alkyl; R′ = hydrogen)

When sodium di-*sec*-butyl phosphonate was dissolved in excess di-*sec*-butyl phosphonate and the mixture was heated at 120° for seven days, the principal ester product formed was tri-*sec*-butyl phosphite. The indicated yield (based on unrecovered di-*sec*-butyl phosphonate) was 81% by n.m.r. and infrared spectral analysis. A small amount of unidentified phosphate was also detected.[3] *No* di-*sec*-butyl *sec*-butylphosphonate was detected by either method. A small portion of the trialkyl phosphite was isolated by column chromatography and was converted to its solid cuprous chloride complex, which was identical with that prepared from authentic tri-*sec*-butyl phosphite.

Discussion

Sodium di-*n*-butylphosphonate undergoes P-alkylation by di-*n*-butyl phosphonate at elevated temperatures, yielding di-*n*-butyl *n*-butylphosphonate and sodium *n*-butyl phosphonate. Sodium di-*n*-dibutyl phosphonate also undergoes P-alkylation by *n*-butyl bromide, yielding di-*n*-butyl *n*-butylphosphonate and sodium bromide (the Nylen reaction). However, it has now been established that di-*sec*-butyl phosphonate reacts differently with its sodium salt, and much more slowly, to give tri-*sec*-butyl phosphite, the product of O-alkylation, and sodium mono-*sec*-butyl phosphonate as the principal products. A rationale for these results may be found in the work of Kornblum and co-workers on the alkylation of ambident anions, such as the nitrite ion.[4] Kornblum states that greater SN1 character (carbonium ion participation) in the transition state leads to greater amounts of the product of bond formation with the atom of greatest electronegativity, and *vice versa.* Our observations are in complete accord with this principle. The oxygen atom of the phosphonate anion is more electronegative than the phosphorus atom. Moreover, the greater stability of secondary carbonium ions as compared to primary carbonium ions should give more SN1 character to the reaction involving *sec*-butyl phosphonates.

One observation not consistent with this relatively simple interpretation is that sodium di-*sec*-butyl phosphonate was alkylated with *sec*-butyl bromide to give predominantly di-*sec*-butylphosphonate, the product of P-alkylation. This suggests that the structures of both the

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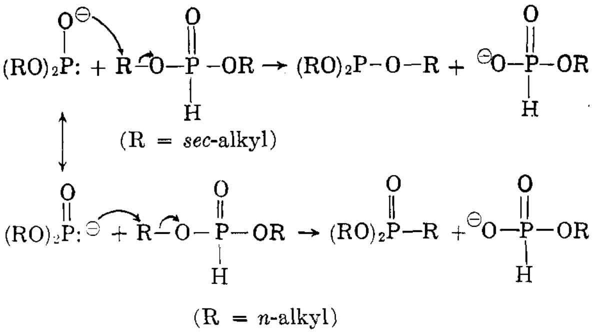
(1) Z. Pelchowicz, S. Brukson, and E. D. Bergmann, *J. Chem. Soc.*, 4348 (1961).

(2) K. A. Petrov, N. K. Bliznyuk, M. A. Korshunov, F. L. Maklyaev, and A. N. Voronkov, *Zh. Obshch. Khim.*, **29**, 3407 (1959).

(3) It was established that both di-*sec*-butyl phosphonate and tri-*sec*-butyl phosphite are oxidized to the corresponding phosphates at 120° in air.

(4) N. Kornblum, R. A. Smiley, R. K. Blackwood, and D. C. Iffland, *J. Am. Chem. Soc.*, **77**, 6269 (1955).



leaving group and the alkylating group are important in controlling the products of the reaction. Kornblum and co-workers have recently reported similar cases in which the leaving group influences the products obtained in the reaction of the lithium salt of 2-nitropropane with various *p*-nitrobenzyl derivatives.[5] They suggest that the more difficultly displaced leaving groups are associated with alkylation of the less electronegative atom. The present work agrees with this hypothesis since it is reasonable to assume that the phosphonate group is more easily displaced than bromide.[6]

Pelchowicz[2] has pointed out that the alkylation of dialkyl phosphonate anion by dialkyl phosphonates can reduce the yield of the desired phosphonate in Nylen reactions. Equimolar quantities of sodium and dialkyl phosphonate, accompanied by the use of moderate temperatures, are recommended for the preparation of the sodio derivatives. These conditions are conveniently met by using sodium dispersions, which react with dialkyl phosphonates smoothly at room temperature.

Experimental[7]

Di-*sec*-butyl Phosphonate.—The method of McCombie[8] was used to prepare the ester from *sec*-butyl alcohol and phosphorus trichloride in carbon tetrachloride. The ester was distilled through a 3-ft. spinning band column. Several preparations gave identical products, b.p. 59° (0.6 mm.), n^{20}_{D} 1.4196, d^{20}_{4} 0.9779.

Anal. Calcd. for $C_8H_{19}O_3P$: C, 49.5; H, 9.86; P, 16.0. Found: C, 49.4; H, 9.70; P, 15.9.

Tri-*sec*-butyl Phosphite.—*sec*-Butyl alcohol, 222 g. (3 moles), and triethylamine, 303 g. (3 moles), dissolved in 300 ml. of dry hexane were treated at 5–13° with phosphorus trichloride, 137 g. (1 mole), dissolved in 300 ml. of hexane. Five hours were required for addition. After an additional 17 hr. at room temperature the amine hydrochloride was filtered off. The solvent was distilled through a 1-ft. Vigreux column, and the phosphite was then distilled through a 3-ft. spinning band column to yield 168 g. (67%) b.p. 49° (0.3 mm.), n^{25}_{D} 1.4262. The infrared spectrum indicated the presence of about 1% di-*sec*-butyl phosphonate.

Anal. Calcd. for $C_{12}H_{27}O_3P$: C, 57.1; H, 10.8; P, 12.3. Found: C, 57.1; H, 10.8; P, 12.0.

Sodium Mono-*sec*-butyl Phosphonate.—Di-*sec*-butyl phosphonate, 2.07 g., was refluxed for 3 hr. in 50 ml. of water containing an equimolar amount of sodium hydroxide. The water and *sec*-butyl alcohol were removed *in vacuo* to give the hygroscopic solid.

Di-*sec*-butyl *sec*-Butylphosphonate.—Sodium di-*sec*-butyl phosphonate (0.2 mole) was prepared at room temperature from the requisite amounts of sodium dispersion (in *n*-octane) and phosphonate. The solution was raised to reflux temperature (125°) and *sec*-butyl bromide (27.4 g., 0.2 mole) was added rapidly. Reflux was maintained 31 hr., the mixture cooled, filtered, and solvent evaporated in a Rinco rotary evaporator. The precipitated sodium bromide totaled 20 g. (97%). The crude residue was distilled through a semimicro still to yield 9 g. (18%)[9] phosphonate ester, b.p. 86–90° (0.1 mm.), n^{26}_{D} 1.4263. The n.m.r. and infrared spectra were consistent with the assigned structure, and gave no indication of the presence of tri-*sec*-butyl phosphite.

Anal. Calcd. for $C_{12}H_{27}O_3P$: C, 57.1; H, 10.8; P, 12.3. Found: C, 56.6; H, 10.7; P, 12.3.

Reactions of Sodium with Di-*sec*-butyl Phosphonate. In Heptane.—Sodium, 2.3 g. (0.1 g.-atom), was added to 550 ml. of dry heptane in a 1-l. three-necked flask equipped with a mechanical stirrer, a reflux condenser protected by a drying tube, and an additional funnel. Di-*sec*-butyl phosphonate, 38.8 g. (0.2 mole) was added to the stirred and refluxing mixture over 30 min. Stirring and heating were continued for 30 hr., the mixture cooled, and 4 g. of hygroscopic sodium mono-*sec*-butyl phosphonate was isolated by filtration. An additional 5 g. of the salt was isolated by distilling the heptane and triturating the residue with anhydrous diethyl ether. The total yield was 9 g. (56%). Infrared and n.m.r. spectra served to identify the salt. An infrared spectrum of the liquid portion of the reaction mixture showed it to be mostly di-*sec*-butyl phosphonate. In one experiment the reactor was vented through a Dry Ice trap. About 2 g. of *n*-butane, identified by its gas-phase infrared spectrum, was isolated. No reasonable explanation for this is apparent.

In Di-*sec*-butyl Phosphonate.—Sodium di-*sec*-butyl phosphonate was prepared from the ester and dispersed sodium in octane at room temperature (octane removed *in vacuo*). Three-tenths mole was dissolved in di-*sec*-butyl phosphonate, 116.5 g. (0.6 mole), contained in a 500-ml. boiling flask under a reflux condenser protected by a drying tube and stirred magnetically. The reaction was carried out at 120° (oil bath controlled by a Therm-O-Watch electronic temperature controller) for 7 days. The mixture was cooled, mixed with 500 ml. of water, and extracted three times with 250-ml. portions of diethyl ether. The combined ether extracts were stripped by distillation through a 1-ft. Vigreux column, leaving 130 g. of residue. Infrared and n.m.r. spectral analyses indicated the ether-free material to have the following composition, expressed as weight %.

Material	N.m.r. analysis	Infrared analysis
$(sec\text{-}C_4H_9O)_2\overset{O}{\overset{\|}{P}}\text{—}H$	63[10]	65
$(sec\text{-}C_4H_9O)_3P$	28	22[11]
Phosphate	9	None found[11]

These analyses correspond to an 81% yield of tri-*sec*-butyl phosphonate, based on unrecovered di-*sec*-butyl phosphonate.

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[5] N. Kornblum, P. Pink, and K. V. Yorka, *J. Am. Chem. Soc.*, **83**, 2779 (1961).

[6] It is generally accepted that the tosylate group, which is structurally analogous to the phosphonate group, is a better leaving group than bromide (J. Hine, "Physical Organic Chemistry," McGraw-Hill, New York, 1956, p. 167).

[7] The boiling points and melting points are uncorrected. The infrared spectra were determined with a Perkin-Elmer Model 137 spectrophotometer using sodium chloride optics. The n.m.r. spectra were determined with a Varian high-resolution Model V4200B spectrometer at 24.3 Mc. with a field strength of 14,000 gauss, using a 15-mm. diameter sample.

[8] H. McCombie, B. C. Saunders, and G. J. Stacey, *J. Chem. Soc.*, 380 (1945).

[9] The bulk of the product was lost through decomposition during distillation.

A 13.8-g. sample of this material was chromatographed on a column of alumina which was partially deactivated by slurrying with alcohol and drying at steam bath temperature. The first 2 g. of product eluted from the column by petroleum ether comprised 90–95% tri-*sec*-butyl phosphite and the balance di-*sec*-butyl phosphonate, by infrared spectral analysis. Because of the very similar boiling points and consequential difficulty in separating the diester from the triester by distillation,[12] no physical constants were obtained. Since the triester forms a solid cuprous chloride complex while the diester does not, separation and identification by this route were chosen. The crude tri-*sec*-butyl phosphite thus obtained gave a cuprous chloride complex melting 161.5–162.5°. An analogous complex prepared from the known phosphite melted at 162–163° and the mixture melting point of the two complexes was 161.5–163.0°. These complexes were somewhat sticky and oxidized readily if not kept in an inert atmosphere.

Acknowledgment.—The authors wish to thank Dr. T. J. Flautt for the n.m.r. spectral data.

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[10] The chemical shifts relative to 85% phosphoric acid for tri-*sec*-butyl phosphite, di-*sec*-butyl phosphonate, and the unknown phosphate were −139.8 p.p.m., −9.9 p.p.m., and +2.0 p.p.m., respectively. The spin-spin interaction of the P and H atoms in di-*sec*-butyl phosphonate resulted in a splitting of 660 c.p.s.

[11] The determination of tri-*sec*-butyl phosphite was based on absorption at 10.7 μ. It is not possible to draw a precise base line for this band because of other strong absorption bands in this region of the spectrum. The similarity between phosphonate and phosphate spectra in the infrared region precluded the determination of phosphate.

[12] The same is true for the *n*-butyl esters. $(BuO)_2POH$, b.p. 124–5° (12 mm); $(BuO)_3P$, b.p. 122–3° (12 mm), see G. M. Kosolopoff, "Organophosphorus Compounds," Wiley, N. Y. 1950, pp. 202, 204.

The Reaction of Azulenes with Trifluoro- and Trichloroacetic Anhydride[1,2]

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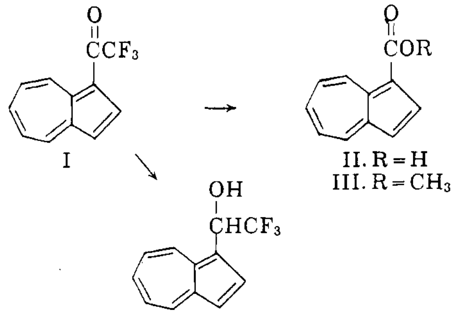
The reaction of certain azulenes with trifluoro- and trichloroacetic anhydrides gives good to high yields of the 1-trihaloacetylazulene derivatives. In these cases hydrolysis gives the corresponding carboxylic acids and the two steps provide perhaps the best route to the acids and their derivatives.

The initial efforts to prepare 1-azuloic acid by the more common methods for aromatic carboxylic acids afforded only one successful route. Reaction of 1-acetylazulene with sodium hypoiodite reagent (but not sodium hypochlorite which gave electrophilic displacement of the acetyl group) yielded the desired acid but not in pure form.[5] Subsequently it occurred to us to attempt the direct introduction of a trihaloacetyl group as a general method leading to 1-(3-)azuloic acids and derivatives.

The use of trifluoroacetic anhydride in the synthesis of ketones from aromatic compounds and carboxylic acids had been reported by Bourne and co-workers.[6] They obtained good yields of ketones from polyalkylbenzenes, phenyl ethers, furan, and thiophene under mild conditions. These reactions, which presumably proceeded through intermediate formation of the mixed anhydride, suggested that the nucleophilic 1-position of azulene might serve to displace the stable trifluoroacetate ion from trifluoroacetic anhydride and form 1-trifluoroacetylazulene (I) directly. The acylation of azulene with acetic anhydride requires a catalyst[5]; in contrast the reaction with trifluoroacetic anhydride proceeded without a catalyst and formed I in 91% yields. The identity of the product was indicated by its absorption maximum (525 mμ) in the visible region. This large hypsochromic shift is observed when a strong electron-withdrawing group occupies the 1-position.[7] The structure of I was confirmed by the formation of 1-azuloic acid (II) on treatment with aqueous sodium hydroxide and esterification with diazomethane to give the known ester (III).[8] II, obtained in 88.5% yield



I

II. R = H
III. R = CH$_3$

IV

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[1] From the Ph.D. thesis of Robert Griffin Anderson.

[2] A preliminary communication of a portion of this work appeared in *Proc. Chem. Soc.*, 72 (1960).

[3] National Science Foundation Senior Postdoctoral Fellow, 1960–1961.

[4] National Science Foundation Predoctoral Fellow, Summer 1959; National Institutes of Health Fellow 1959–1961. Present address: California Research Corp., Richmond, California.

[5] A. G. Anderson, J. A. Nelson, and J. J. Tazuma, *J. Am. Chem. Soc.*, **75**, 4980 (1953).

[6] E. J. Bourne, M. Stacey, J. C. Tatlow, and J. M. Tedder, *J. Chem. Soc.*, 718 (1951).

[7] A. G. Anderson and B. M. Steckler, *J. Am. Chem. Soc.*, **81**, 4941 (1959); A. G. Anderson, R. Scotoni, E. J. Cowles, and C. G. Fritz, *J. Org. Chem.*, **22**, 1193 (1957); E. J. Cowles, *J. Am. Chem. Soc.*, **79**, 1093 (1957); E. Heilbronner, "Non-Benzenoid Aromatic Compounds," D. Ginsburg, ed., Interscience Publishers, Inc., New York, 1959, Chap. V.

[8] A. G. Anderson and J. J. Tazuma, *J. Am. Chem. Soc.*, **75**, 4979 (1953).