Reaction of Diazonium Salts with Nucleophiles. XVIII. Dimethyl Phosphonate in Base¹

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The rates of reaction of diazonium salts with dimethyl phosphonate have been followed in two cases. The kinetics, almost but not exactly third order, indicate that the ionization of dimethyl phosphonate by base occurs before the attack of diazonium salt on the phosphonate anion, but neither step is rate determining at accessible concentrations. Most of the isolated arylazophosphonates probably have syn stereochemistry.

Aromatic diazonium salts react with nucleophiles at the terminal nitrogen, yielding covalent diazo compounds which have the syn configuration in those cases when both stereoisomers are known. Studies in this area are usually complicated by side reactions, and. because both the desired and side reactions are very sensitive to substituent, often the reactions can be studied only over a small range of substituents. A type of nucleophile not vet extensively studied quantitatively in this reaction includes phosphorus compounds in lower oxidation states. Some of these, such as hypophosphorous acid and phosphorous acid, lead to replacement of the diazonium group by hydrogen by way of a free radical chain reaction.³ In contrast, triphenylphosphine reacts with diazonium salts, again with ultimate reduction but with the intermediacy of the covalent diazo compound, $ArN_2P(C_6H_5)_3^{+4}$ Dialkyl phosphonates react to form stable dialkyl diazophosphonates,⁵ which are the subject of this paper, and the preparation is shown in reaction 1. We were

$$MeO_{2}PHO + ArN_{2}^{+} \longrightarrow ArN_{2}PO(OMe)_{2} + H^{+}$$
(1)

able to prepare several of these compounds (1) following the literature methods⁵ in which 1 precipitates from an aqueous mixture of diazonium salt and dimethyl phosphonate at about pH 7, but the change to conditions suitable for a kinetic study was difficult. When the solvent was changed to methanol the reaction in most cases followed a different course, as indicated by uv absorption, and when very dilute solutions were used in water various side reactions in most cases overwhelmed the desired process. With $Ar = p - O_3 SC_6 H_4$, the product 1 is water soluble, and the reactions could be studied and, with $Ar = p - N \equiv CC_6H_4$, the side reactions were slow enough to allow the study. With Ar = p-CH₃O, p-CH₃, H, p-NO₂, and p-Cl-phenyl, the only other ones tried, no reasonably accurate study was possible in either water or methanol, although the product could be readily prepared.

The reaction 1 was not detectably reversed in water, but, when 1 was dissolved in concentrated sulfuric acid, the product showed the coupling reaction after neu-

(2) From a portion of the Ph.D. Thesis of Edward C. Nieh, Rice University, 1972.

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 72, 3013 (1950); N. Kornblum, A. E. Kelley, and G. D. Cooper, *ibid.*, 74, 3074 (1952).

 (4) L. Horner and H. Stöhr, Ber., 86, 1066, 1073 (1953); L. Horner and H. Hoffmann, Angew. Chem., 68, 473 (1956).

(5) F. Suckfull and H. Haubrick, Angew. Chem., **70**, 238 (1958); see also German Patents 1,008,313 (1955), 1,011,432 (1955), 1,015,443 (1955), and 1,075,627 (1956). We thank Drs. Suckfull and Haubrick for copies of these patents.

tralization. We may conclude that the equilibrium lies very far to the right.

The reaction rates were readily followed; they were very strongly pH dependent and reminiscent of some other chemistry of dialkyl phosphonates, the oxidation with halogens⁶ and the deuterium exchange,⁷ in which the anion $(MeO)_2PO^-$ (2) or its O-protonated conjugate acid, dialkyl phosphite, is implicated as a reactive intermediate. Using this analogy as a basis for the present work, the mechanism would be that given by eq 2 and 3. This leads to the rate equation (eq 4),

$$(MeO)_2PHO + B^- \xrightarrow{k_2}_{k_{-2}} (MeO)_2PO^- + BH \qquad (2)$$

$$(MeO)_2PO + ArN_2^+ \xrightarrow{k_3} ArN = NPO(OMe)_2$$
 (3)

$$\frac{d[1]}{dt} = \frac{k_3[ArN_2^+][(MeO)_2PHO]\Sigma_i k_{2i}[B_i^-]}{k_3[ArN_2^+] + \Sigma_i k_{-2i}[B_iH]}$$
(4)

where the summations recognize the multiplicity of bases and conjugate acids, and this equation reduces to two limiting forms, depending on which term in the denominator is predominant. If the second term predominates, the equation reduces to one specific hydroxide ion catalysis, eq 5,⁸ and, if the first term predominates, eq 6 applies, showing general base catalysis

$$d[\mathbf{1}]/dt = k[OH^{-}][ArN_{2}^{+}][(MeO)_{2}PHO]$$
(5)

$$d[\mathbf{1}]/dt = [(MeO)_2 PHO] \boldsymbol{\Sigma}_i k_{2i} [\mathbf{B}_i^{-}]$$
(6)

and a rate-determining first step. The first experiments showed that the rate is insensitive to a twofold buffer concentration and dependent on diazonium ion concentration, excluding the limit (eq 6). However, the distinction between the limit (eq 5) and the more general eq 4 was more difficult, for the range of concentrations without serious side reactions was limited. The method of accounting for a minor side reaction is described in the Experimental Section. The pseudofirst-order rate constant, k_{ψ} , for the reaction (1) was calculated by the method of Guggenheim⁹ from the absorbance vs. time curves. At constant [ArN₂⁺], a plot of log k_{ψ} vs. pH is linear with a slope of +1, and a plot of k_{ψ} vs. [ArN₂⁺] at constant pH was linear.¹⁰ We therefore calculated $k' = k_{\psi}/[OH^{-}][ArN_2^{+}]$, which

(7) Z. Luz and B. Silver, J. Amer. Chem. Soc., 84, 1095 (1962).
(8) This reduction is not an algebraic identity; it requires further relations between the terms in the summation such as is required by microscopic

⁽¹⁾ Paper XVII: E. S. Lewis and D. J. Chalmers, J. Amer. Chem. Soc., 93, 3267 (1971). This work was supported by a grant from the Robert A. Welch Foundation which we gratefully acknowledge.

⁽⁶⁾ P. Nylen, Z. Anorg. Allg. Chem., 235, 161 (1938).

reversibility. (9) E. A. Guggenheim, Phil. Mag., 2, 538 (1926).

⁽¹⁰⁾ Although diazonium salts react with high pH buffers to give diazotates, this does not occur perceptibly at these pH's: E. S. Lewis and H. Suhr, *Chem. Ber.*, **91**, 2350 (1958).

would be pH and concentration independent if eq 5 holds exactly. The results are shown in Table I. The

TABLE I								
Rates of Diazophosphonate Formation at $6.0\pm0.1^\circ$								
From p -XC ₆ H ₄ N ₂ ⁺ and (MeO) ₂ PHO ^a								
	$({\rm ArN_2^+})$ \times		$k\psi$ \times 10 ⁻⁸ ,	$k' \times 10^{-6}$,				
х	$10^2, M$	$_{\rm pH}$	sec ⁻¹	M^{-2} sec ⁻¹				
SO_3	0.8	7.0	3.75	4.46				
SO₃−	1.0	7.0	3.99	3.99				
SO_3^-	1.2	7.0	4.33	3.60				
SO_3^-	1.4	7.0	4.87	3.47				
SO_3-	1.6	7.0	5.32	3.32				
SO_3	1.8	7.0	5.77	3.20				
SO_3^-	1.6	6.2	0.93	3.65				
SO₃−	1.6	7.4	14.70	.3.68				
CN	1.0	6.4	2.86	, 11.4				
\mathbf{CN}	1.2	6.4	3.25	10.8				
CN	1.4	6.4	3.54	10.1				
CN	1.6	6.4	3.82	9.55				
CN	1.8	6.4	4.28	9.51				

^a All runs were done with an initial $6.8 \times 10^{-4} M (MeO)_2 PHO$; a more extensive set is to be found in E. C. Nieh's thesis (ref 2). Registry number for (MeO)₂PHO, 868-85-9.

pH effect (as shown by the virtual identity of k' at pH 6.2 and 7.4 at constant $[ArN_2^+]$) is very clearly of the correct form, but the rate dependent on $[ArN_2^+]$ less than is demanded by eq 5.

Equation 4 will clearly give a better fit, and only the term with $B^- = OH^-$ is very significant. We use these data to calculate the limiting rate at high diazonium salt concentrations most easily as the slope of a plot of 1/k' vs. [ArN₂⁺], since eq 4 with only an OH⁻ term becomes eq 7, and using the data with $X = SO_3^-$ we

$$k' = \frac{k_{\rm s}k_{\rm 2}}{k_{-2} + k_{\rm s}[{\rm ArN}_2^+]} \tag{7}$$

find $k_2 = 3.3 \times 10^5 M^{-1} \sec^{-1}$, and that from X = CN gives $k_{-2} = 1.4 \times 10^5 \text{ M}^{-1} \text{ sec}^{-1}$. Making suitable corrections for pH and temperature, and counting only the [OH-] term, we get from Nylen's iodine oxidation data $k_2 = 7 \times 10^5$. The roughness of our calculation, severely limited by the small range of variation of $[ArN_2^+]$ imposed by solubility, together with other uncertainties of comparison make the better than order of magnitude agreement satisfactory, and we therefore believe that the mechanism of eq 2 and 3 is adequately demonstrated.

The separate constants k_3 or k_2 are not firmly established, although the ratio of k_3/k_{-2} is determined; for the sulfonate case a value between 0.01 and 0.1 results. The equilibrium constant, K_2 , for reaction 2 with B⁻ = OH⁻ is k_2/k_{-2} ; it is available from the pK_a of dimethyl phosphonate, *i.e.*, $K_2 = K_a/K_w$. Hammond¹¹ has estimated the pK_a of diethyl phosphonate as about 15, but without a clear basis. Using this value we find $k_{-2} = 10k_2 = 3 \times 10^6 \text{ sec}^{-1}$ and k_3 is then of the order of $10^5 M^{-1} \text{ sec}^{-1}$. Dimethyl phosphite as an intermediate rather than its anion is possible if its reactivity is very high and its acidity is improbably low. Since we did not find evidence of acid catalysis, and since acid catalyzes the iodine reaction, a reaction probably passing through this tautomer, the anion is a more acceptable intermediate.

A question of product stereochemistry appears; the observation that with $Ar = p-CH_3OC_6H_4$ the uv spectrum changed with time may be relevant. The intensity of the visible band increased from a value with ϵ ca. 100 at 475 nm to ϵ 240 at 475 nm in an hour or so. The other bands [λ_{max} 345 nm ($\epsilon 2 \times 10^4$), λ_{max} 242 $(\epsilon 1.3 \times 10^4)$] were unaltered. If this corresponds to a syn-anti change, then the other substances are rearranged either too fast to see or too slow to see; an extremum for the rate with p-OCH₃ substituent is reasonable. The nmr spectrum does not change noticeably, so that we rule out a reaction far more extensive than this stereoisomerization. Since the phosphonate group is electron withdrawing, it is most reasonable to assume that the fastest isomerization will be with para electron-rich substituents (like that of the diazo cyanides¹²) rather than the reverse characteristic of electron-supplying groups on nitrogen, such as in the diazotates¹³ which isomerize most rapidly with the pnitro substituent. It is thus reasonable that all the diazophosphonates studied are syn, and that isomerization to the anti form is detectable only for the *p*-methoxy case. A further support for this argument lies in the extinction coefficients. All the substances had extinction coefficients at the longest wavelength absorption maximum in the range 73–107, including the early measurements on the *p*-methoxy compound. After the spectrum became time stable, the *p*-methoxy compound was well outside this range with ϵ 240.

Experimental Section

Materials .-- Dimethyl phosphonate, Matheson Coleman and Bell practical grade, was dried over Drierite and then distilled through a 14-in. column packed with glass helices. The fraction with bp 62-63° was collected and used; proton nmr found no contaminants.

Diazonium salts were prepared as the fluoroborates and purity was assayed by the uv absorption.¹⁴ The diazotization of sulfanilic acid yielded the inner salt, not requiring any external anion.

Dimethyl Arylazophosphonates.-To a suspension of 0.2 mol of diazonium salt with 0.2 mol of dimethyl phosphonate in 30 ml of water at 0° was added in small portions 15 g of sodium bicarbonate over a period of 15 min. After stirring for an additional 15 min at 0°, the solution was extracted several times with dichloromethane, and evaporation of the solvent left the azophosphonates as red oils in 75-80% yields. The *p*-nitro and the p-cyano compounds were recrystallized [mp 114-116° (lit.⁵ mp 119°) and 74-75°, respectively] from dichloromethane-pentane. The uv spectra are presented in Table II, and in the two cases where recrystallization was possible no significant change was found.

Kinetic Procedures.---A buffer solution with total phosphate 0.1 M made up according to Britten¹⁵ and cooled to 0° was added to a weighed sample of diazonium salt in a volumetric flask. After mixing, the solution was used to fill a 10-cm cell in the thermostated (at 6.0°) compartment of the spectrophotometer. Temperature equilibrium was attained in a few minutes. After about 15 min a 2-µl sample of dimethyl phosphonate was added, the cell was shaken, and then absorbance was recorded at the absorption maximum (485 nm for the p-SO3- compound, 505 nm for the *p*-CN compound).

The absorbances used to calculate the rate constances contained a small correction for a side reaction. Diazotized sulfanilic acid is slightly unstable at the pH used, and an absorbing species is produced. In the times used this change in absorbance

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 (14) E. S. Lewis and M. P. Hanson, J. Amer. Chem. Soc., **89**, 6268 (1967).
 (15) H. S. T. Britten, "Hydrogen Ions," Vol. 1, 3rd ed, Van Nostrand, Princeton, N. J., 1943, p 135.

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ULTRAVIOLE	T Absol	RPTION MAXIM	IA OF p -XC ₆ H ₄ .	$N_2 PO(OMe)_{2^a}$
Registry no.	x	λ_1 , nm (ϵ)	λ2, nm (e)	λ_{δ} , nm (ϵ)
42334 - 47 - 4	NO_2	510(108)	257 (21, 800)	
42334 - 48 - 5	\mathbf{CN}	505 (84)	286 (16,000)	235 (11,000)
42334 - 49 - 6	Cl	496 (96)	310 (17,000)	230 (10,900)
e	OCH_3	475 (240) ^b	345(20,000)	242(12,600)
42398 - 38 - 9	SO_3	$485~(\sim 100)^{\circ}$		
42334 - 52 - 1	CH_3	490(107)	304(14,700)	22 (9370)
42334 - 53 - 2	Η	485 (73) ^d	293 (12,000)	

^a In methanol solutions; extinction coefficients are in parentheses. ^b This extinction coefficient was that obtained after several hours of standing; the initial value was about 100. ^c In water solution assuming a quantitative reaction, the pure azophosphonate was not isolated. Shorter wavelength absorption was not studied because of possible contamination. ^d This maximum was at 487 nm in dioxane solution, with the same extinction coefficient. ^e 42334-51-0 (anti), 42334-50-9 (syn).

is essentially linear with time, *i.e.*, $A = A_0 + k_0 t$, where k_0 is a zero-order rate constant for change of absorbance (A) with time (t). The absorbance was then measured for a while to establish A_0 and k_0 before the dimethyl phosphonate was added. After

the reaction with dimethyl phosphonate was virtually complete, the absorbance continued to increase with the same slope. The corrected absorbances were those calculated by subtracting those due to the zero-order process. This correction was typically up to about 10% of the absorbance change resulting from reaction 1 over about 3 or 4 half-lives. If the extinction coefficient is the same as that of 1, this corresponds to a loss of about 0.5% of the diazonium salt. The correction increased with pH; it is presumably the known decomposition of diazonium salts near pH 7.¹⁶ This correction was negligible with *p*-cyanobenzenediazonium ion, but another absorbance change after the reaction was complete was presumed to represent the hydrolysis of the methoxy groups of the azophosphonate. The effect was minimized by using data from the first two half-lives only.

This known hydrolytic instability, characteristic of all these substances, prevented the study of these methods over very long periods which would have answered questions about possible isomerization rates.

Registry No.—p-XC₆H₄N₂⁺: X = SO₃⁻, 305-80-6; X = CN, 19262-72-7; X = NO₂, 14368-49-1; X = Cl, 17333-85-6; X = OMe, 17333-79-8; X = Me, 14597-45-6; X = H, 2684-02-8.

(16) See, for example, C. Rüchardt and E. Merz, Tetrahedron Lett., 2431 (1964).

Anomalous Photocyclization of Methyl 2-(1-Naphthyl)-3-(4-pyridyl)acrylate¹

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Oxidative photocyclization of methyl 2-(1-naphthyl)-3-(4-pyridyl)acrylate (5b) gave acenaphthene and acenaphthylene derivatives by cyclization to the 8 position of the naphthalene ring rather than the expected azachrysene that would result from cyclization into the 2 position. Chemical and spectral evidence is presented to support structural assignments of the products.

The oxidative photocyclization of stilbene and related compounds is a useful synthetic route to many polycyclic compounds.² For example, oxidative photocyclization of 2-phenyl-3-(4-pyridyl)acrylonitrile (1) is reported to yield 6-cyanobenz [h]isoquinoline (2) in good yield,³ and likewise, 1-styrylnaphthalene has been reported to yield chrysene.⁴ In a similar manner, photocyclization of 4-styrylquinoline (3) gave benzo[i]-



 ⁽¹⁾ Supported by Contract NIH-71-2070 from the Division of Cancer Treatment, National Cancer Institute, National Institutes of Health.
 (2) See, for example, A. Schönberg, "Preparative Organic Photochem-

phenanthridine (4).⁵ Based on these reactions, oxidative photocyclization of **5b** appeared to be a reasonable synthetic approach to the naphth [1,2-h] isoquinoline **6a**.

An attempt to prepare azachrysene **6a** by oxidative photocyclization of **5b** in methanol (see Experimental Section) led to isolation of a yellow solid in low yield. The 60-MHz nmr spectrum of the yellow product was



not consistent with structure 6a, as it lacked a singlet near δ 10.0 expected for H₄,⁶ and 100-HMz nmr revealed that the 4-pyridyl group was unchanged from 5b. The mass spectrum showed a molecular ion at m/e287, indicating a loss of 2 in molecular weight from 5b.

Examination of the photocyclization products (Scheme I) from **5b** by chromatography on silica gel gave as the major fraction (75-80% by weight) a yellow oil, which exhibited two overlapping spots on tlc (ethyl acetate or chloroform), one of which corresponded to the yellow solid. Nmr examination of the oil revealed a set of doublets not present in the crystalline solid.

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⁽⁵⁾ C. E. Loader and C. J. Timmons, J. Chem. Soc. C, 1457 (1967); 330 (1968).

⁽⁶⁾ H₁ in **2**, prepared during the course of this investigation, was found at δ 10.08. See also O. De Silva and V. Snieckus, Synthesis, 254 (1971).