Pentacovalent Phosphorus. III. Reactions of Dimers of Dimethylketene with Cyclic Trivalent Phosphorus Acid Amides. Isolation of Stable Pentacovalent Intermediate[1]

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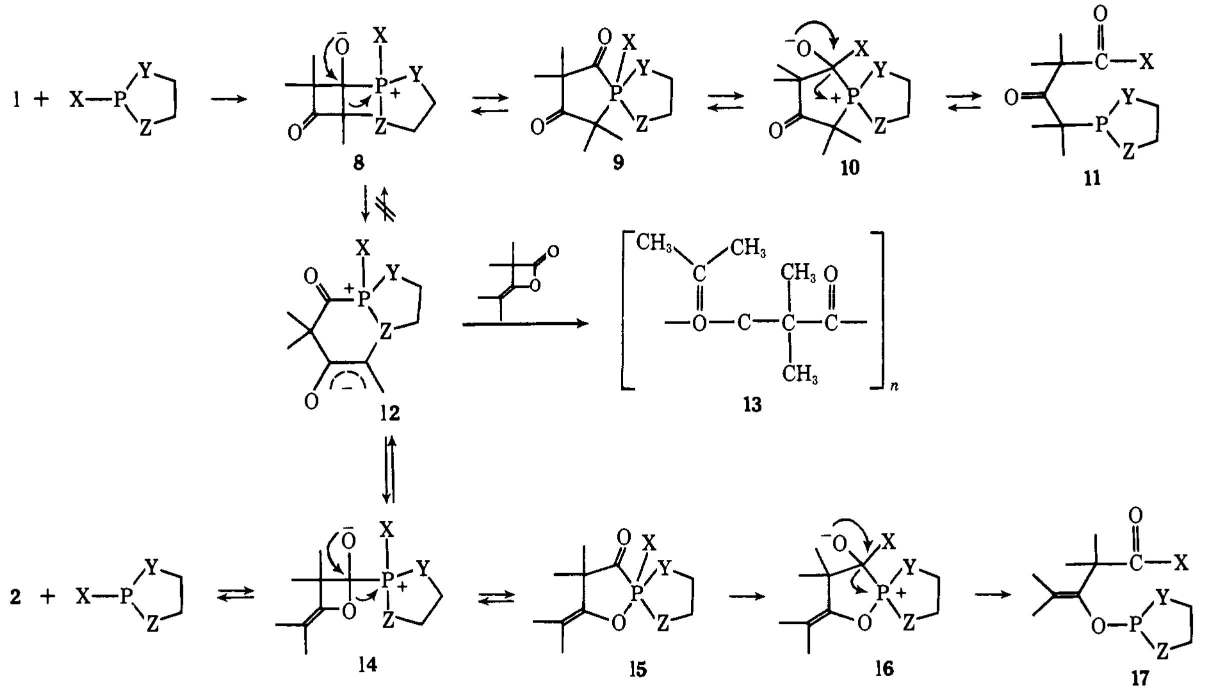
Abstract: Reactions of the dione (**1**) and lactone (**2**) dimers of dimethylketene with a series (**3–7**) of cyclic aminophosphines, alkyl phosphorodiamidites, and dialkyl phosphoramidites were studied. Essentially the same products resulted with a given trivalent phosphorus compound (**3–7**) and either **1** or **2**, the product being a carboxamide or carboxy ester (**17**, X = $(CH_3)_2N$ or CH_3O). With **2** and 2-dimethylamino-3-methyl-1,3,2-oxazaphospholane (**6**) a stable pentacovalent phosphorus intermediate, **24**, was isolated and characterized. It is postulated that **24** arises from ring expansion of the initial four-membered ring **6–2** adduct formed by phosphorus attack at carbonyl carbon of **2**. When **24** is heated at 60° an equilibrium is established between **6**, **2**, and **24**, while the final product carboxamide **17** (specifically **21**) is slowly formed. The presence of a pentacovalent intermediate is also detected in the reaction of **2** with 2-dimethylamino-1,3,2-dioxaphospholane (**7**). These findings support the previously postulated reaction sequence involving pentacovalent phosphorus intermediates which give product by migration of a substituent from pentacovalent phosphorus atom to the adjacent carbonyl. With **3–7** only exocyclic oxygen or nitrogen atoms are observed to undergo migration. The formation of stable pentacovalent intermediates in these cases and not in others is shown to be consistent with the rules believed to govern the formation, stability, and subsequent reactions of pentacovalent phosphorus species. The relative reactivities of **3–7** appear to be better explained in terms of phosphorus rather than nitrogen attack on carbonyl carbon.

We have previously shown that dimethylketene dimers **1** and **2** undergo reactions with trialkyl phosphites,[3] dimethyl methylphosphonite,[3] and various phosphoramidites[4] to give products of the general type **11** and **17**. These reactions were rationalized in terms of the series of processes depicted in Scheme I. The important features of Scheme I are: attack by phosphorus at carbonyl carbon; the formation of pentacovalent intermediates **9** and **15** *via* ring expansions in which the incipient enolate ions **8** and **14** are trapped; and the subsequent migration steps **9** → **10** and **15** → **16**. Both the intramolecular nucleophilic attack at a phosphonium center and the 1,2 shift appear to be unusual for phosphorus systems. The ring expansion is similar to those noted in carbonium ion systems.

Scheme I



Previous results showed[3,4] that although reaction of a given nucleophile, PXYZ, with **1** may give either

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(2) National Institutes of Health Predoctoral Fellow, 1966–1969.

(3) W. G. Bentrude, W. D. Johnson, W. A. Khan, and E. R. Witt, to be published elsewhere; W. G. Bentrude and E. R. Witt, *J. Amer. Chem. Soc.*, 85, 2522 (1963).

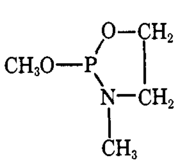
(4) W. G. Bentrude, W. D. Johnson, and W. A. Khan, to be published elsewhere; W. G. Bentrude and W. D. Johnson, *Tetrahedron Lett.*, 4611 (1967).

11 or **17**, reaction with **2** gives only **17** along with polymer **13** in some cases. The relative amounts of **11** and **17** from **1** depend on the nature of substituents X, Y, and Z and the ease of isomerization of **11** to **17**, results interpretable in terms of effects on the rates of the various reactions in Scheme I. These and other factors such as the relative ease of translocation of substituents on phosphorus are discussed in terms of Scheme I in the Summary at the end of this paper.

Up to now, however, direct evidence for species **11** or **17** has been lacking. In this paper are reported the isolation and characterization of one pentacovalent intermediate of type **17** and the detection of another. The formation of relatively stable pentacovalent intermediates in these instances can be shown to be consistent with currently postulated principles governing the stability, structures, and reaction patterns of pentacovalent phosphorus intermediates.

Results

Reactions were run under a nitrogen atmosphere using the cyclic phosphorous amide esters (phosphoramidites and phosphorodiamidites) **3**–**7**.



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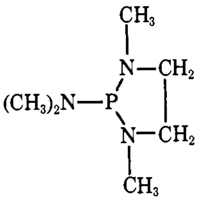

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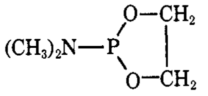

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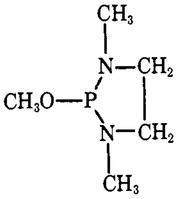

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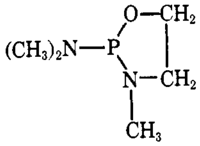

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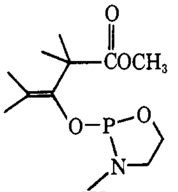
Dimers **1** and **2** both gave products of type **17** (Scheme I) to the complete exclusion of **11**. Vinyl phosphorus esters **18**–**22** are the actual products resulting from reactions of **1** and **2** with **3**–**7**. Results of reactions of **3**–**7** with **1** and **2** appear in Tables I and II. Dione had been found previously[3] to give products of general structure **11** with certain phosphites, dimethyl methylphosphonite, and with dimethyl dimethylphosphoramidite,[4] $(CH_3O)_2PN(CH_3)_2$. In no case was a product resulting from apparent migration of Y or Z rather than X in the conversion **15** → **16** noted. That is to say, a nonring oxygen or nitrogen atom was always attached to carbonyl carbon in product **17**. Products **18**–**21** were readily identified by their spectral properties (Experimental Section) and reference to those of products from the previously studied reactions of **1** and **2** with trivalent phosphorus. The vinyl methyls appeared in the nmr as a pair of doublets at δ 1.4–1.5 (J_{HP} = 2.5–3.0 Hz) and 1.7–1.8 (J_{HP} = 1.5–2.0 Hz) and the geminal methyls as a singlet at 1.25–1.50. Methoxyls, methyl, dimethylamino, and methylene absorptions could also be readily assigned. The ir spectra were characterized by carbonyl absorptions at 1730 cm^{-1} for the methyl carboxylates and at 1630 cm^{-1} for the carboxamides. Quantitative elemental analysis was carried out on the sulfur derivatives **23**. Pmr spectra of **23** were completely analogous to those of **18**–**21** with slightly larger values of J_{HP} and small differences in chemical shifts. The structures of the products **18**–**21** were further elucidated by methanolysis to the methyl ester or *N*,*N*-dimethylamide of



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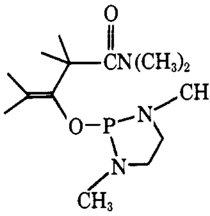

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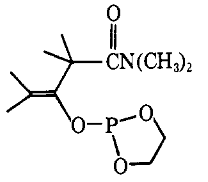

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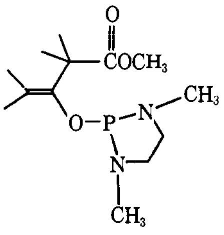

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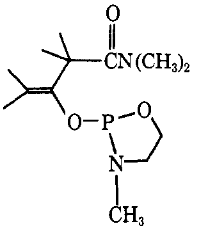

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Table I. Reaction of Lactone **2** with **3**–**7**[a]

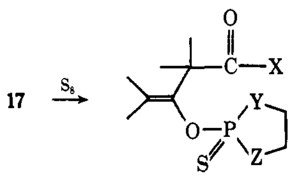
PXYZ	Time	*T*, °C	% conversion	Yield[b]	Product
3	310 hr	60	100	97[c] (73)	**18**
	6 hr	110	90	95	**18**
4	4 days	25	100	100 (82)	**19**
5	6 days	60	80	90 (90)[d]	**20**
6	40 hr	25	100	(98)[c]	**24**
	86 hr	92	100	100 (70)	**21**
7	80 days	25	75	*e*	**29**
	10 days	120	95	90 (41)	**22**

[a] Neat mixtures; the molar ratio of PXYZ/**2** was 1.0 except for **6**/**2** at 25° which was 0.9. [b] Yield determined by vpc; isolated yield in parentheses; based on reacted lactone. [c] Gravimetric yield of crude product in reaction shown by vpc or nmr to yield a single product. [d] Yield based on crude product. [e] Major amount of probable **29** formed.

Table II. Reaction of Dione **1** with **3**–**7**[a]

PXYZ	Time	*T*, °C	% conversion	Yield[b]	Product
3	26 days	92	90	95	**18**
				Trace	**2**
4	7 days	92	90	90 (71)	**19**
				5	**2**
5	14 days then 15 hr at 92°	60	100	80 (54)	**20**
				Trace[g]	**2**
				20	*c*
6	158 hr	92	90[e]	70[e] (54)	**21**
				25[e]	*d*
	60 days	60	75[e]	50[e]	**21**
				50[e]	*d*
7	9 days	120	100	60	**22**
				10	**2**
				15	*f*

[a] Neat mixtures under nitrogen; equimolar reactant amounts. [b] Estimated by vpc; isolated yields in parentheses. [c] Unidentified long retention time product. [d] Unidentified intermediate with 1725-cm^{-1} ir band (Experimental Section). [e] Estimated by ir. [f] *N*,*N*-Dimethyl-2,2,4-trimethyl-3-oxovoleramide. [g] Large amounts of **2** were noted (vpc) during reaction.



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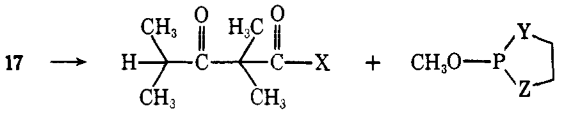
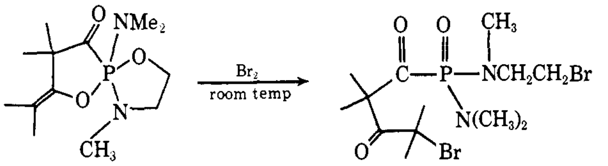
2,2,4-trimethyl-3-oxovaleric acid and the corresponding trivalent phosphorus ester. The latter in most instances had undergone partial methanolysis to trimethyl phosphite and the diamine or amino alcohol. In no instance was any polymer **13** observed in contrast to previous results with acyclic analogs of **3**–**7**.





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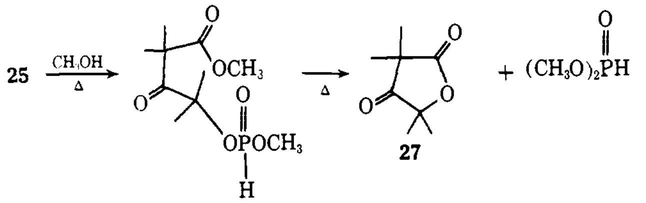

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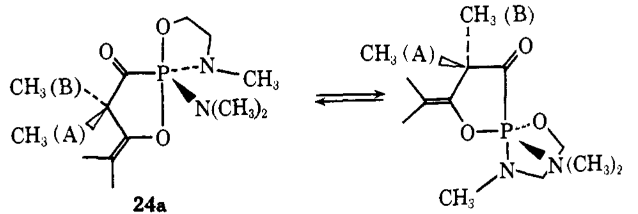
Lactones **2** and **6** underwent complete reaction in 40 hr at room temperature to give quantitatively a solid adduct (mp 63–65°) to which the pentacovalent phosphorus structure **24** has been assigned on the basis of both spectral and chemical evidence. A chemical shift of +73 ppm relative to external 85% H_3PO_4 is consistent with the pentacovalent formulation for **24**.[5] The ir showed intense absorptions at 1680 and 1725 cm^{-1} attributable to carbon–carbon and carbon–oxygen double bonds, respectively. Although a carbonyl in a five-membered ring might be expected to absorb at a higher frequency, the effect of the attached phosphorus is not known. In acyclic cases, a phosphoryl group attached to carbonyl causes a strong shift to lower frequencies,[6] probably as the result of $p\pi$–$d\pi$ interactions. The pmr spectrum (benzene) of **24** showed peaks of appropriate areas at δ 1.62 and 1.77. These peaks are close to the position, δ 1.52 and 1.78, of the vinyl methyl doublets of the ultimate product **21**. Apparently long-range coupling through the olefinic system of the type seen in **21** and its analogs (2–4 Hz) is reduced in pentacovalent structures, as at 100 MHz only very small (0.5 Hz) splittings as apparent triplets (?) are noted. In benzene the geminal methyls are slightly nonequivalent, δ 1.25 and 1.28, and appear as doublets,[4] J_{HP} = 0.8 and 1.2 Hz, respectively, apparently from long-range interaction with the phosphorus atom. In $CDCl_3$ the geminal methyls appear at δ 1.23 as two peaks about 1 Hz apart. (The vinyl methyls at δ 1.70 are separated by about 1.5 Hz.) The nonequivalence of the geminal methyls is to be expected if pseudorotational processes are restricted to structures **24a** and **24b** at nmr probe temperature by the presence of the five-membered ring. CH_3(A) and CH_3(B) can become equivalent only by way of relatively high-energy pentacovalent structures involving diequatorial attachment of the ring. Barriers to such processes of 15–20 kcal have been noted[7] in similar spirophosphoranes. In products of type **17** the geminal methyl peaks are found generally in the range δ 1.25–1.35.[3,4] The dimethylamino group in **24** is seen in a doublet at δ 2.62 with J_{HP} = 9.5 Hz. Both parameters are characteristic of a $(CH_3)_2N$ on pentacovalent phosphorus in cyclic adducts formed from dimethylketene with **6** and **7**.[8] The uv spectrum of **24** showed a maximum at 195 mμ (ϵ 9230) as expected for a molecule with olefinic functionality.



24a 24b

24 decomposed on attempted recrystallization. But correct elemental analysis and molecular weight, 301 (theory 288), were obtained on a sharply melting sample of freshly prepared adduct. Vpc analysis gave only peaks for **2** and **6**, apparently from decomposition of **24**. Chemical evidence for structure **24** was gained from its instantaneous reaction at 5° with bromine in benzene to give nearly pure **25**, a compound which resisted ultimate purification but whose structure was adduced from its approximate elemental analysis, mass spectrum parent peak near 450 (theory 448), ir and nmr spectral characteristics, and subsequent methanolysis reaction. **25** had intense ir bands at 1670 and 1695 cm^{-1}. Both the α-ketophosphonate and sterically crowded ketone carbonyl would be expected to absorb below 1700 cm^{-1}.[6,9] The pmr spectrum of **25** showed the geminal methyls between the carbonyls at δ 1.59 (singlet). By comparison we have found such geminal methyls in the pentacovalent oxides and sulfides of **11** at δ 1.39–1.54. Two singlets at δ 1.96 and 2.02 are assigned to the methyls on carbon attached to bromine. The nonequivalence of these methyls could result from either or a combination of the presence of the asymmetric phosphorus center and inhibition of rotation because of steric restrictions. The methyls in **28** are found at δ 2.00.[8] Other peaks of appropriate area in the pmr spectra of **25** were at δ 2.53 (6 H, doublet, J_{HP} = 9.5 Hz [$(CH_3)_2NP$]), 2.59 (3 H, doublet, J_{HP} = 9.0 Hz, [CH_3N]), and 3.3 (multi-

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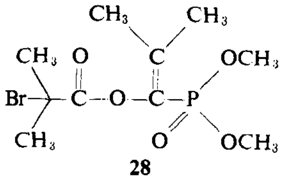
[5] (a) The significance of the ^{31}P shift is discussed thoroughly in F. Ramirez, *Accounts Chem. Res.*, **1**, 168 (1968); see also: (b) D. B. Denney, D. Z. Denney, and B. C. Chang, *J. Amer. Chem. Soc.*, **90**, 6332 (1968); (c) F. Ramirez, A. V. Patwardhan, H. J. Kugler, and C. P. Smith, *ibid.*, **89**, 6276 (1967); (d) F. Ramirez, A. V. Patwardhan, H. J. Kugler, and C. P. Smith, *Tetrahedron*, **24**, 2275 (1968).

[6] (a) K. D. Berlin and H. A. Taylor, *J. Amer. Chem. Soc.*, **86**, 3862 (1964); (b) B. Ackerman, T. A. Jordan, C. R. Eddy, and D. Swern, *ibid.*, **78**, 4444 (1956).

[7] D. Houalla, R. Wolf, D. Gagnaire, and J. B. Robert, *Chem. Commun.*, 443 (1969); D. Gorenstein, *J. Amer. Chem. Soc.*, **92**, 644 (1970).

[8] W. G. Bentrude, W. D. Johnson, and W. A. Khan, to be published.

[9] L. J. Bellamy, "The Infrared Spectra of Complex Molecules," 2nd ed, Wiley, New York, N. Y., 1958, p 312.



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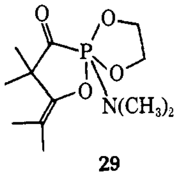
plet, [NCH_2CH_2Br]).

In methanol at 70°, **25** underwent conversion in 4 days to **26** in a rather remarkable reaction. Bands at 1720 and 1750 cm^{-1} are noted in the ir spectrum of **26**. The two sets of geminal methyls are seen as singlets in the pmr spectrum of **26** at δ 1.34 and 1.68. The methoxy appears at δ 3.32 (3 H, doublet, J_{HP} = 12 Hz). A 3 H singlet at 3.39 is clearly that of the carbomethoxy group. A doublet at δ 6.6 with the expected large phosphorus–hydrogen coupling, 700 Hz, is clearly visible. The mass spectrum has assignable fragments at *m/e* 266 (parent), 207 ($P - CO_2CH_3$), 137 [$(CH_3)_2COP(O)(OCH_3)H$], 128 [$CH_3OCOC(CH_3)_2CO - H$], 101 [$C(CH_3)_2CO_2CH_3$], 79 ($CH_3OP(O)H$), 59 (CO_2CH_3), 31 (CH_3O). When **26** was refluxed in benzene, conversion to **27** and dimethyl phosphite was noted. The products of this unusual reaction were identified by spectral and vpc comparisons with authentic samples. Product **27**, 2,2,4,4-tetramethyl-3-oxobutyrolactone, was synthesized by the reaction[10] of peroxy maleic acid with **1**. As would be expected, the geminal methyl pmr peaks of **27** appear at similar frequencies, δ 1.30 and 1.48, to those of **26**. However, the C=O bands for **27** are found at higher frequencies, 1800 and 1750 cm^{-1}, as befits the five-membered ring structure.

When a solution of **24** in benzene was heated at 60°, an equilibrium was established (as shown by pmr analysis) between **2**, **6**, and **24** involving a ratio of **24**:**6**:**2** of approximately 2:1:1; $\mathbf{6} + \mathbf{2} \rightleftarrows \mathbf{24} \rightarrow \mathbf{21}$. The same mixture and composition were obtained on heating a freshly prepared equimolar solution of **2** and **6** for 3 hr at 60°. The former solution at 55° for 2 weeks gave a 50% conversion of the above mixture to **21** during which time the **24**:**6**:**2** ratio remained nearly constant.

The reaction of **7** with **2** at room temperature similarly gave evidence for a pentacovalent intermediate which could not be isolated in near-pure form, however. Vpc monitoring of the reaction showed only starting materials (as was the case with **6** and **2**). However, ir analysis showed a slow disappearance of **2** and **7** and a corresponding formation of product with a new carbonyl band at 1750 cm^{-1}. After 80 days conversion was roughly 75% complete. The presence of a pentacovalent species is inferred from the strong ^{31}P absorption at +53.0 ppm upfield from external 85% H_3PO_4, presumably a result of the presence of **29**. At 120° ir shows an equilibrium between **7**, **2**, and probably **29**, and a slow formation of **22**.



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Dione reactions with **3**–**7**, as previously stated, also gave **18**–**22**, but the reactions (Table II) were considerably slower than those with **2**. Minor side products are also noted. Reactions of **3** and **6** were accompanied by formation of a trace of lactone (**2**). A 5% yield of **2** resulted in 90% conversion of **1** by **4** and 10% of **2** remained after **1** was consumed in reaction with **7**. Although only a trace of **2** remained at the conclusion of the reaction with **5**, the reaction mixture after 14 days at 60° showed no remaining **1** and large amounts of **2** along with some **20**. Complete conversion to **20** required a further 15 hr at 90°.

Reaction of dione with **6** at 60° gave no detectable **24**. Instead, at 6 weeks the ^{31}P spectrum showed a major peak at −40.8 ppm and smaller absorption at −129.4 and −137.3. The peak at −40.8 would be consistent[11] with a phosphonium compound such as **12**. The other peaks were shown to be those of **6** and **21**. The ir spectrum showed peaks for the dione (1750 cm^{-1}) and **21** (1630 cm^{-1}) and also one at 1725 cm^{-1}, probably corresponding to the intermediate having the −40.8-ppm ^{31}P chemical shift. At 92°, the peak at 1725 cm^{-1} gradually disappeared as did the dione absorption, and the 1630-cm^{-1} absorbance dominated the region. When the reaction was run entirely at 92°, a lower concentration of the intermediate absorbing at 1725 cm^{-1} was noted.

Toward lactone a reactivity order $\mathbf{6} > \mathbf{4} > \mathbf{5} \approx \mathbf{3} > \mathbf{7}$ is noted (Table I). In reaction with dione the order is $\mathbf{5} > \mathbf{4} \approx \mathbf{6} > \mathbf{3} > \mathbf{7}$ (Table II).

Discussion

These studies have given the first direct evidence for the intermediacy of phosphoranes of type **9** or **15** in the reactions of trivalent phosphorus nucleophiles with dimers **1** and **2**. This lends considerable credence to the general correctness of Scheme I as a description of these processes. As noted, when **24** is heated to 60°, an equilibrium between **6** and **2** and **24** is established and **21** is slowly formed. Although it is conceivable that **6** and **2** may form **21** in an independent manner, the conversion of **24** to **21** in a rate-determining step is a reasonable postulation.

The isolation of **24** from the reaction of **2** and **6** and the observation of a pentacovalent intermediate, probably **29**, in reactions of **7** with **2** but not when other trivalent phosphorus compounds are used are best understood in terms of results of other reactions in this series[3,4] and also in the context of the general structure and reaction patterns of cyclic pentacovalent phosphorus intermediates.[5a,12] These include the following: (1) the groups bonded to pentacovalent phosphorus preferentially occupy the points of a nearly regular trigonal bipyramid; (2) a five-membered ring containing pentacovalent phosphorus will prefer to have one phosphorus substituent axial and the other equatorial; (3) the more electronegative groups preferentially occupy the axial positions of the bipyramid; (4) groups prefer to enter (phosphorane forma-

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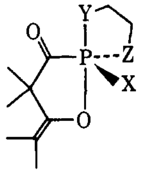
[10] R. W. White and W. D. Emmons, *Tetrahedron*, 17, 31 (1962); Rohm and Haas Co., British Patent 986,058 (1965).

[11] V. Mark, C. H. Dungan, M. H. Crutchfield, and J. R. Van Wazer, *Top. Phosphorus Chem.*, 5, 227 (1967).

[12] These principles are well enunciated in three review articles: (a) F. H. Westheimer, *Accounts Chem. Res.*, 1, 70 (1968); (b) E. L. Muetterties, *ibid.*, 3, 266 (1970); (c) K. Mislow, *ibid.*, 3, 321 (1970).

tion) and leave (migration to carbonyl) by way of the axial position; (5) migration of an acyclic methoxy group occurs more readily than migration of an acyclic dimethylamino group on the same phosphorus atom;[4] (6) an oxygen or nitrogen atom which is part of a five-membered ring is translocated more slowly than if that same atom is part of a methoxy or dimethylamino group.

The last point is made clear by the results of this study. In no case did the reaction of **3**–**7** with either **1** or **2** lead to a product of ring-atom migration. In contrast, our previous work[4] had shown nearly exclusive apparent methoxy migration with $CH_3OP[N(CH_3)_2]_2$ and $(CH_3O)_2PN(CH_3)_2$. Based on points 1–4 above, a reasonable, preferred configuration for the first-formed intermediate **15** would be **30**. This allows the ring oxygen from the lactone to enter the axial position which it probably also prefers as a more electronegative atom than carbonyl carbon. In some instances in **15**, an electronegative oxygen in the other ring will be held preferentially axial. Yet no migration of ring oxygen is noted. Likewise, if translocation is preferentially from the equatorial position, a ring atom though held in that position is never involved. Hence some unknown restriction is placed by the ring on migration and outweighs any other consideration.



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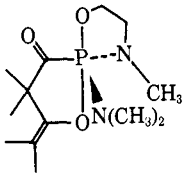

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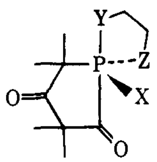
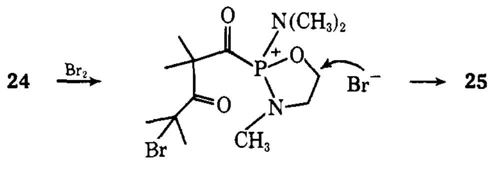
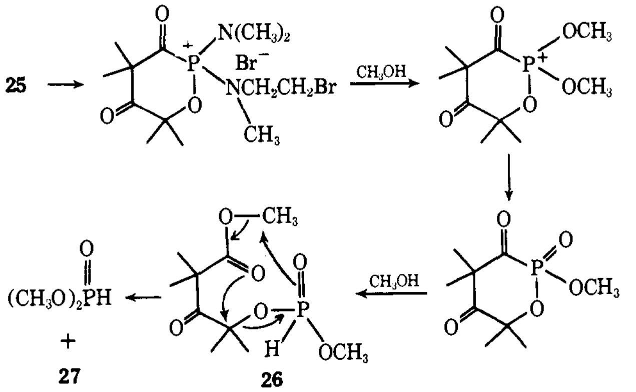


32

These same considerations render **31** the preferred structure for **24** and explain its stability. The ring oxygen being apical should migrate more readily than either of the alkylamino groups (assumptions 4 and 5). However, the position of the oxygen in the ring tends to lower its migrational potential (assumption 6). The ring alkylamino should not translocate readily, because: it is not in the apical position; it migrates generally less readily than alkoxy; and it is part of the ring (assumptions 4, 5, and 6, respectively). The dimethylamino is held equatorial and thereby should exhibit a reduced tendency to migrate (assumption 4). The net effect is the overall stabilization of **24** (**31**) toward translocation of any of the three groups. Similarly, **29** is rendered a relatively stable species. The potential intermediates from the reaction of **2** with **3** and **4** have a reactive methoxy group able to undergo relatively more rapid translocation. Hence, intermediates of type **15** are not detected. The probable instability of **15** from **5** and **2** is discussed below.

The reaction converting **24** to **25** appears to involve a straightforward electrophilic bromine addition to the double bond followed by Arbuzov-like collapse of the phosphonium intermediate. A similar type reaction is noted[13] with the unsaturated oxyphosphorane formed from biacetyl and trimethyl phosphite and with those resulting from reaction of phosphites with dimethylketene.[8] The conversion of **25** to **27** appears to be somewhat complex but can be explained *via* a reasonable series of reactions. Ionization of the labile bromine of **25** with concomitant phosphoryl oxygen attack[14] gives a phosphonium intermediate, the amino groups of which are then replaced[15] by methoxy substituents. Collapse of the thus formed phosphonium intermediate to a six-membered ring ketophosphonate, which undergoes expected[6] rapid methanolysis, yields the isolable product **26**. The subsequent, facile formation of **27** may be viewed as a concerted process or as one involving neighboring acetoxy assistance of a C–O cleavage which features $^{-}O{-}P(=O)(H)OCH_3$ as the leaving group.





Another effect of the ring in the reactions of **3**–**7** is to cause only the product of type **17** to be formed in the dione reactions whereas $(CH_3O)_2PN(CH_3)_2$ gave[4] considerable amounts of dione product analogous to **11**. This is consistent with the conversion of **8** to **12** being able to better compete with the migration **8** → **9** → **10** because of the reduced rate of the latter step. A preferred structure of **9** is given by **32**. Whether the migration from the spirophosphoranes takes place from the equatorial position or from the axial position after pseudorotation, an increased composite activation energy for the step is predicted, since the latter forces one of the rings to be in the equatorial plane. These results are consistent with previous work[3] in which we found that methylethylene phosphite and dione **1** gave only product **17** even though the acyclic analog, trimethyl phosphite, yielded a high percentage of **11**. An alternative explanation for these systems is that the ring structure may have a favorable effect on the ease of isomerization of any **11** which might be formed into **17**. Such an isomerization, well-demonstrated[3] with adducts (**11**) of trimethyl and triethyl phosphite with **1**, could not be checked out here.

It should also be pointed out that inclusion of substituents in a five-membered ring imparts added stability to a pentacovalent species compared to its ionic

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[13] F. Ramirez, K. Tasaka, N. B. Desai, and C. P. Smith, *J. Org. Chem.*, 33, 25 (1968).

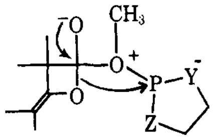
[14] (a) R. F. Hudson, "Structure and Mechanism in Organo-Phosphorus Chemistry," Academic Press, New York, N. Y., 1965, p 281; (b) J. I. G. Cadogan, R. K. Mackie, and J. A. Maynard, *J. Chem. Soc. C*, 1356 (1967).

[15] Reference 14a, p 137.

alternative such as **12**.[5c,d,16] This may be an additional reason for the stability of **24** and **29**. Consistent with this idea is the failure to observe formation of **13** in the reactions of **2** and **3**–**7** in contrast to its ready generation in reaction with acyclic counterparts of **3**–**7** having two or three dimethylamino substituents on phosphorus.[4] We have suggested in another paper[4] that **13** formation is initiated by **12** from ring opening of **14** or **15** or by CH_3O^- and $(CH_3)_2N^-$ formed from ionic dissociation of **15**.

Again, as with phosphites[3] and acyclic amides,[4] the reactions of dione to give product **17** appear to involve isomerization of **1** to **2** to varying degrees. With **5**, as with its acyclic analog,[4] $[(CH_3)_2N]_3P$, the isomerization occurs first followed by conversion of **2** to **20** (**17**). It seems likely that the relative rates of steps **14** → **2** and **14** → **15** → **16** along with the rate of **2** → **14** must play an important role in determining the extent of lactone buildup. (The reactions of **24** and **29** at 60° show clearly the reversibility of phosphorane **15** formation.) As more nitrogen substituents appear on phosphorus the rate of formation of **17** may be reduced as the migration rate is slowed. At the same time, since the rate of attack by phosphorus (**2** → **14**) on **2** has been increased by the enhanced nucleophilicity of phosphorus when amino substituents replace methoxy, the barrier for its microscopic reverse (**14** → **2**) may also be reduced, unless the intermediate **14** is increased in stability at the same time. It seems likely that the increased phosphorus nucleophilicity with added amino substituents may be counterbalanced at least partially by increased steric interactions in **14**. Some combination of these factors then makes the reactions of **2** reversible giving lactone an opportunity to build up concentration temporarily in certain reactions of **1** with trivalent phosphorus. No evidence for the buildup of an intermediate of type **15** was found with the reaction of **5**. This may be because although the dimethylamino migration is rate determining, the equilibrium involving **2**, **5**, and **15** lies well toward **2** and **5** at the temperature required for reaction.

Additional evidence for the correctness of the postulated[4] initial attack by phosphorus rather than oxygen or nitrogen comes not only from observation of **24** and **29** but also from the rough relative reactivities of **3**–**7**, noted in Tables I and II. When carboxylic ester product is formed, oxygen attack *via* **33** could be postulated. However, this would require oxygen to be more nucleophilic than nitrogen or phosphorus, since in the reaction of **3** and **4** and also of $(CH_3O)_2PN(CH_3)_2$ and $CH_3OP[N(CH_3)_2]_2$, ester rather than amide is formed. We believe this to be extremely unlikely. On the other hand, nitrogen attack (**34**) as a reasonable alternative to phosphorus attack (softer nucleophile) at a somewhat hard carbon center (C=O) is a reasonable postulate in other carbonyl systems.[17] However, in this case, comparison of relative reactivities of **3**–**7** shows a general increase in reactivity with increased amino substitution on phosphorus, even when the product of possible nitrogen attack, carboxamide, is not formed. The reaction of **6** is much faster than that of **7**. More equal rates would be predicted by rate-determining nitrogen attack. Again **4** is much more reactive than **3**, contrary to prediction if oxygen attack were rate determining. Furthermore, if oxygen and nitrogen attack were important, **7** ought to be more reactive than **3**, whereas the opposite is true. In these arguments as well as in those regarding apparent migrational abilities of substituents on phosphorus, it should be made clear that the final product observed may not be that found most rapidly. This is illustrated by the recent report[18] that aminophosphines rapidly give CS_2 adducts involving phosphorus attack at carbon but that these are ultimately converted under conditions of equilibrium control to materials best accounted for by nitrogen attack.



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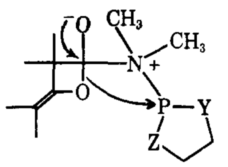

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The rough reactivity data in Table I and from our previous work also fail to give evidence for the rate-determining formation of **15**. It has been suggested[17a] on reasonable grounds that the greater stability of a given cyclic pentacovalent phosphorus intermediate, compared with that of its otherwise analogous acyclic counterpart, should render the rate of a reaction in which the pentacovalent species is formed in the rate-determining step much faster for the cyclic derivative. Reactions of **3** and $(CH_3O)_2PN(CH_3)_2$ with **2** at 110–115° occur at about the same rate, 6–7 hr being needed for 100% conversion of reactants. **4** reacts only about twice as fast as $CH_3OP[N(CH_3)_2]_2$ at room temperature,[4] and methylethylene phosphite is notably less reactive[3] than trimethyl phosphite toward both **1** and **2** at 100–120°. Arbuzov reactions involving rate-determining formation of a phosphonium ion intermediate (phosphorus attack) are postulated[17a] to be slower when phosphorus is part of a five-membered ring.

The failure of dione to give products **24** and **29** on reaction with **6** and **7** is surprising. Apparently an intermediate, possibly **12**, is formed which is converted to a product of type **17** in each instance. A possible explanation is that a barrier of undetermined origin exists for the conversion of **12** to **14** which, once formed in low concentrations, reacts rapidly enough that lactones **6** or **7** do not build up appreciably. That the probable microscopic reverse (**15** → **12** or **14** → **12**) has a high barrier has been already discussed in regard to the failure to form polymer **13**.

Summary

The reaction patterns for various PXY with dimers **1** and **2** reported in this and other papers[3,4] are summarized in Table III in terms of the products **11**, **17**, and **13**. These trends and the migrational tendencies for various X, Y, and Z may be outlined and generalized so far as possible in terms of Scheme I as follows.

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[16] F. Ramirez, A. S. Gulati, and C. P. Smith, *J. Amer. Chem. Soc.*, **89**, 6283 (1967); *J. Org. Chem.*, **33**, 13 (1968).

[17] (a) R. Greenhalgh and R. F. Hudson, *Chem. Commun.*, 1300 (1968); (b) R. F. Hudson, R. J. G. Searle, and F. H. Devitt, *J. Chem. Soc. B*, 789 (1966); (c) R. F. Hudson and R. J. G. Searle, *ibid.*, *B*, 1349 (1968); *Chimia*, 20, 119 (1966).

[18] K. A. Jensen, O. Dahl, and L. Engels-Hendriksen, *Acta Chem. Scand.*, **24**, 1179 (1970).

Table III. Product Distributions from the Reaction of **1** and **2** with PXYZ

PXYZ reactant			Carbonyl reactant	Products[a]		
X	Y	Z		**11**	**17**	**13**
CH_3O	CH_3O	CH_3O	**1**	+	+	−
			2	−	+	−
C_2H_5O	C_2H_5O	C_2H_5O	**1**	+	+	−
			2	−	+	−
n-C_3H_7O	n-C_3H_7O	n-C_3H_7O	**1**	−	+	−
			2	−	+	−
n-C_4H_9O	n-C_4H_9O	n-C_4H_9O	**1**	−	+	−
			2	−	+	−
i-C_3H_7O	i-C_3H_7O	i-C_3H_7O	**1**	+	+	−
			2	−	+	−
sec-C_4H_9O	*sec*-C_4H_9O	*sec*-C_4H_9O	**1**	+	+	−
			2	−	+	−
CH_3O	CH_3O	C_6H_5O	**1**	+	−	−
			2	−	+	−
CH_3O	$-OCH_2CH_2O-$		**1**	−	+	−
			2	−	+	−
CH_3O	CH_3O	CH_3	**1**	+	−	−
			2	−	+	−
CH_3O	CH_3O	$(CH_3)_2N$	**1**	+	+	−
			2	−	+	−
CH_3O	$(CH_3)_2N$	$(CH_3)_2N$	**1**	−	+	+[b,c]
			2	−	+	+
$(CH_3)_2N$	$(CH_3)_2N$	$(CH_3)_2N$	**1**	−	+	+[b,c]
			2	−	+	+
$(CH_3)_2N$	$(CH_3)_2N$	C_6H_5O	**1**	−	+	+[b]
			2	−	+	+
CH_3O	$-OCH_2CH_2N(CH_3)-$		**1**	−	+	−
			2	−	+	−
CH_3O	$-N(CH_3)CH_2CH_2N(CH_3)-$		**1**	−	+	−
			2	−	+	−
$(CH_3)_2N$	$-OCH_2CH_2O-$		**1**	−	+	−
			2	−	+	−
$(CH_3)_2N$	$-OCH_2CH_2N(CH_3)-$		**1**	−	+	−
			2	−	+	−
$(CH_3)_2N$	$-N(CH_3)CH_2CH_2N(CH_3)-$		**1**	−	+	−
			2	−	+	−
n-C_4H_9	n-C_4H_9	n-C_4H_9	**1**	−	−	+[b]
			2	−	−	+

[a] + indicates >3% of the given product is formed at least under some conditions. [b] Following isomerization of **1** to **2**. [c] In detectable amounts, not determined quantitatively.

(1) Reaction with lactone **2** generally gives exclusively product **17** unless ring opening is favored by the presence of acyclic dimethylamino substituents. In such cases some polymer **13** results, presumably *via* ring opening to **12** which is stabilized by the nitrogens on phosphorus. The cyclic amino compounds give no polymer which is to be expected if, as found with other phosphoranes, the five-membered ring stabilizes the pentacovalent intermediate. (2) When X, Y, and Z = alkyl, migration (**15** → **16**) does not occur and polymer **13** formation from **2** is the exclusive process. (3) Reaction of PXYZ with dione (**1**) can give either **11** or **17** depending on the rate of ring expansion (**8** → **9**) and subsequent migration (**9** → **10**) relative to that of ring opening (**8** → **12**). (4) Amino substituents, which stabilize a positive charge on phosphorus, appear to favor step **8** → **12**. As a result, if two substituents on phosphorus are dimethylamino groups, only **17** results from **1**. (5) Steps **9** → **10** and **15** → **16** appear to be faster for CH_3O than for $(CH_3)_2N$ since carboxy esters rather than carboxamides result. This may also influence the **8** → **9** → **10** *vs.* **8** → **12** competition. (6) If O or N is part of a five-membered ring it migrates slower than O or N not in a ring as only exocyclic groups are translocated. Thus PXYZ containing a five-membered ring gives only **17** with **1**. (A single exception[3] is the reaction of **2** with methyl ethylene phosphite which gives a minor portion of 9-membered ring product.) (7) With increasing nitrogen substitution at phosphorus, conversion of **1** → **2** becomes faster than subsequent formation of **11**. Thus PXYZ becomes a catalyst for isomerization of **1**. This effect is rationalized in terms of competing steric and electronic effects on the stability of **8** and on the relative rates of the steps **8** → **12**, **8** → **9**, and **9** → **10**. *E.g.*, reactions of $[(CH_3)_2N]_3P$, $C_6H_5OP[N(CH_3)_2]_2$, and **5** with **1** are accompanied by the buildup of large amounts of **2**. (8) When X = Y = Z = alkyl, isomerization of **1** to **2** occurs readily followed by formation of **13**. (9) The relative amounts of **11** and **17** formed can also be influenced by the degree of reversibility of the reactions forming **17**. This was clearly shown by the conversion on heating of **11**, from **1** and triethyl phosphite, into **17**. This isomerization was accompanied by the formation of **1** and triethyl phosphite. However, solid evidence for reversibility of **11** formation in the reaction of $(CH_3O)_2PN(CH_3)_2$ could not be found. (10) Whether a stable phosphorane intermediate such as **15** (illustrated by **24** and **29**) can be isolated depends on a balance of factors based on the known reactivity patterns in these and other pentacovalent phosphorus systems.

Experimental Section

Elemental analyses were by Schwarzkopf Microanalytical Laboratory, Woodside, N. Y., and Galbraith Laboratories, Knoxville, Tenn.

Infrared spectra were obtained on a Beckman IR5A. Unless otherwise noted, bands reported (cm^{-1}) are of strong or medium intensity. Proton magnetic resonance (pmr) spectra were taken on Varian A-60, A-56/60, and XL-100 instruments. Reported chemical shifts are in δ units, parts per million downfield from tetramethylsilane (TMS) internal standard. Multiplicity of peaks is indicated by: s, singlet; d, doublet; t, triplet; m, multiplet. Consolidated Electrodynamics Corporation Type 21-110 and Perkin-Elmer Model 270 instruments were used for mass spectral measurements.

Vpc analyses were run on thermal conductivity F and M Model 810 and Varian Aerograph A90-P3 instruments. Analytical work was done on two columns: column A, 6 ft × $^1/_4$ in. 20% SE-30 on 60–80 mesh Chromosorb W; column B, a 6 ft × $^1/_4$ in. 30% Celanese Ester No. 9 on the same solid support. Both were usually programmed 10°/min at a gas flow rate of 120 ml/min. Preparative vpc work was accomplished with a 10 ft × $^3/_8$ in. 20% SE-30 on Chromosorb column. Quantitative estimates of percentage conversion and yield were made as follows. Under identical chromatographic conditions and injection sample sizes, the total area of reactants was determined before reaction along with that of remaining reactants and products formed at a certain time during the reaction. Per cent conversion was based on the area of remaining reactants compared to that measured at the start of the reaction. The percentage yield was determined from areas of product formed and the amount of reactants consumed. While this is not a highly accurate method, the relative yields thus determined are considered accurate enough for the purposes of this paper.

2-Methoxy-3-methyl-1,3,2-oxazaphospholane (**3**) was prepared from **6** by the method of Mukaiyama:[19] 21% yield; bp 51–52° (23 Torr); pmr ($CDCl_3$) δ 2.73 (3 H, d, J_{HP} = 11 Hz, CH_3NP), 3.35 (3 H, d, J_{HP} = 10 Hz, CH_3O), 3.1 (2 H, m, NCH_2), 4.3 (2 H, m, OCH_2).

2-Methoxy-1,3-dimethyl-1,3,2-dioxaphospholane (**4**) was synthesized from **5** on reaction with methanol according to Mukaiyama[19] in 51% yield: bp 73° (27 Torr); lit.[19] 56° (20 Torr).

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[19] J. Mukaiyama and Y. Kodaira, *Bull. Chem. Soc. Jap.*, **39**, 1297 (1966).

2-Dimethylamino-1,3-dimethyl-1,3,2-diazaphospholane (5). Trisdimethylaminophosphine (38.0 g, 0.234 mol) and 1,2-bis(methylamino)ethane (22.0 g, 0.249 mol) in 750 ml of refluxing benzene for 5 hr followed by distillation gave 15.8 g (0.098 mol) (42%) of **5**: bp 41–44° (4 Torr); lit.[5c] 36° (0.5 Torr); pmr (neat) δ 2.53 (6 H, J_{HP} = 9.0 Hz, $PN(CH_3)_2$), 2.56 (6 H, d, J_{HP} = 12 Hz, NCH_3), 3.0 (4 H, m, NCH_2CH_2N).

2-Dimethylamino-3-methyl-1,3,2-oxazaphospholane (6) was prepared according to Sanchez, *et al.*,[20] from trisdimethylaminophosphine and 2-(methylamino)ethanol in 20% yield: bp 60–63° (13 Torr); lit.[20] 66–68° (16 Torr); pmr ($CDCl_3$) δ 2.60 (6 H, d, J_{HP} = 8.5 Hz, $(CH_3)_2NP$), 2.64 (3 H, d, J_{HP} = 11 Hz, CH_3N), 3.1 (2 H, m, NCH_2), and 4.2 (2 H, m, OCH_2).

2-Dimethylamino-1,3,2-dioxaphospholane (7). Trisdimethylaminophosphine (14.6 g, 89.9 mmol) in 35 ml of benzene and ethylene glycol (5.58 g, 89.9 mmol) suspended in 35 ml of ethyl acetate were simultaneously added dropwise to 100 ml of stirred, refluxing benzene over a 2-hr period. After the reaction mixture had stood overnight in a refrigerator it was distilled through a short Vigreux column to give 7.16 g (53.0 mmol) (59%) of **7**: bp 68–69° (20 Torr); lit.[21] 61–62° (11 Torr); pmr (neat) δ 2.52 (6 H, d, J_{HP} = 8.5 Hz, $(CH_3)_2N$), 3.9 (4 H, m, OCH_2CH_2O).

Reactions of Dione and Lactone with Phosphorous Amides. Reactants were mixed neat under nitrogen and heated in a sealed or stoppered container. Analysis by vpc was carried out periodically to determine per cent conversions of reactants and to detect products being formed.

Reactions of 2-Methoxy-3-methyl-1,3,2-oxazaphospholane (3) with Lactone (2). **2** (0.83 g, 5.9 mmol) and **3** (0.80 g, 5.92 mmol) were completely converted into a single product **18** in 310 hr at 60° (97% yield, 1.58 g of crude material). The same reactants at 110° produced the same product (90% conversion) in 95% yield in 6 hr. Distillation yielded **18**, a colorless viscous liquid (1.20 g, 4.36 mmol, 73% yield, bp 78–80° (0.08 Torr): pmr ($CDCl_3$) δ 1.34 (6 H, s, geminal methyls), 1.48 (3 H, d, J_{HP} = 3.0 Hz, vinyl CH_3), 1.72 (3 H, d, J_{HP} = 2.0 Hz, vinyl CH_3), 2.86 (3 H, d, J_{HP} = 11.5 Hz, NCH_3), 3.2 (2 H, m, $PNCH_2$), 3.66 (3 H, s, CH_3O), 4.3 (2 H, m, $POCH_2$); ir (film) 685, 722, 762, 933, 1021, 1071, 1120, 1148, 1190, 1255, 1385, 1470, 1670 (w), 1730, and 2950 cm^{-1}.

Upon slight warming, **18** (neat) reacted with sulfur to give a white solid which was recrystallized from hexane: mp 91–92°; pmr ($CDCl_3$) δ 1.43 (s, geminal methyls), 1.52 (3 H, d, J_{HP} = 4.5 Hz, vinyl CH_3), 1.72 (3 H, d, J_{HP} = 3.0 Hz, vinyl CH_3), 2.78 (3 H, d, J_{HP} = 12 Hz, NCH_3), 3.68 (3 H, s, CH_3O), 3.4 (2 H, m, $PNCH_2$), 4.3 (2 H, m, $POCH_2$); ir (Nujol) 770, 835, 853, 897, 935, 952, 1011, 1031, 1075, 1150, 1170, 1195, 1260, 1665 (w), and 1725 cm^{-1}.

Anal. Calcd for $C_{12}H_{22}NO_4PS$: C, 46.89; H, 7.22; P, 10.08; S, 10.43. Found: C, 46.68; H, 7.10; P, 10.57; S, 10.70.

Heating **18** with an excess of methanol for 18 hr at 60° yielded major amounts of the following products, trimethyl phosphite, 2-methoxy-3-methyl-1,3,2-oxazaphospholane (**3**), methyl 2,2,4-trimethyl-3-oxovalerate, and 2-(methylamino)ethanol. These products were identified by pmr analysis of the reaction solution and comparison of retention times to those of authentic samples on vpc columns A and B.

Reaction of 2-Methoxy-3-methyl-1,3,2-oxazaphospholane (3) with Dione (1). **1** (1.08 g, 7.70 mmol) and **3** (1.04 g, 7.69 mmol), heated 26 days at 92°, produced a 95% yield of a single product **18** (greater than 90% conversion of reactants to product). **18** was identified by comparing the ir and pmr spectra of the reaction solution and vpc retention time with those of the product from **2** and **3**. The product from this reaction was not isolated. A small peak corresponding in retention time to **2** was observed to build up very slowly throughout the course of the reaction.

Reaction of 2-Methoxy-1,3-dimethyl-1,3,2-diazaphospholane (4) with Lactone (2). **2** (0.99 g, 7.06 mmol) and **4** (1.04 g, 7.02 mmol) after 4 days at room temperature gave nearly complete conversion of reactants to a single product **19** (100% yield). Distillation yielded **19** as a clear, viscous liquid (1.66 g, 5.76 mmol, 82% yield, bp 75–77° (0.06 Torr)): pmr ($CDCl_3$) δ 1.37 (3 H, s, geminal methyls), 1.48 (3 H, d, J_{HP} = 3.0 Hz, vinyl CH_3), 1.72 (3 H, d, J_{HP} = 1.5 Hz, vinyl CH_3), 2.78 (6 H, d, J_{HP} = 12.5 Hz, $PNCH_3$), 3.2 (4 H, m, $PNCH_2$), 3.7 (3 H, s, CH_3O); ir (neat film) 693, 758, 942, 1033, 1071, 1120, 1150, 1255, 1385, 1470, 1670 (w), 1730, 2900, and 2950 cm^{-1}.

19 (neat) reacted with sulfur on slight warming to give solid sulfide, crystallized from hexane as white crystals (mp 65–66°): pmr ($CDCl_3$) δ 1.44 (6 H, s, geminal methyls), 1.48 (3 H, d, J_{HP} = 4.0 Hz, vinyl CH_3), 1.75 (3 H, d, J_{HP} = 3.0 Hz, vinyl CH_3), 2.76 (6 H, d, J_{HP} = 12.5 Hz, $PNCH_3$), 3.3 (4 H, m, $PNCH_2$), 3.7 (3 H, s, CH_3O); ir (Nujol) 710, 786, 828, 945, 1038, 1072, 1110, 1150, 1210, 1248, 1665 (w), and 1730 cm^{-1}.

Anal. Calcd for $C_{13}H_{25}N_2O_3PS$: C, 48.74; H, 7.87; P, 9.67. Found: C, 48.83; H, 7.76; P, 9.91.

Heating **19** at 60° with excess methanol for 18 hr yielded major amounts of the following products (as identified by comparison of vpc retention times on columns A and B with authentic samples and by pmr analysis of the reaction solution): trimethyl phosphite, 1,2-bis(methylamino)ethane, 2-methoxyl-1,3-dimethyl-1,3,2-diazaphospholane (**4**), and methyl 2,2,4-trimethyl-3-oxovalerate.

Reaction of 2-Methoxy-1,3-dimethyl-1,3,2-diazaphospholane (4) with Dione (1). **1** (1.00 g, 7.13 mmol) and **4** (1.06 g, 7.15 mmol) were mixed neat in a vial, and sealed after being purged with nitrogen. Seven days at 92° produced a single high-boiling product (*ca.* 90% conversion and 90% yield). A very small peak corresponding to **2** appeared early in the reaction and increased slowly to approximately 5% yield as the reaction proceeded. Distillation gave **19** as a colorless viscous liquid (1.32 g, 4.58 mmol, 71% yield, bp 80–90° (0.1 Torr)), identified by comparing the ir and pmr spectra and vpc (column A) retention time with those of the product from **2** and **4**.

Reaction of 2-Dimethylamino-1,3-dimethyl-1,3,2-diazaphospholane (5) with Lactone (2). **2** (0.71 g, 5.08 mmol) and **5** (0.82 g, 5.0 mmol) gave in 6 days at 60° approximately 80% conversion into primarily one product, **20** (90% yield estimated by vpc). Several minor high-boiling products were also observed. No solid material corresponding to **13** was noted. The product, a viscous yellow liquid, resisted an attempt at distillation (after removal of volatiles, 1.10 g remained, 90% crude yield): pmr ($CDCl_3$ solution of sample from removal of volatiles in attempted distillation) δ 1.36 (6, H, s, geminal methyls), 1.48 (3 H, d, J_{HP} = 2.5 Hz, vinyl CH_3), 1.72 (3 H, d, J_{HP} = 1.5 Hz, vinyl CH_3), 2.94 (6 H, s, $CON(CH_3)_2$), 2.84 (6 H, d, J_{HP} = 12.5 Hz, $PNCH_3$), and 3.2 (4 H, m, $-PNCH_2-$); ir (film) 700, 726, 758, 785, 938, 1030, 1066, 1118, 1150, 1215, 1230, 1390, 1465, 1630 (shoulder at 1670), and 2930 cm^{-1}.

20 (neat) reacted with sulfur on gentle warming to yield the sulfide derivative which was recrystallized from hexane as white crystals: mp 93–95°; pmr ($CDCl_3$) δ 1.40 (s, geminal methyls), 1.50 (3 H, d, J_{HP} = 4.5 Hz, vinyl CH_3), 1.75 (3 H, d, J_{HP} = 3.0 Hz, vinyl CH_3), 2.91 (6 H, s, $CON(CH_3)_2$), 2.73 (6 H, d, J_{HP} = 12.5 Hz, $PNCH_3$), and 3.3 (4 H, m, $PNCH_2$); ir (Nujol) 721, 780, 835, 942, 1033, 1068, 1100, 1121, 1160, 1208, 1600, and 1630 cm^{-1}.

Anal. Calcd for $C_{14}H_{28}N_3O_2PS$: C, 50.43; H, 8.35; P, 9.28. Found: C, 49.99; H, 8.25; P, 9.15.

Heating **20** for 18 hr at 60° with excess methanol yielded major amounts of trimethyl phosphite, 1,2-bis(methylamino)ethane, 2-methoxyl-1,3-dimethyl-1,3,2-diazaphospholane (**4**), and *N*,*N*-dimethyl-2,2,4-trimethyl-3-oxovaleramide, identified by comparing their retention times on vpc columns A and B and the pmr spectrum of the reaction solution with those of authentic samples.

Reaction of 2-Dimethylamino-1,3-dimethyl-1,3,2-diazaphospholane (5) with Dione (1). A neat mixture of **1** (0.96 g, 6.85 mmol) and **5** (1.10 g, 6.82 mmol) after 14 days of heating at 60°, showed nearly complete isomerization of dione to lactone and the appearance of predominantly one product corresponding to **20**. An additional 15 hr at 92° completed conversion of lactone and aminophosphine into **20** (80% yield) and a less than 20% yield of an unidentified long retention time product. Distillation of the solution was very difficult, but **20**, a clear viscous liquid, was collected (1.10 g, 3.65 mmol, 54% yield, bp 95–105° (0.07 Torr)) which crystallized upon standing, mp 38–39.5°. Ir and pmr spectra and vpc retention time (column A) of this material were identical with those obtained from the product from **2** and **5**.

Reaction of 2-Dimethylamino-3-methyl-1,3,2-oxazaphospholane (6) with Lactone (2). **2** (0.67 g, 4.8 mmol) and **6** (0.63 g, 4.3 mmol) were mixed neat in a vial under a nitrogen atmosphere. Ten minutes after mixing, the solution had turned slightly yellow. After 17 hr at room temperature the solution was yellow and very viscous. Vpc analysis showed only starting materials and a very small high boiling peak; however, the ir spectrum of the solution showed very little lactone remaining. After 40 hr at room temperature, ir analysis indicated that the reaction was complete. Evacuation for several hours removed the excess lactone leaving **24** (1.20 g, 4.16 mmol, 98% yield) which solidified upon standing in a refrigerator (mp 63–65°). Attempted recrystallization of **24** re-

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sulted in decomposition: pmr (benzene) δ 1.25 (3 H, d, J_{HP} = 0.8 Hz, geminal CH_3), 1.28 (3 H, d, J_{HP} = 1.2 Hz, geminal CH_3), 1.62 (3 H, t, J = 0.5 Hz, vinyl CH_3,), 1.77 (7 H, t, J = 0.5 Hz, vinyl CH_3), 2.62 (6 H, d, J_{HP} = 9.5 Hz $(CH_3)_2N$), 2.79 (3 H, d, J_{HP} = 8 Hz, $PNCH_3$), 2.58 (2 H, m, $PNCH_2$), 3.70 (2 H, m, $POCH_2$); ir (film) 695, 746, 774, 885, 938, 960, 982, 1000, 1078, 1145, 1280, 1460, 1680, 1725 (shoulder at 1740), and 2950 cm^{-1}; ^{31}P chemical shift, +73.1 ppm *vs.* external $H_3PO_4(CH_2Cl_2)$; osmometric mol wt (benzene), 301 (theory 288); uv λ_{max} 195 nm (ϵ 9230), hexane.

Anal. Calcd for $C_{13}H_{25}O_3N_2P$: C, 54.16; H, 8.74; P, 10.74. Found: C, 53.59; H, 8.94; P, 10.54.

To **24** (0.20 g, 0.69 mmol) dissolved in benzene and cooled to 5° was added dropwise with vigorous stirring a 1 *M* solution of bromine in benzene until the yellow color of the bromine persisted throughout the solution. Evaporation of the solvent left **25**, a viscous, pale yellow liquid (0.30 g, 0.67 mmol, 97% yield). **25** was purified by column chromatography over 25.0 g of 100–200 mesh Florisil by elution with 0–10% ether in benzene: yield 0.30 g; ir 763, 970, 996, 1033, 1103, 1176, 1208, 1252, 1300, 1328, 1365, 1380, 1460, 1670, 1695, and 2950 cm^{-1}; pmr (CS_2) δ 1.59 (6 H, s, $COC(CH_3)_2CO$), 1.96 and 2.02 (3 H each, s, $BrC(CH_3)_2$), 2.53 (6 H, d, J_{HP} = 9.5 Hz, $PN(CH_3)_2$), 2.59 (3 H, d, J_{HP} = 9.0 Hz, $PNCH_3$), and 3.3 ppm (4 H, m, NCH_2CH_2Br); mass spectrum, parent at approximately 450 (theory 448).

Anal. Calcd for $C_{13}H_{25}N_2PO_3Br_2$: C, 34.84; H, 5.62; Br, 35.66; P, 6.91. Found: C, 35.52, 36.10; H, 6.02, 6.01; Br, 34.50; P, 6.52.

A solution of **25** in benzene was heated for 4 days at 75° with a threefold excess of methanol which resulted in a 75% conversion (estimated from pmr spectrum integration) into primarily two products (12 and 88% yields estimated from pmr spectrum integration). A small amount of dimethyl phosphite was also noted. The two products were collected on vpc column A at 180° isothermal. The major product **26** was a viscous colorless liquid which solidified slowly on standing into white crystals (mp 38–39°): pmr (benzene) δ 1.34 (6 H, s, $CO(CH_3)_2CO$), 1.68 (6 H, s, $POC(CH_3)_2CO$), 3.32 (3 H, d, J_{HP} = 12 Hz, $POCH_3$), 3.39 (3 H, s, CO_2CH_3), and 6.6 (1 H, d, J_{HP} = 700 Hz, PH); ir (CCl_4) 885, 969, 1052, 1148, 1168, 1185, 1265, 1363, 1383, 1430, 1465, 1720, 1750, 2430 (w), 2950, and 2980 cm^{-1}; mass spectrum (70 MeV) *m/e* (relative intensity) >10% of base, 266 (0.6), 207 (13), 137 (13), 128 (36), 102 (28), 97 (30), 87 (45), 80 (46), 79 (44), 69 (60), 59 (39), 47 (29), 44 (29), 43 (100), 41 (100), 39 (68), 31 (94).

Anal. Calcd for $C_{10}H_{19}O_6P$: C, 45.12; H, 7.19; P, 11.63. Found: C, 44.73; H, 7.51; P, 11.57.

The minor product **27**, a viscous colorless liquid which solidified rapidly on standing into white crystals (mp 41–42°), was identified by comparing the ir and pmr spectra and vpc retention time (column A) with those of an authentic sample. Authentic **27** was prepared by the method of White and Emmons[10] and purified by preparative vpc: mp 41–42°; pmr (CCl_4) δ 1.30 and 1.48, two singlet, equal intensity; ir (CCl_4) 2980, 1800, 1750, 1465, 1385, 1365, 1293, 1268, 1190, 1105, 1031, 968, and 941 cm^{-1}.

Anal. Calcd for $C_8H_{12}O_3$: C, 61.52; H, 7.74. Found: C, 61.40; H, 7.72.

When a solution of **26** in benzene was heated at 75° for 190 hr, complete conversion into **27** and dimethyl phosphite was achieved as shown by comparison of ir and pmr spectra and vpc retention times (column A) with those of authentic samples.

A solution of **24** in benzene was heated for 3 hr at 60°. Pmr analysis showed an equilibrium to be established between **24** and starting materials **6** and **2** (ratio of **24**:**6**:**2** approximately 2:1:1). During extended heating at 55°, pmr, ir, and vpc analysis showed that the above ratio remained nearly constant while a high-boiling product **21** was slowly formed. After 2 weeks at 55° approximately 50% of the equilibrium components were converted to **21**. An equimolar solution of **6** and **2** in benzene heated for 3 hr at 58° reached the same state of equilibrium as did **24**.

A neat solution of **6** (1.01 g, 6.81 mmol) and **2** (0.94 g, 6.70 mmol) was heated for 86 hr at 92°. Vpc and ir analysis showed nearly complete conversion of starting materials to a single product **21** (100% yield, vpc). Distillation yieded **21** as a viscous, colorless liquid (1.35 g, 4.69 mmol, 70% yield, bp 93–96° (0.06 Torr)) which crystallized slowly upon standing (mp 60–62°): pmr (benzene) δ 1.48 and 1.50 (3 H each, s, geminal methyls), 1.52 and 1.78 (3 H each, d, J_{HP} = 3.0 and 1.5 Hz, vinyl CH_3), 2.75 (6 H, s, $CON(CH_3)_2$), 2.62 (3 H, d, J_{HP} = 12.5 Hz, methylamino group), 2.8 (2 H, m, $PNCH_2$), and 4.1 (2 H, m, $POCH_2$); ir (film) 682, 702, 736, 762, 794, 928, 1018, 1065, 1105, 1162, 1385, 1460, 1630 (shoulder at 1660), and 2950 cm^{-1}.

21, upon warming neat with sulfur, gave the corresponding sulfide: white crystals (hexane); mp 101–102.5°; pmr ($CDCl_3$) δ 1.41 (6 H, s, *gem*-dimethyls), 1.53 and 1.73 (3 H each, d, J_{HP} = 4.0 and 3.0 Hz, vinyl methyls), 2.92 (6 H, s, $CON(CH_3)_2$), 2.80 (3 H, d, J_{HP} = 12.5 Hz, $PNCH_3$), 3.3 (2 H, m, $PNCH_2$), and 4.3 (2 H, m, $POCH_2$): ir (Nujol) 762, 769, 838, 855, 933, 1008, 1033, 1071, 1105, 1178, 1250, 1620, and 1645 (shoulder) cm^{-1}.

Anal. Calcd for $C_{13}H_{25}N_2O_3PS$: C, 48.74; H, 7.87; P, 9.67. Found: C, 48.59; H, 7.81; P, 9.93.

21 with excess methanol at 60° for 60 hr was completely converted into major amounts of trimethyl phosphite, 2-methoxyl-3-methyl-1,3,2-oxazaphospholane (**4**), and *N*,*N*-dimethyl-2,2,4-trimethyl-3-oxovaleramide, identified by comparing the pmr spectrum of the reaction solution and the retention times on vpc columns A and B with those of authentic samples.

Reaction of 2-Dimethylamino-3-methyl-1,3,2-oxazaphospholane (6) with Dione (1). Reaction of **1** (0.75 g, 5.4 mmol) and **6** (0.79 g, 5.3 mmol) at 92° was monitored by vpc and ir. Indications that an intermediate, possibly **12**, was being formed and consumed came from the ir which showed the appearance of a carbonyl band at 1725 cm^{-1} in addition to those at 1750 cm^{-1} for dione and 1630 cm^{-1} for the observed product. After 158 hr, vpc indicated that **6** was nearly completely consumed. Vpc showed the major product **21** to be present in approximately 70% yield. Other peaks were present suggesting decomposition of the intermediate. Also noted was a very small peak corresponding in retention time to **2** which seemed to remain constant in size throughout the course of the reaction. Distillation of the dark brown reaction solution yielded **21** (0.83 g, 2.9 mmol, 54% yield) which was identified by comparing the ir and pmr spectra with those obtained from the product of the high-temperature reaction of **2** and **6**. The intermediate was unstable and resisted attempts at isolation.

1 and **6** in equimolar ratios were heated at 60°. Ir analysis showed a higher concentration of the intermediate with absorption at 1725 cm^{-1} during the course of the reaction than at 92°. ^{31}P nmr (CH_2Cl_2) of the reaction solution after 6 weeks heating showed a major signal at −40.8 ppm relative to external H_3PO_4 and smaller absorptions at −129.4 and −137.3 ppm, shown to correspond to **6** and **21**.

Reaction of 2-Dimethylamino-1,3,2-dioxaphospholane (7) with Lactone (2). A mixture of **2** (1.18 g, 8.42 mmol) and **7** (1.14 g, 8.44 mmol) at room temperature was monitored by vpc and ir. Throughout the course of the reaction, vpc showed only starting materials, whereas the ir spectra showed a slow disappearance of the carbonyl peaks due to lactone and the appearance of a new band at 1750 cm^{-1}. After 80 days at room temperature, the approximate ratio of the new carbonyl band to the remaining lactone carbonyl band was 4:1. The predominant compound, probably **29**, seemed to be unstable and resisted attempts at isolation. ^{31}P nmr of the reaction solution (CH_2Cl_2) showed a peak at +53.0 ppm relative to external H_3PO_4.

A small amount (0.63 g) of the reaction solution (80 days at room temperature) was heated under nitrogen for 10 days at 120°. Ir monitoring of the reaction showed that after 6-hr heating an equilibrium was established in which the starting materials, **2** and **7**, were predominant. During extended heating the ratio of the ir carbonyl bands of **2** and **7** remained approximately constant while another product, **22**, was slowly formed. (After 10 days, vpc and ir showed that the starting materials were approximately 95% converted to **22**, 90% yield.) Distillation yielded **22** as a viscous colorless liquid (0.26 g, 0.95 mmol, 41% yield) which slowly solidified on standing at room temperature (mp 92–95°): pmr (25% v/v $CDCl_3$ in benzene) δ 1.35 (6 H, s, *gem*-dimethyls), 1.43 and 1.68 (3 H each, d, J_{HP} = 3.0 and 1.5 Hz, vinyl methyls), 2.70 (6 H, s, $CON(CH_3)_2$), and 3.7 (4 H, m, OCH_2CH_2O); ir (film) 735, 767, 793, 926, 1012, 1068, 1115, 1390, 1465, 1635 (shoulder at 1660), and 2930 cm^{-1}.

22, on warming neat with sulfur, yielded a single product sulfide: white crystals (hexane); mp 95–96°; pmr ($CDCl_3$) δ 1.43 (6 H, s, geminal methyls), 1.58 and 1.76 (3 H each, d, J_{HP} = 4.5 and 3.5 Hz, vinyl methyls), 2.92 (6 H, s, $CON(CH_3)_2$), and 4.4 (4 H, m, OCH_2CH_2O); ir (CCl_4) 868, 892, 926, 1035, 1071, 1110, 1370, 1392, 1465, 1635, 2920, and 2980 cm^{-1}.

Anal. Calcd for $C_{12}H_{22}NO_4PS$: C, 46.89; H, 7.21; N, 4.56; P, 10.08. Found: C, 46.54; H, 7.22; N, 4.35; P, 9.72.

Reaction of 2-Dimethylamino-1,3,2-dioxaphospholane (7) with Dione (1). **1** (1.25 g, 8.91 mmol) and **7** (1.21 g, 8.94 mmol) were heated 9 days at 120° to give complete conversion of dione to products, including: an approximately 10% yield of lactone; a 15%

yield of *N*,*N*-dimethyl 2,2,4-trimethyl-3-oxovaleramide; and a 60% yield of **22** (yields estimated from vpc and ir analysis). The major product was identified as **22** by comparing its ir and pmr spectra and vpc retention time (column A) with the product from **2** and **7**. ^{31}P nmr analysis of the product solution showed a single absorption at -140 ppm.

Upon extending heating at 60 and 90° the same reactants showed no change observable by vpc or ir.

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Trapping of Picolyl Cations in the Reactions of 2- and 4-Picoline *N*-Oxide with Acetic Anhydride[1a–c]

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Abstract: Attempts to trap the picolyl cations thought to be intermediates in the reactions of 4-picoline *N*-oxide (**1**) and 2-picoline *N*-oxide (**5**) with acetic anhydride are reported. In anisole, **1** and acetic anhydride yield, in addition to 4-pyridylcarbinol acetate (**3**) and 3-acetoxy-4-methylpyridine (**4**) in a ratio of 55:45, 20% of a mixture of the 4-picolylanisoles, 4-*o*-, 4-*m*-, and 4-*p*-methoxybenzylpyridine (relative yields 65:7:28). The same reaction in benzonitrile produces the esters in the same ratio and 11% of *N*-4-picolyl-*N*-acetylbenzamide (**14**); no product having a picolyl group substituted into the benzonitrile nucleus can be detected. In acetic acid, the ratio of esters **3** to **4** increases to 90:10. The reaction of **5** with acetic anhydride in anisole produces, in addition to 2-pyridylcarbinol acetate (**7**), 5-acetoxy-2-methylpyridine (**8**), and 3-acetoxy-2-methylpyridine (**9**) in relative yields of 76:12:12, 2% of a mixture of 2-*o*-, 2-*m*-, and 2-*p*-methoxybenzylpyridine (**15a**, **b**, and **c**) in relative yields of 57:4:39. The same reaction in acetic acid yields the same ester mixture as in anisole. In benzonitrile less than 2% of a mixture of *N*-2-picolylbenzamide (**17**) and 3-phenyl-2,3a-diazaindene (**18**) is produced. No product having a picolyl group substituted into the benzonitrile nucleus can be detected. The reaction of **1** with pivalic anhydride in anisole and in benzonitrile yields none of the solvent-derived products which are formed in the corresponding reactions using acetic anhydride. The results are consistent with the presence of picolyl cation–acetate anion pairs as principal intermediates in the reactions of both amine oxides with acetic anhydride. Collapse of the ion pairs leads to attack of acetate both on the methylene group and on the ring. On the other hand, neutral, weak nucleophiles attack the picolyl cations only at the methylene position, and probably for reasons of ionic juxtaposition, such solvent capture competes with ion pair collapse more efficiently for the 4- than for the 2-picolyl cation.

The reaction of 4-picoline *N*-oxide (**1**) with acetic anhydride yields a mixture of 4-pyridylcarbinol acetate (**3**) and 3-acetoxy-4-methylpyridine (**4**).[2] Under the same conditions, 2-picoline *N*-oxide (**5**) yields mainly 2-pyridylcarbinol acetate (**7**) and small amounts of 5-acetoxy-2-methylpyridine (**8**) and 3-acetoxy-2-methylpyridine (**9**).[2] It is known that the anhydrobases **2** and **6**, respectively, are reaction intermediates.[2]

Oae has shown by ^{18}O labeling studies that in the presence of aromatic diluents the esters are formed from **6** by a completely intramolecular process and from **2** by a process that is very largely intramolecular.[3] When the reaction is performed in neat acetic anhydride, the conversion of **6** to esters is still intramolecular while the production of esters from **2** is mainly intermolecular.[4]

The substantial ^{18}O shuffling observed in the intramolecular rearrangement in the **2** case indicates that the process is not concerted.[5,6] By analogy, the intramolecular rearrangement of **2** is probably also not concerted.

Until recently, it was believed that the intramolecular rearrangements of the anhydrobases occur by a radical-pair mechanism.[3,7] However, the successful production of esters by the treatment of 2-picoline *N*-oxide with phenylacetic[8,9] and trichloroacetic[9] anhydrides led to the suggestion that ion pairs (**10**) consisting of 2-picolyl cations and acylate anions are involved in the case of **6**. Recent support for such an intermediate has been presented by Bodalski and Katritzky[10] who observed typical carbonium ion rearrangement and elimination products from the reaction of acetic anhydride with various 2-substituted pyridine *N*-oxides. The reaction of 4-picoline *N*-oxide with phenylacetic anhydride produced very low yields of ester and this result was considered inconclusive with regard to the radical or ion pair character of the intermediate in the acetic anhydride case.[8] Very recently, Traynelis and

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[1] (a) We wish to thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this work; (b) taken from the Ph.D. thesis of GLD, University of Pittsburgh, Pittsburgh, Pa., 1969; (c) part of this work has been reported in preliminary form: T. Cohen and G. L. Deets, *J. Amer. Chem. Soc.*, **89**, 3939 (1967); (d) NASA Predoctoral Fellow.

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