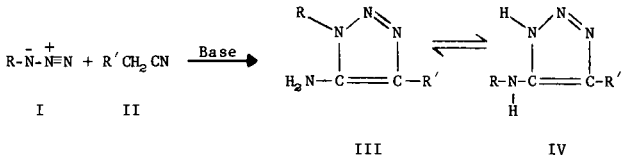
The Condensation of Diphenylphosphinic Azide with Substituted Acetonitriles - Formation of Phosphorylated tetrazolines (1)

K. D. Berlin, R. Ranganathan (2) and H. Haberlein (3)

Department of Chemistry, Oklahoma State University

The condensation between diphenylphosphinic azide and several substituted phenylacetonitriles was investigated. Rather than a substituted aminotriazole, a phosphorylated tetrazoline (IX) was isolated from several reactions. In addition, a phosphorylated nitrile (X) and a phosphorylated eniminonitrile (XI) were found. *N*-Acylation of IX, followed by warming, lead to a phosphorylated oxadiazoline (XX). Structural assignments are based on UV, IR, and NMR spectral data and chemical degradative evidence. A brief analysis of the results is presented.

The reaction between azides and activated or "strained" alkenes with a view to obtaining the corresponding triazolines and/or their decomposition products has been the object of investigation by a number of research workers (4a-d) in recent years. Another approach to such a ring system, which was first reported by Dimroth (5) and later developed by other workers (6), is the condensation between an azide (I) and a substituted acetonitrile (II) in the presence of base to yield 1,4-disubstituted-5-amino-1,2,3-triazoles (III). These 5-amino-1,4-dialkyl-1,2,3-triazoles (III) seem to have a propensity to undergo

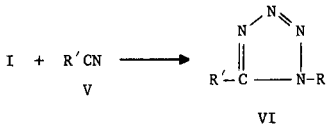


I II III IV

Ia. R=$(C_6H_5)_2P(O)$; IIa. R′=R-C_6H_4

rearrangement to 5-alkylamino-4-alkyl-1,2,3-triazoles (IV), and the factors governing the migration of the alkyl group from the ring nitrogen atom to the amino group has been investigated in detail by two different groups (6-8). The kinetics of this rearrangement and the effect of reaction media and substituents on this reaction have come under the purview of these authors.

Under non-alkaline conditions the reaction between substituted nitriles (V) and azides (I) has been known (9-11) to yield 1,5-disubstituted 1,2,3,4-tetrazoles (VI). The reaction has been carried out only with nitriles which



V VI

do not possess α-hydrogens; electron-withdrawing groups on the nitriles seem to affect favorably the course of the reaction. In some instances 2,5-disubstituted 1,2,3,4-tetrazoles have been isolated (11).

Recently, a number of phosphorylated 1,2,4-triazoles and other nitrogen-bearing five-membered heterocyclic systems were prepared by subsequent phosphorylation of the initially formed heterocycles (12-15). We have found that reaction of diphenylphosphinic azide (Ia) with arylacetonitriles leads to *tetrazolines* which contrasts with the amino triazoles reported by others when alkyl or aryl azides were employed (4-6). Our conditions employed potassium *t*-butoxide as the base to generate the anion from acetonitrile in tetrahydrofuran. In view of the known sensitivity of the P-N bond in Ia towards electrophilic attack (16), the displacement of the azide group by the alkoxide ion, or the ion formed from the acetonitrile, was expected to be a significant side-reaction. Preliminary experiments indicated that with sodium methoxide in methanol, the displacement reaction by methoxide ion predominated. Although potassium *t*-butoxide reacts with Ia to form *t*-butyl diphenylphosphinate (16), by proper selection of the conditions and the mode of addition of the reactants, it was possible to enhance the yield of the heterocyclic product. Under alkaline conditions, an important side reaction of the nitriles bearing α-hydrogens

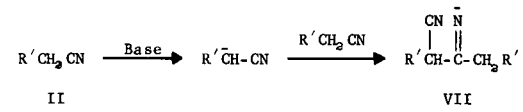
TABLE I

Properties, Analyses and Yields of the Tetrazolines and the Nitriles

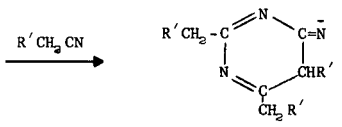
Compound	M.p. °C	Formula	u Elemental analysis Found (Calculated) C	H	N	P	Halogen	Yield (%)
IXa	277-278 (dec.)	$C_{20}H_{17}N_4OP$	66.71 (66.75)	4.62 (4.76)	15.64 (15.55)	8.71 (8.60)		20.5
IXb (a)	266.5-267.5	$C_{20}H_{16}ClN_4OP$	60.65 (60.84)	4.22 (4.09)	14.07 (14.19)	7.75 (7.85)	9.14 (8.98)	18.2
Xb (b)	215-216	$C_{20}H_{25}ClNOP$	68.00 (68.28)	4.37 (4.27)	4.02 (3.98)	8.72 (8.82)	10.31 (10.10)	28.0
Xc	208-209	$C_{20}H_{15}ClNOP$	68.11 (68.28)	4.14 (4.27)	4.01 (3.98)	8.63 (8.82)	10.37 (10.10)	6.3
XIa	202-203	$C_{28}H_{23}N_2OP$	76.87 (77.42)	5.30 (5.30)	6.44 (6.45)	7.35 (7.14)		26.0
XId (c)	206-207	$C_{28}H_{21}F_2N_2OP$	71.62 (71.48)	5.02 (4.47)	5.93 (5.96)	6.80 (6.60)	7.61 (8.09)	16.3
XIe	196-197	$C_{30}H_{27}N_2O_3P$	72.95 (72.89)	5.40 (5.47)	5.60 (5.67)	6.46 (6.26)		37.0

(a) molecular weight found 402 (Calcd. 394.5), (b) molecular weight found 354 (Calcd. 351.5), (c) molecular weight found 480 (Calcd. 470)

would be their self-condensation which has been shown (17-19) to lead to β-iminonitriles (the precursor is VII) and pyrimidines (the precursor is VIII). Products expected from the phosphorylation of VII could be isolated in moderate yields. However, no evidence for the



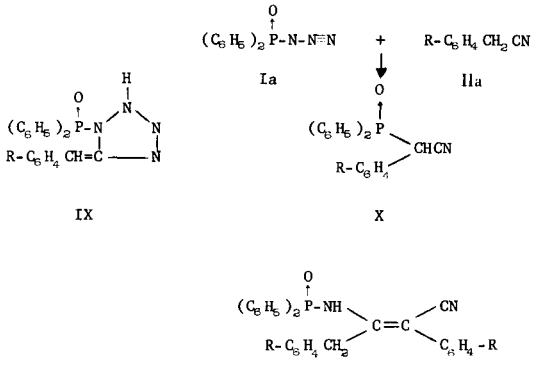
II VII



VIII

formation of pyrimidine derivatives was obtained in this study.

The reaction sequence consisted of adding a freshly



a) R = H; b) R = *p*-Cl; c) R- *m*-Cl; d) R = *p*-F; d) R = *p*-OCH_3

prepared solution of the anion from II in tetrahydrofuran, prepared by treating the arylacetonitrile (IIa) with a solution of potassium *t*-butoxide in this same solvent, to a solution of Ia in tetrahydrofuran. This mode of operation was chosen as it was found that the alternative mode of addition precluded formation of the heterocycles to a considerable extent and led only to displacement products. Analysis of the reaction mixture from Ia and several

TABLE II

IR and UV Spectral Data of the Tetrazolines and the Nitriles

Compound	Infrared Data KBr Wave Number (cm^{-1})	Assignment	Ultraviolet Data 2-Propanol (or ethanol) Wave Length (mμ)	ε
IXa	2250-3500	N-H	(254), (260)	*
	1179	P → O	(266), (273)	
IXb	2250-3500	N-H	(260)	(16,500)
	1180	P → O	(266)	(20,400)
			(273)	(16,500)
Xb	2235	C≡N	261	1708
	1206	P → O	267	2160
			274	1882
			303	200.9
Xc	3058	C-H Ar	262	1470
	2237	C≡N	267	1854
			274	1656
	1198	P → O	300	277.5
XIa	2205	C≡N	274	12,900
	1211	P → O		
XId	2203	C≡N	270	15,000
			320-338 (inflection)	3,440
	1202	P → O		
XIe	2210	C≡N	278	17,930
	1191	P → O		

* ε value could not be determined due to low solubility.

substituted phenylacetonitriles (IIa); R = H, *p*-Cl, *m*-Cl, *p*-F and *p*-OCH_3) resulted in the characterization of mainly three classes of products; the phosphorylated tetrazoline (IX), the monomeric phosphorylated nitrile (X) and the dimeric phosphorylated eniminonitrile (XI). (See Tables I, II and III for physical properties of these compounds). Table IV gives an idea of the nature and distribution of the products from the different substituted phenylacetonitriles.

With the tetrazolines (IX), the first indication that they might be products of simple addition came from their elemental analyses and molecular weight determination. The heterocyclic IXb had a molecular weight of 403 (calcd., 394.5). The two compounds, IXa and IXb, absorbed in the UV at 254-273 mμ with high molecular extinction coefficient values indicative of the presence of an extended conjugated system. In the IR spectrum the presence of a broad multi-shouldered band in the 2250-3500 cm^{-1} region was characteristic of the presence of an acidic proton on nitrogen. [The solubility of these two compounds in cold aqueous alkali and their acylation (see later) corroborate this inference.] A deeper insight into the structure of these compounds was available by NMR spectrometry, though their poor solubility in the common solvents posed some problems. In trifluoroacetic acid, in which they were freely soluble, IXa and IXb exhibited the aromatic protons as a complex multiplet between 430 and 500 c/s analyzing for the required number of protons. In addition there was a doublet at 374 c/s in IXa and 385 c/s in IXb (a total of one proton in each compound) and this was attributed to the olefinic proton. Obviously the N-H proton could not be observed in this solvent as rapid chemical exchange is expected to occur between this

TABLE III

NMR Data of the Tetrazolines and the Nitriles

Compound	Solvent	Aromatic* Protons	Methine Protons* (Methoxy Protons)	Methylene* Protons	NH proton*	Remarks
IXa	TFA	430-492,15,m	374,1,d,J=10	--	--	NH proton exchanges with that of the solvent.
IXb	TFA	430-500,14,m	385,1,d,J=10	--	--	NH proton exchanges with that of the solvent.
	C_5D_5N†	426-511,14,m	405,1,d,J=10	--	overlaps on the aromatic peaks, 1,m.	The compound reacts with the solvent upon standing.
	TMU	430-499,14,m	385,1,d,J=10	--	overlaps on the aromatic peaks, 1,m.	A 17% solution was used. Integration not accurate due to the solvent peak.
	TMU + D_2O	430-500,14,m	380,1,d,J=10	--	--	NH proton exchanges with D_2O. HDO peak appears at high-field.
	DMSO-d_6	410-500,14,m	391,1,d,J=10	--	overlaps on the aromatic peaks, 1,m.	A 17% solution was used.
	DMSO-d_6 +D_2O	410-500,14,m	387,1,d,J=10	--	--	NH proton exchanges with D_2O. HDO peaks appears at high-field.
Xb	TFA	419-490,14,m	323,1,3,J=18	--	--	No reaction with solvent.
	$CDCl_3$	418-488,14,m	284,1,d,J=18	--	--	Methine proton does not exchange with D_2O.
Xc	TFA	417-492,14,m	320,1,d,J=17	--	--	No reaction with solvent.
	$CDCl_3$	425-492,14,m	284,1,d,J=18	--	--	Methine proton does not exchange with D_2O.

XIa	TFA	430-500,20,m	--	255,2,s	395,1,d,J=10	Reacts slowly with solvent.
	$CDCl_3$	420-470,20,m	--	255,2,s	366,1,d,J=10	NH proton exchanges with D_2O.
XId	TFA	400-480,18,m	--	255,2,s	387,1,d,J=10	Reacts slowly with solvent.
	$CDCl_3$	400-480,18,m	--	254,2,s	357,1,d,J=10	NH proton exchanges with D_2O.
XIe	$CDCl_3$	393-467,18,m	(277,3,s) (223,3,s)	249,2,s	258,1,d,J=10	NH proton exchanges with D_2O. The compound reacts rapidly with trifluoroacetic acid.

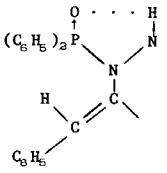
*Data are given in the following order: chemical shift, No. of protons, multiplicity, coupling constant in c/s. m = multiplet, d = doublet, s = singlet. Chemical shifts in c/s from TMS.
† Spectrum taken using the C-1024 computer. No. of scans varied from 100-400. TFA - Trifluoroacetic acid. TMU - Tetramethylurea C_5D_5N - Pyridine-d_5.

TABLE IV

Nature and Distribution of the Products

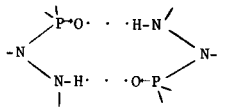
Substituent	Products (distribution)		
	Tetrazoline IX	Monomeric Nitrile X	Dimeric Eniminonitrile XI
m-Cl	--	Xc (100%)	--
p-Cl	IXb (39.1%)	Xb (60.9%)	-- --
H	IXa (43.5%)	--	XIa (56.5%)
p-F	--	--	XId (100%)
p-OCH_3	--	--	XIe (100%)

proton and that of the solvent. The tetrazoline (IXa) could not be studied in any other solvent due to poor solubility. However, IXb in DMSO-d_6 displayed the N-H proton as a broad signal superimposed on the complex multiplet arising from the aromatic protons. The ratio of the peaks in this region to the single proton doublet in the downfield region was, as expected, 15:1. On the addition to deuterium oxide, however, the ratio changed to 14:1 and a new broad signal appeared between 338 and 246 c/s, assignable to the HDO formed. Similar results were obtained in tetramethylurea and pyridine-d_5, although the data were less accurate due to lower solubility. The splitting (J = 10 c/s) of the olefinic proton in IXb, although not expected, may be traced to long-range coupling of this proton to the P-atom through the system P(=O)-N-C=C-H. A similar splitting was also noticed in the case of the phosphorylated oxadiazoline (XX) described below, where again the olefinic proton and the P atom are linked in the same manner. Such P, H coupling through four intervening bonds, one of which incorporates a π system and/or where at least one of the linking atoms is a heteroatom, is not without analogy in the literature. Long-range couplings in the saturated P-N-C-C-H system where J values of the order of 0.7 c/s have been detected (20). In the P-O-C=C-H system, coupling constants of about 1.8 cps (*cis*) and 0.9 cps (*trans*) have been reported (21, 22) between the P and H atoms. In the tetrazolines, IXa and IXb, hydrogen bonding (in the oxadiazoline (XX) no similar hydrogen bonding can occur but $J_{PNC=CH} = 12$ c/s; some difference from this value for XII would be expected since the structural environment differs in XX from that of XII) may occur between the proton on nitrogen and the oxygen atom of P → O groups.

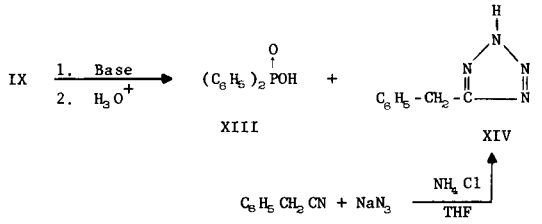


XII

Long range coupling between P and H have been reviewed (23). Dilution studies with IXb (10% solution) in DMSO indicate strong absorption at 3424, 2400-2700 (polymeric intermolecular hydrogen bonding), and 1207 cm^{-1} (P→O) in the infrared. Upon an initial 50% dilution, the peak at 3424 cm^{-1} increased in intensity while the frequencies associated with the polymeric hydrogen bonding and P → O group decreased as expected in a fixed pathlength cell. Further dilution leads to small decreases in absorption for all peaks. This suggests perhaps a dimeric structure of IXb in increased in concentration upon dilution perhaps of the structure shown. We cannot rule out intramolecular hydrogen bonding as shown in XII (24). It has been shown previously that simple acidic compounds of phosphorus do form dimeric substances upon dilution (25). Such hydrogen bonding should be particularly favored in compound IX as the double bond, being *exo* to the five-membered ring, should force the phosphoryl and the benzylidene groups away from each other.



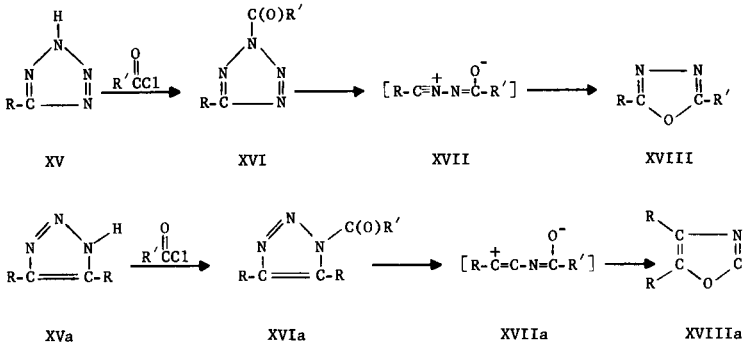
Additional evidence for the structure IXa was furnished when on alkaline hydrolysis, it yielded diphenylphosphinic acid (XIII) and 5-benzyl-1,2,3,4-tetrazole (XIV) in quantitative yield (10). Proof of the identity of this compound followed from an independent synthesis of 5-benzyl-1,2,3,4-tetrazole (XIV) obtained by a known procedure (10). The UV, IR and NMR spectra of the two samples were identical in all respects and the mixture melting point was undepressed. The mass spectrum of XIV showed the M^+ peak at m/e 160, while the base peak was at m/e 91.



XIII XIV

This peak is probably due to the tropylium cation formed by cleavage of the benzyl group. Two other intense peaks at m/e 132 and m/e 117 could have arisen by the loss of N_2 and hydrazoic acid, respectively. In the NMR spectrum of XIV, in DMSO-d_6, the N-H proton signal, being very broad, could be detected only by the integration curve and it occurred between 730 and 850 c/s and analyzed for one proton. On addition of deuterium oxide, this signal disappeared giving rise to the HDO peak at 146 c/s. The phenyl and methylene protons were seen as sharp singlets at 440 c/s (5H) and 260 c/s (2H), respectively.

Since tetrazoles are known (26) to be relatively stable to base, it is reasonable to assume that no rearrangements are likely under the conditions of hydrolysis. This leads to an affirmation of the tetrazoline nature of the heterocycle IX. Basic hydrolysis resulted in cleavage of the P-N bond; this was followed by the migration of the double bond *via* protonation at the benzylic carbon atom during acidification of the mixture. Surprisingly, com-

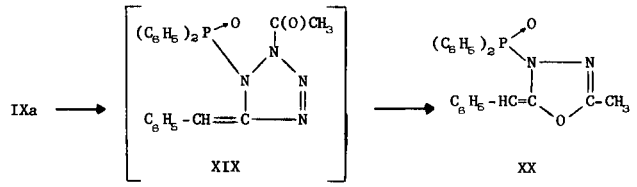


XV XVI XVII XVIII

XVa XVIa XVIIa XVIIIa

pound IXa was resistant to hydrolysis by boiling 3*N* alcoholic hydrochloric acid and was quantitatively recovered unchanged after this treatment.

Acylation of 5-substituted-1,2,3,4-tetrazoles (XV) is known (27) to lead to 1,3,4-oxadiazoles (XVIII) at mild temperatures (< 60°) by elimination of N_2 from the initially formed *N*-acyltetrazoles (XVI). *N*-Acylnitrilimines (XVII) have been postulated as hypothetical intermediates on the basis of labelling studies (28). However, 1,2,3-triazoles (XVa) yield *N*-acyltriazoles (XVIa) which are reported to be more stable (29) and lose N_2 only at very high temperatures (254°) to give oxazoles (XVIIIa) in low yield. This difference between tetrazoles and triazoles has been explained (29b) as resulting from the lower stability of the intermediate XVIIa compared to XVII. In the light of this fact, acetylation of IXa was carried out in boiling pyridine to obtain, in excellent yields, the 1,3,4-oxadiazoline (XX). No attempt was made to isolate the *N*-acyltetrazoline (XIX), and it apparently lost



IXa XIX XX

N_2 to yield the oxadiazoline (XX). In the IR spectrum of XX, the P → O absorption occurred at 1189 cm^{-1} while the two sharp bands at 1587 and 1552 cm^{-1} were tentatively assigned to the C=C and C=N bonds. In the NMR spectrum, the phenyl protons were observed as a multiplet (15 H) between 420 and 480 c/s, and the methyl protons occurred as a sharp singlet (3 H) at 145 c/s. A doublet (1 H; J = 12 c/s) at 321 c/s was ascribed to the olefinic proton.

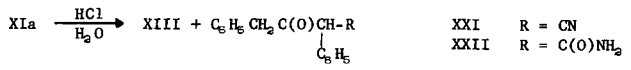
An attempt was made to hydrolyze XX to obtain the parent compound 2-methyl-5-benzyl-1,3,4-oxadiazole. Treatment with alcoholic hydrochloric acid gave a crystalline solid which, from its non-melting nature and from its IR spectrum (broad peaks in the region 2500-3600 cm^{-1}; peaks at 1652 and 1170 cm^{-1}), was presumed to be the corresponding oxadiazolium salt. On reacting XX with alcoholic potassium hydroxide, the oxadiazole ring was cleaved to diphenylphosphinic acid (XIII) and phenylacetic acid.

The two groups of nitriles, X and XI, could be identified mainly from their spectral characteristics. The doublet at 284 c/s in the NMR spectra of the compounds X with J = 18 c/s is assigned to the methine proton which is expected to be split by the P atom. The aromatic protons occurred between 418 and 490 c/s and analyzed for the required number of protons in each case. In the IR spectra of compounds X, the nitrile absorbed at 2235-2242 cm^{-1} in potassium bromide (or in chloroform), indicative of an unconjugated nitrile group (see below). Weak bands in the region 1587-1600 cm^{-1} were assigned to the aromatic residue. In sharp contrast, these bands (1587-1600 cm^{-1}) in the IR spectra of the eniminonitriles (XI) were strong, suggestive of the presence of a styrene residue. In agreement with this, the nitrile absorption was observed at 2203-2210 cm^{-1} as expected of an α,β-unsaturated nitrile group. The N-H band, which should be present if structure XI was the true representative of these compounds, was located in chloroform at about 3400 cm^{-1} though in potassium bromide this band was hardly discernable. The UV spectral data of the two groups of nitriles point to the same conclusions. In the region 250-280 mμ, the monomeric nitriles (X), in chloroform as well as in 2-propanol, exhibited the benzenoid absorption with molecular extinction coefficient values in the expected range (ϵ = 1470-2242). The eniminonitriles (XI), however, absorbed very strongly in this region, in the same solvents; the molecular extinction coefficients (ϵ, values ranged from 10,790 to 17,930. The presence of a conjugated moiety in the molecule is thus indicated.

The NMR spectra in deuteriochloroform of the eniminonitriles (XI) provided strong evidence of their structure.

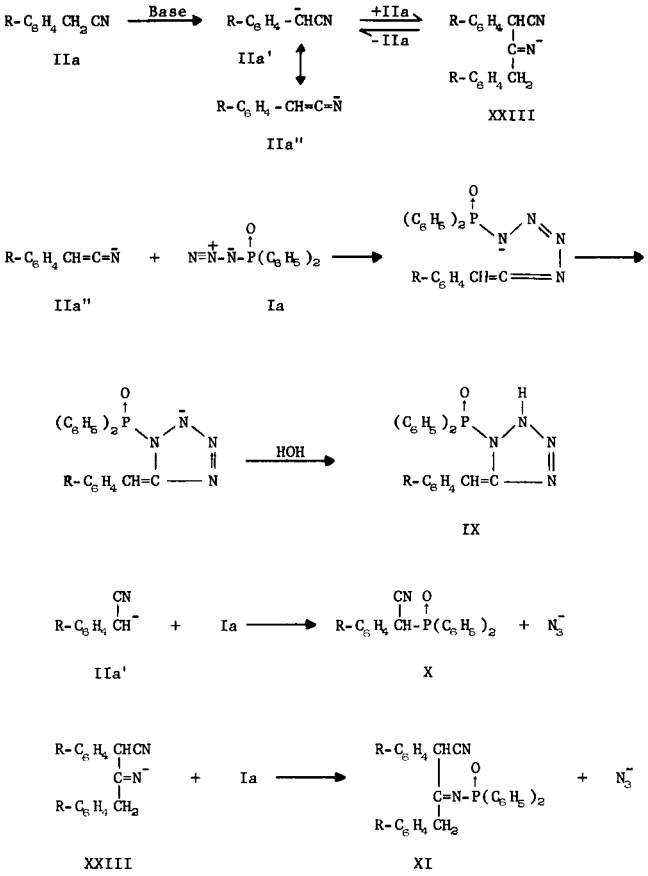
The methylene group appeared as a sharp singlet (2 H) at 255 c/s and the N-H proton as a doublet of multiplets (1 H) in the region 357-366 c/s with J = 10 c/s. The latter disappeared when XI was shaken with deuterium oxide. The aromatic protons were observed as a complex multiplet between 400 and 480 c/s. In trifluoroacetic acid, the N-H proton of XI was deshielded by about 30 c/s (from the chemical shift in deuteriochloroform) as expected for a labile proton. These compounds (XI) decompose upon standing in trifluoroacetic acid. In the case of the nitriles of structure X, the methine proton was also deshielded by 36-40 c/s in trifluoroacetic acid as compared to its chemical shift in deuteriochloroform, but, however, it did *not* exchange with deuterium oxide. In full agreement with the assignments for the two groups of nitriles, X and XI, the molecular weight of Xb was found to be 359 (calcd. 351.5) and that of XId gave a value of 480 (calcd. 470).

Degradation of the dimeric eniminonitrile (XIa) by aqueous acid produced α,γ-diphenyl-β-keto-butyronitrile (XXI) or products therefrom. Treatment of XIa with alcoholic potassium hydroxide yielded only diphenylphosphinic acid (XIII) and phenylacetic acid which are to be expected from XXI. From reaction of XIa with dilute alcoholic hydrochloric acid it was possible to isolate XIII and α,γ-diphenyl-β-keto-butyramide (XXII), a known compound (30).



In the IR spectrum of XXII, peaks are visible at 3378 and 3178 (NH_2), 1704 (C=O) and 1626 and 1592 cm^{-1} ($CONH_2$). In the NMR spectrum, in deuteriochloroform (31), the aromatic protons occurred in the region 416-452 c/s, the $-NH_2$ protons between 284 and 330 c/s (broad-2H), the methine proton at 230 c/s (singlet-1H) and the methylene protons at 206 c/s (singlet-2H). On treatment with deuterium oxide, the signal in the region 284-330 c/s disappeared giving rise to the HDO peak. The mass spectrum showed the M^+ peak at m/e 253. Again the base peak, due to the tropylium ion, was at m/e 91. The other significant peaks were at m/e 162, 165, 135, 119, 118, 92, 66, 65 and 63. The isolation of the substituted butyramide (XXII) places the structure of the dimeric eniminonitriles (XI) on a sound basis.

A brief analysis of our results is now in order. The first step in the reaction of IIa would be the formation of the anion (IIa′ ⇄ IIa″) which presumably exists in equilibrium with the dimeric anion (XXIII). Attack by the ketimine form (IIa″) of the monomeric anion (IIa′) at the terminal nitrogen atom of the azide molecule followed by cyclization, as indicated, and subsequent protonation is a reasonable pathway leading to the tetrazolines (IX). A simple nucleophilic displacement of the azide anion by the monomeric anion (IIa′) on the phosphorous atom of the azide molecule (Ia) would produce the nitriles (X). On the other hand if the dimeric anion (XXIII) attacks Ia, the dimeric eniminonitriles (XI) results. Obviously the rate for the dimerization of IIa′ and the factors governing the fate of this intermediate are intimately related to its stability which in turn is probably dependent on the substituents on the aromatic nucleus. Although the data (Table IV) available to us do not permit a rigorous analysis of the electronic effects on the dimerization (IIa′ ⇄ XXIII), it suggests that with the *m*-chloro substituted compound (inductive effect operative rather than resonance effect) there is enhancement for formation of the respective anion. Since the anion (IIc′, from the *m*-Cl compound) would also be a weak base compared to *t*-butoxide ion, the dimerization reaction involving IIc and



IIc′ might be less facile. In the case of strong electron-donating substituents (*e.g.*, *p*-OCH_3), the equilibrium might favor the dimeric anion (XXIII) significantly because of the twin factors of greater basicity and availability of undissociated molecules. As regards substituents which have an influence on the reaction course in between these two extremes (*e.g.*, *p*-Cl, H, *p*-F), the corresponding anions are probably less selective thereby leading to mixtures of products. To be sure, our interpretation is qualitative and the actual situation could be governed by several other parameters not investigated here such as solvation of the anions.

EXPERIMENTAL

All melting points are uncorrected. UV spectra were taken on a Cary 14 recording spectrophotometer. Infrared spectra were recorded with a Beckman IR-5A instrument. Nuclear magnetic resonance spectra were obtained on a Varian A-60 spectrometer. Time averaged NMR spectra were recorded using the Varian C-1024 computer. The mass spectra were run on an LKB 9000 mass spectrometer.

Diphenylphosphinic Azide (Ia).

This compound was prepared as described by Baldwin and Washburn (32a). Attempts to distill Ia at pressures of the order of 0.05 mm. led to extensive decomposition and proved hazardous once. The compound could be purified, however, without any decomposition in a molecular-still at a pressure of about 0.1 μ (32b).

(5-Benzylidene-1,2,3,4-2*H*-tetrazoline-1-yl)-*P,P*-diphenylphosphine Oxide (IXa) and *N*-2-(1-Phenyl-3-cyano-3-phenyl-propene-2-yl)-*P,P*-diphenylphosphinic Amide (XIa).

Potassium *t*-butoxide (13.44 g., 0.12 mole) was dissolved in dry tetrahydrofuran (200 ml.) under nitrogen. Phenylacetonitrile (12.87 g., 0.11 mole) was added dropwise and the resulting reddish-brown solution was stirred at room temperature for 30 minutes. A solution of diphenylphosphinic azide (Ia) (24.3 g., 0.1 mole) in dry tetrahydrofuran (200 ml.) was placed in a 2-necked flask under nitrogen. The reddish-brown solution of the anion of phenylacetonitrile was added dropwise (after filtration through glass wool under nitrogen) to the stirred solution of the azide (Ia) at room temperature over a period of 3 hours. The resulting dark-red mixture was stirred overnight and then acidified with glacial acetic acid (30 ml.) at which time it turned to a clear orange solution. The solution was cooled (5°) and diluted with ice-cold water (1.5 l.). A yellow precipitate formed and was filtered and dried at 100°. The crude product (19.4 g.) was extracted five times with hot benzene. The residual white crystalline solid (7.38 g.) was identified as (5-benzylidene-1,2,3,4-2*H*-tetrazoline-1-yl)-*P,P*-diphenylphosphine oxide (IXa). Recrystallization from glacial acetic acid gave the analytically pure sample, m.p. 277-278° (dec.).

The combined orange-colored benzene extracts were evaporated to about 200 ml. On standing, a precipitate of *N*-2-(1-phenyl-3-cyano-3-phenyl-propene-2-yl)-*P,P*-diphenylphosphinic amide (XIa) was deposited; this was filtered and crystallized twice benzene-*n*-hexane) to obtain fine white needles (8.24 g.), m.p. 202-203°.

[5-(*p*-Chlorobenzylidene)-1,2,3,4-2*H*-tetrazoline-1-yl]-*P,P*-diphenylphosphine Oxide (IXb) and (α-Cyano-*p*-chlorobenzyl)-*P,P*-diphenylphosphine Oxide (Xb).

The procedure was the same as for IXa. The following starting materials were used: *p*-chlorophenylacetonitrile (16.7 g., 0.11 mole); diphenylphosphinic azide (26.3 g., 0.10 mole); potassium *t*-butoxide (13.5 g., 0.12 mole). The crude yellow product (20.7 g.) was extracted with hot benzene. The residual solid (7.19 g.) was identified as [5-(*p*-chlorobenzylidene)-1,2,3,4-2*H*-tetrazoline-1-yl]-*P,P*-diphenylphosphine oxide (IXb). After one crystallization from glacial acetic acid, the product melted at 256-257° (dec.). The yellow benzene extracts were evaporated to a small volume and (α-cyano-*p*-chlorobenzyl-*P,P*-diphenylphosphine oxide (Xb) precipitated. It was crystallized twice (benzene-*n*-hexane) to give white needles (9.9 g.), m.p. 215-216°.

(α-Cyano-*m*-chlorobenzyl)-*P,P*-diphenylphosphine Oxide (Xc).

The procedure was the same as for IXa. The following materials were used: *m*-chlorophenylacetonitrile (8.35 g., 0.055 mole); diphenylphosphinic azide (12.15 g., 0.050 mole); potassium *t*-butoxide (8.40 g., 0.075 mole). The crude yellow oil obtained was dissolved in hot acetone and addition of *n*-hexane yielded a yellow solid which was crystallized (benzene) to give (α-cyano-*m*-chlorobenzyl)-*P,P*-diphenylphosphine oxide (Xc) (1.2 g.), m.p. 208-209°.

N-2-[1-(*p*-Fluorophenyl)-3-cyano-3-(*p*-fluorophenyl)-propene-2-yl]-*P,P*-diphenylphosphinic Amide (XId).

The procedure was the same as for XIa. The starting materials were: *p*-fluorophenylacetonitrile (7.63 g., 0.055 mole); diphenylphosphinic azide (12.15 g., 0.050 mole); potassium *t*-butoxide (6.72 g., 0.060 mole). The crude product (7.0 g.) was crystallized (benzene-*n*-hexane) to obtain *N*-2-[1-(*p*-fluorophenyl)-3-cyano-3-(*p*-fluorophenyl)-propene-2-yl]-*P,P*-diphenylphosphinic amide (XId) as white flakes (3.0 g.), m.p. 203-205°. Further purification gave the analytical sample, m.p. 205-206°.

N-2-[1-(*p*-Methoxyphenyl)-3-cyano-3-(*p*-methoxyphenyl)-propene-2-yl]-*P,P*-diphenylphosphinic Amide (XIe).

The procedure was the same as for XIa. The starting materials were: *p*-methoxyphenylacetonitrile (8.10 g., 0.055 mole); diphenylphosphinic azide (12.15 g., 0.050 mole); potassium *t*-butoxide (6.72 g., 0.060 mole). The crude yellow product (8.72 g.) was dissolved in benzene-*n*-hexane. The fine white needles were identified as *N*-2-[-1-(*p*-methoxyphenyl)-3-cyano-3-(*p*-methoxyphenyl)-propene-2-yl]-*P,P*-diphenylphosphinic amide (XIe) (6.43 g.), m.p. 197.8°.

Degradation of (5-Benzylidene-1,2,3,4-2*H*-tetrazoline-1-yl)-*P,P*-diphenylphosphine Oxide (IXa).

(a) Attempted acid hydrolysis:

The tetrazoline (IXa, 0.2 g.) was heated at reflux for 8 hours with a solution of concentrated hydrochloric acid (15 ml.) and 95% ethanol (35 ml.). The mixture was diluted with water, filtered and the white residue washed and dried. The IR spectrum of this material was identical with that of the starting material. The compound was quantitatively recovered.

(b) Basic hydrolysis:

The tetrazoline (IXa, 1.0 g.) was heated to reflux with 30% aqueous potassium hydroxide (60 ml.) for 4 hours. The cooled solution was acidified with ice-cold 2*N* hydrochloric acid. The precipitate was filtered, washed with water, dried and then

crystallized (ethanol) to provide XIII, m.p. 193-194°, identified as such by the undepressed mixture melting point with an authentic sample and by its IR spectrum.

The original filtrate was evaporated to dryness, and the residue was extracted (methylene chloride) in a soxhlet extractor. Removal of the solvent left a solid residue which was twice crystallized (benzene) and gave 5-benzyl-1,2,3,4-tetrazole (XIV), m.p. 124-125° (lit. (10) 123-125°), white needles; UV λ max (ethanol); 248 (ε, 20,600), 252 (ε, 27,500), 258 (ε, 34,600), 264 (ε, 33,200) and 268 mμ (ε, 27,500); IR (potassium bromide), broad peaks in the region 3500-2200 (NH), 1540 (C=N), 1750-2000 and 670-750 cm^{-1} (aromatic ring). The two compounds XIII and XIV were obtained in quantitative yields.

5-Benzyl-1,2,3,4-tetrazole (XIV).

The procedure described by Finnegan and coworkers (10) was followed. The starting materials were: phenylacetonitrile (11.7 g.); sodium azide (7.15 g.); ammonium chloride (12 g.); dimethylformamide (50 ml.). The product (10.7 g.) was crystallized from benzene twice to give 5-benzyl-1,2,3,4-tetrazole (XIV) (8.5 g.), m.p. 122-126°, yield 53.1%. Mixture melting point with the sample obtained by the hydrolysis of IXa was 123-125.5°. The IR spectra of the two compounds were superimposable.

Conversion of (5-Benzylidene-1,2,3,4-2*H*-tetrazoline-1-yl)-*P,P*-diphenylphosphine Oxide (IXa) into (2-Methyl-5-benzylidene-1,3,4-oxadiazoline-4-yl)-*P,P*-diphenylphosphine Oxide (XX).

A mixture of the tetrazoline IXa (0.5 g.) and acetic anhydride (4 ml.) in dry pyridine (25 ml.) was heated to reflux for 1 hour. The reaction mixture was diluted with water (200 ml.) and saturated with sodium chloride. The solid which precipitated was filtered, washed and dried. The crude material (0.49 g.), yield 94.3%, m.p. 237-238°, was crystallized once (chloroform-*n*-hexane) to give (2-methyl-5-benzylidene-1,3,4-oxadiazoline-6-yl)-*P,P*-diphenylphosphine oxide (XX), as a white solid, m.p. 237-238°.

Anal. Calcd. for $C_{22}H_{19}N_2O_2P$: C, 7.49; P. 8.29. Found: N, 7.81; P. 8.32.

Degradation of (2-Methyl-5-benzylidene-1,3,4-oxadiazoline-4-yl)-*P,P*-diphenylphosphine Oxide (XX).

(a) Attempted acid hydrolysis:

The oxadiazoline (XX, 0.1 g.) was heated to reflux with a mixture of concentrated hydrochloric acid (1 ml.) and 95% ethanol (9 ml.) for 2 hours. The mixture was then diluted with brine and filtered. The white residue was washed and dried (sodium sulfate). This material (0.1 g.) did not melt up to 330° and showed in its IR spectrum, peaks in the region 2500-3600, 1652 and 1170 cm^{-1}. It was presumed to be the corresponding oxadiazolium chloride.

(b) Basic hydrolysis:

A mixture of the oxadiazoline (XX, 0.1 g.), potassium hydroxide (2.8 g.) water (5 ml.) and 95% ethanol (5 ml.) was heated at reflux for 4 hours and was then diluted with brine. The solution was extracted (ether) and then acidified (ice-cold hydrochloric acid). The solid which precipitated (48 mg.), m.p. 192-196°, was identified as diphenylphosphinic acid (XIII) by comparison with an authentic sample. The filtrate was extracted with ether. The ether layer was washed with brine and dried (sodium sulfate). Removal of the solvent gave a brown residue (55 mg.) which was crystallized from warm water to give phenylacetic acid (6 mg.), m.p. 78-79°.

Degradation of *N*-2-(1-Phenyl-3-cyano-3-phenylpropene-2-yl)-*P,P*-diphenylphosphinic Amide (XIa).

(a) Basic hydrolysis:

The eniminonitrile XIa (1.0 g.) was heated to reflux for 12 hours with 25% methanolic potassium hydroxide (50 ml.). The solution was cooled and acidified with 2*N* hydrochloric acid. Water was added until precipitation ceased. The precipitate was filtered, washed with water and dried (sodium sulfate). This product was extracted (ether) and the ether-insoluble residue was identified as diphenylphosphinic acid (XIII). Evaporation of ether from the extracts left an oily residue which was treated twice with boiling water. The hot aqueous solution was filtered and cooled. The white crystals formed were filtered and dried (sodium sulfate). The compound, m.p. 77-78°, was identified as phenylacetic acid.

(b) Acid hydrolysis to α,γ-Diphenyl-β-ketobutyramide (XXII):

The eniminonitrile (XIa, 0.5 g.) was heated at reflux with a mixture of 90% ethanol (45 ml.) and concentrated hydrochloric acid (5 ml.) for 1.5 hours. The reaction mixture was diluted with brine (200 ml.), cooled in ice, neutralized (aqueous sodium bicarbonate) and filtered. The residue was dried to give 0.25 g. of a white solid, m.p. 80-135°. Crystallization (chloroform-*n*-hexane) gave white needles of α,γ-diphenyl-β-ketobutyramide (XXII), (83 mg.), yield 30.8%, m.p. 157-160°. Two more crystallizations gave the analytical sample, m.p. 165-166° (lit. (28) 161-162°). The original aqueous layer was acidified and filtered. The residue was washed and dried to obtain diphenylphosphinic acid (XIII) (0.113 g.); yield, quantitative.

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