J. Ferguson, A. R. Katritzky, and D. M. Read, *J. Chem. Soc., Chem. Commun.*, 255 (1975).
(22) S. F. Nelsen and P. J. Hintz, *J. Am. Chem. Soc.*, **94**, 7108 (1972).
(23) It should be noted that a transmission coefficient of 1 was used for calculations of the activation parameters for **5–11**, whereas Anderson and Lehn[4b] would have used ½ for **5–7** because they expected a Figure 1A type of barrier. If ½ were used, the $\Delta S^\ddagger$ values would be 1.37 eu more positive, and $\Delta G^\ddagger_{298}$ 0.41 kcal/mol lower.
(24) (a) J. M. Lehn and J. Wagner, *Chem. Commun.*, 414 (1970); (b) J. M. Lehn and J. Wagner, *Chem. Commun.*, 148 (1968).
(25) J. M. Lehn and J. Wagner, *Tetrahedron*, **26**, 4227 (1970).
(26) J. D. Roberts, F. J. Weigert, J. I. Kroschwitz, and H. J. Reich, *J. Am. Chem. Soc.*, **92**, 1338 (1970).
(27) H. Eggert and C. Djerassi, *J. Am. Chem. Soc.* **95**, 3710 (1973).
(28) K. Alder and M. Vogt, *Justus Liebigs Ann. Chem.*, **564**, 109 (1949).
(29) M. P. Cava, C. J. Wilkins, Jr., D. R. Dalton, and K. Bessho, *J. Org. Chem.*, **30**, 3772 (1965).
(30) W. Schneider and R. Dillman, *Chem. Ber.*, **96**, 2377 (1963).
(31) A. B. Smith and W. C. Agosta, *J. Org. Chem.*, **37**, 1259 (1972).
(32) (a) H. Koch, *Monatsch. Chem.*, **93**, 1343 (1962); (b) E. Pettit, M. Pecque, and M. Blanchard, *Bull. Soc. Chim. Fr.*, 747 (1972); (c) B. A. Kazanskii and P. I. Svirskaya, *Zh. Obshch. Khim.*, **29**, 2584 (1959).
(33) G. Binsch, *Top. in Stereochem.*, **3**, 122 (1968).
(34) A. J. Gordon and R. A. Ford, "The Chemist's Companion", Wiley-Interscience, New York, N.Y., 1972, p 491.
(35) (a) A. Allerhand, F. Chen, and H. S. Gutowsky, *J. Chem. Phys.*, **42**, 3040 (1965); (b) H. S. Gutowsky and C. H. Holm, *J. Chem. Phys.*, **25** 1228 (1956).

Conformations of Saturated Phosphorus Heterocycles. IV. ^{1}H, ^{13}C, and ^{31}P Nuclear Magnetic Resonance Studies of Geometrical Isomers of 2-Z-4-Methyl- and 4-*tert*-Butyl-1,3,2-dioxaphospholanes

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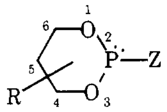
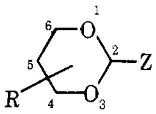
Abstract: The cis-trans stereoisomerism and conformations of a series of 2-Z-4-Me- and 2-Z-4-*tert*-butyl-1,3,2-dioxaphospholanes were studied by ^{1}H, ^{13}C, and ^{31}P NMR methods. For the 4-Me compounds (Z = Me_2N MeO, *t*-BuO, *t*-Bu, $PhCH_2$, and Ph), the trans/cis ratio regardless of Z was (65 ± 2)/(35 ± 2) at ambient temperatures corresponding to $\Delta G°$ = 0.4 kcal/mol. The trans/cis ratio was increased for the 4-*t*-Bu compounds (Z = MeO, Me_2N, *t*-Bu) with $\Delta G°$ = 0.8–1.0 kcal/mol. The greater thermodynamic stability of the trans isomer in these systems is directly opposite to the case for 2-Z-4-R-1,3-dioxanes in which the cis isomer is favored. This emphasizes the importance of the presence of the phosphorus heteroatom as found previously with the 2-Z-5-*tert*-butyl-1,3,2-dioxaphosphorinanes which have cis-trans thermodynamic stabilities opposite to those found for the analogous 1,3-dioxanes. The results of this work are reasonably well interpreted for each isomer in terms of two rapidly equilibrating half-chair conformers with 4-alkyl pseudoaxial or pseudoequatorial, although possible alternative explanations cannot be excluded. The cis isomers appear to be conformationally biased toward the form with 4-alkyl pseudoequatorial. The cis or trans geometry of a given isomer is easily assigned from ^{13}C or ^{31}P NMR spectroscopy alone. The ^{31}P resonance of the cis isomer appears in each case 2.4 to 7.4 ppm *downfield* from the trans isomer absorption, presumably as a result of the δ interaction of the 2-Z and 4-alkyl substituents. The cis and trans isomer assignments for the 4-Me compounds are made from ^{13}C spectra on the basis of the chemical shifts of the C-4, C-5, and C-4′ as influenced by the δ effect. The similarities of the 2-Z-4-R-1,3,2-dioxaphospholanes to other 1,3-dioxa and 1,3-dithia five-membered ring systems with P, As, or S at the 2 position are noted.

Over the past several years, there has been an increasing amount of interest in saturated heterocycles containing phosphorus and oxygen in five- and six-membered rings. The trivalent 1,3,2-dioxaphosphorinanes (**1**) and 1,3,2-dioxaphospholanes (**3**) are clearly analogous to the 1,3-dioxanes (**2**) and 1,3-dioxolanes (**4**). Differences in bond distances and angles imposed on such rings by substitution of phosphorus for carbon, however, might well be expected to affect the relative energies of cis or trans isomers and of their various conformers in important ways. Furthermore, in **1** and **3**, the presence of an electron lone pair on phosphorus will change the steric competition between the substituents at the 2 position and also result in vicinal interactions (between the oxygens and the substituents on the atom at the 2 position) different from those present in **2** and **4**. An example of the consequence of such effects is seen in the 2-Z-5-*tert*-butyl-1,3,2-dioxaphosphorinane series[1,2] (**1**, R = 5-*t*-Bu). For Z equal Cl, MeO, Ph, Me, and *i*-Pr, the cis isomer is the more stable form and populates almost entirely the conformer **5**. By contrast, the most stable conformer of the *less stable* isomer in the comparable 1,3-dioxane is **6**.[3] We have suggested[1,4] that the strong axial preference of Z in the 1,3,2-dioxaphosphorinanes is probably a result of more favorable vicinal interactions between the lone pairs on oxy-



1



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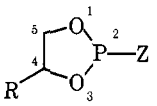

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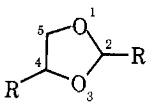

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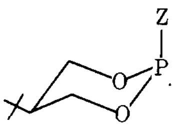

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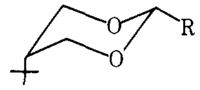

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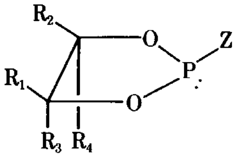
Table I. ^{1}H NMR and ^{31}P Spectral Parameters for 7–17[a]



Compound	$J_{1,2}$[b]	$J_{1,3}$	$J_{1,4}$	$J_{1,5}$	$J_{2,3}$	$J_{2,4}$	$J_{2,5}$	$J_{3,4}$	$J_{3,5}$	$J_{4,5}$	J_{PZ}	ν_1[c]	ν_2	ν_3	ν_4	ν_Z
7	6.54 (0.02)[d]	−8.56 (0.01)	6.26 (0.01)	4.35 (0.01)	6.26 (0.01)	−8.56 (0.01)	4.35 (0.01)	7.01 (0.02)	8.67 (0.02)	8.67 (0.02)	8.3 (Me_2N)	383.49 (0.01)	383.49 (0.01)	357.24 (0.01)	357.24 (0.01)	241.0 (Me_2N)
8					0.77[i] (0.01)	−8.20 (0.01)	0.01 (0.02)			15.17 (0.03)	8.2 (Me_2N)	75.0[f] (Me)	211.26 (0.01)	69.0[f] (Me)	211.53 (0.01)	147.5 (Me_2N)
9a		6.00[h]		0.70[j]	9.72 (0.03)	−8.41 (0.03)	−0.24 (0.04)	5.90 (0.03)	1.50 (0.04)	15.26 (0.04)	8.2 (Me_2N)	111.5[g] (Me)	326.05 (0.02)	391.86 (0.02)	365.96 (0.02)	244.0 (Me_2N)
9b	5.92 (0.04)	6.00[h]	7.17 (0.04)	1.57 (0.06)		−8.81 (0.04)	6.09 (0.06)		0.60[j]	6.32 (0.06)	8.2 (Me_2N)	414.26 (0.03)	393.81 (0.03)	100.0[g] (Me)	318.75 (0.03)	241.0 (Me_2N)
9a[e]		6.00[h]		0.80[j]							8.4 (Me_2N)	143.0[g] (Me)				263.5 (Me_2N)
9b[e]	5.93 (0.03)	6.00[h]	7.18 (0.03)	1.48 (0.05)		−8.72 (0.03)	6.42 (0.05)		0.60[j]	6.19 (0.04)	8.4 (Me_2N)	446.30 (0.02)	428.26 (0.02)	125.5[g] (Me)	343.13 (0.02)	260.0 (Me_2N)
10a		6.00[h]		0.60[j]	9.14 (0.04)	−8.50 (0.06)	−0.31 (0.09)	6.39 (0.03)	3.55 (0.05)	13.09 (0.06)	10.7 (MeO)	118.0[g] (Me)	344.76 (0.05)	402.12 (0.03)	383.65 (0.03)	325.0
10b	6.64 (0.02)	6.00[h]	6.79 (0.02)	0.77 (0.02)		−8.48 (0.02)	2.91 (0.02)		0.60[j]	7.45 (0.02)	10.3 (MeO)	429.64 (0.01)	399.35 (0.01)	104.0[g] (Me)	327.18 (0.01)	324.0
11a		5.90[h]		0.55[j]	8.83 (0.02)	−8.35 (0.02)	−0.42 (0.03)	6.66 (0.02)	4.93 (0.02)	12.97 (0.03)	0.7 (*t*-BuO)	120.0[g] (Me)	358.91 (0.02)	394.43 (0.01)	378.41 (0.01)	128.6 (*t*-BuO)
11b	6.72 (0.01)	6.10[h]	6.78 (0.01)	0.38 (0.01)		−8.21 (0.01)	2.09 (0.01)		0.70[j]	8.11 (0.01)	0.8 (*t*-BuO)	436.48 (0.01)	400.53 (0.01)	100.0[g] (Me)	319.25 (0.01)	129.9 (*t*-BuO)
12a		6.00[h]		0.85[j]	9.97 (0.02)	−8.38 (0.02)	−1.10 (0.02)	5.61 (0.02)	0.71 (0.03)	14.67 (0.03)	11.6 (*t*-Bu)	106.8[g] (Me)	321.82 (0.01)	391.42 (0.01)	367.00 (0.01)	90.7 (*t*-Bu)
12b	6.24 (0.01)	6.00[h]	6.88 (0.01)	0.79 (0.02)		−8.50 (0.01)	4.84 (0.02)		0.55[j]	5.92 (0.02)	11.6 (*t*-Bu)	416.66 (0.01)	392.04 (0.01)	98.9[g] (Me)	321.71 (0.01)	88.5 (*t*-Bu)
13a		5.80[h]		0.70[j]							6.9 ($PhCH_2$)	99.2[g] (Me)				259.2 ($PhCH_2$)
13b	6.76 (0.02)	5.80[h]	6.85 (0.02)	0.76 (0.03)		−8.75 (0.02)	2.03 (0.02)		0.55[j]	7.57 (0.02)	6.2 ($PhCH_2$)	396.22 (0.02)	371.61 (0.01)	93.3[g] (Me)	313.08 (0.01)	256.6 ($PhCH_2$)
14a		6.00[h]										99.0[g] (Me)				
14b	6.75 (0.02)	6.00[h]	6.85 (0.02)	0.33 (0.04)		−8.35 (0.02)	2.11 (0.03)			7.16 (0.03)		388.86 (0.02)	367.65 (0.01)	99.0[g] (Me)	319.96 (0.01)	
15a											11.6 (MeO)	83.5 (*t*-Bu)				322.7 (MeO)
15b	7.45 (0.02)		6.48 (0.04)	0.63 (0.03)		−8.83 (0.04)	1.43 (0.03)			8.97 (0.03)	10.4 (MeO)	394.62 (0.03)	385.12 (0.03)	75.5 (*t*-Bu)	360.82 (0.02)	319.0 (MeO)
16a											8.1 (Me_2N)	85.5 (*t*-Bu)				146.0 (Me_2N)
16b	6.87 (0.02)		6.58 (0.03)	1.34 (0.04)		−8.82 (0.04)	4.19 (0.04)			8.12 (0.04)	8.1 (Me_2N)	388.48 (0.02)	388.05 (0.02)	80.5 (*t*-Bu)	358.92 (0.02)	139.5 (Me_2N)
17a											11.7 (*t*-Bu)	83.2 (*t*-Bu)				94.0 (*t*-Bu)
17b	7.12 (0.03)		6.29 (0.06)	0.95 (0.05)		−8.89 (0.06)	2.53 (0.05)			7.89 (0.05)	11.5 (*t*-Bu)	394.22 (0.04)	389.80 (0.03)	79.5 (*t*-Bu)	364.74 (0.03)	89.4 (*t*-Bu)

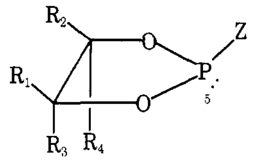
[a] Measured at ambient probe temperatures, Varian Associates XL-100-15 spectrometer, except for 8 (Varian A-60 instrument). Approximate 25% (v/v) solution in benzene-d_6. [b] Coupling constants in Hz. $J_{2,4}$ assumed negative. [c] Chemical shifts in Hz downfield from Me_4Si as internal standard. [d] Number in parentheses is probable error in Hz of parameter determined from LAOCN3 iterative analysis. Root mean square errors of line positions: 7, 0.039; 8, 0.044; 9a, 0.055; 9b, 0.091; 9a,[e] 0.073; 10a, 0.058; 10b, 0.037; 11a, 0.028; 11b, 0.029; 12a, 0.038; 12b, 0.029; 13b, 0.033; 14b, 0.040; 15b, 0.044; 16b, 0.047; 17b, 0.058. [e] Approximate 25% (v/v) solution in $CDCl_3$. [f] Broad singlet, ring Me. [g] Broad doublet. [h] $^{13}J_{HH}$ for CH_3CH. [i] ^4J, CH_3CCH. [j] J_{HP}, CH_3COP.

gen and the empty antibonding orbitals on phosphorus when Z is axial than when it is equatorial. Reduced 1,3-synaxial interactions in **1** may play a role as well.

In view of the findings in the 1,3,2-dioxaphosphorinane rings (**1**), we decided to apply to **3** the same sorts of ^{1}H, ^{13}C, and ^{31}P NMR techniques used to study **1**. Although ^{1}H NMR studies of certain 4-substituted-2-alkoxy- and 2-Cl-1,3,2-dioxaphospholanes have been reported,[5] no complete study of *both* cis and trans isomers has been published nor has an investigation of a variety of phosphorus substituents been attempted. Such studies allow a considerably more detailed understanding of conformational effects in these systems.

Results

Syntheses. The 2-Z-4-methyl-1,3,2-dioxaphospholanes (**7–14**) were synthesized in fairly routine fashion. The phosphonites **12** and **13** are considerably more stable than the analogues unsubstituted at carbon, which we find to be rapidly converted to higher molecular weight products.[6] The formation of dimers and trimers from the 2-phenyl-1,3,2-dioxaphospholane has been documented.[7] The monomeric nature of **12** and **13** was affirmed by their low GLC retention times and boiling points (comparable to other **3**). Furthermore, on standing neat for several days at room temperature, they remain as mobile liquids unlike their unsubstituted counterparts. Reaction with S-8 converts **12** and **13** to the sulfides which also are readily analyzed by GLC with retention times similar to those for other **3**-sulfides. Additionally, only two isomeric forms of **12** and **13** were found by ^{31}P NMR. The dimer and trimers of **3** would be expected to show the presence of several isomers. Also, the conformational bias indicated by the PMR parameters for the cis isomers of **1** and **13** (to be discussed later) would not be expected of a 12- or 18-membered ring, which should be highly flexible.



7, R$_1$,R$_2$,R$_3$,R$_4$ = H; Z = Me$_2$N
8, R$_1$,R$_3$ = Me; R$_2$,R$_4$ = H; Z = Me$_2$N
9a, R$_1$ = Me; R$_2$,R$_3$,R$_4$ = H; Z = Me$_2$N
9b, R$_3$ = Me; R$_1$,R$_2$,R$_4$ = H; Z = Me$_2$N
10a, R$_1$ = Me; R$_2$,R$_3$,R$_4$ = H; Z = MeO
10b, R$_3$ = Me; R$_1$,R$_2$,R$_4$ = H; Z = MeO
11a, R$_1$ = Me; R$_2$,R$_3$,R$_4$ = H; Z = *t*-BuO
11b, R$_3$ = Me; R$_1$R$_2$,R$_4$ = H; Z = *t*-BuO
12a, R$_1$ = Me; R$_2$,R$_3$,R$_4$ = H; Z = *t*-Bu
12b, R$_3$ = Me; R$_1$,R$_2$,R$_4$ = H; Z = *t*-Bu
13a, R$_1$ = Me; R$_2$,R$_3$,R$_4$ = H; Z = PhCH$_2$
13b, R$_3$ = Me; R$_1$,R$_2$,R$_4$ = H; Z = PhCH$_2$
14a, R$_1$ = Me; R$_2$,R$_3$,R$_4$ = H; Z = Ph
14b, R$_3$ = Me; R$_1$,R$_2$,R$_4$ = H; Z = Ph
15a, R$_1$ = *t*-Bu; R$_2$,R$_3$,R$_4$ = H; Z = MeO
15b, R$_3$ = *t*-Bu, R$_1$,R$_2$,R$_4$ = H; Z = MeO
16a, R$_1$ = *t*-Bu; R$_2$,R$_3$,R$_4$ = H; Z = Me$_2$N
16b, R$_3$ = *t*-Bu; R$_1$,R$_2$,R$_4$ = H; Z = Me$_2$N
17a, R$_1$ = *t*-Bu; R$_2$,R$_3$,R$_4$ = H; Z = *t*-Bu
17b, R$_3$ = *t*-Bu; R$_1$,R$_2$,R$_4$ = H; Z = *t*-Bu

^{1}H NMR Analyses. Compounds **7–14** were analyzed at 100 MHz (Table I). Conjugate solutions were resolved by analysis at 60 MHz or by analysis of the phosphorus-decoupled spectrum. In all cases, hand-calculated spectral parameters were refined using the LAOCN3 program. Error limits are given in Table I. In the ^{1}H NMR analyses of **7–17**, the maximum errors in line assignments were generally less than twice the root mean square error. It was possible to assign 70–95% of the transitions. Since for the AA′BB′X spin systems $J_{AA'}$ cannot be distinguished from $J_{BB'}$, the values for J_{12} and J_{34} for **7** in Table I may be reversed. In all previous studies, the couplings J_{12} and J_{34} for such AA′BB′X systems have been assumed or found to be equal.[5,8] The nonequivalence of these couplings has been noted[9] with 2-phenyl-1,3,2-dithiaphospholane but not for 1,3,2-dioxaphospholanes. The 4,4′-dimethyl compound **7** was analyzed in the ABX form and then refined as an ABK$_3$X system since one ring methyl is coupled to a methylene hydrogen.

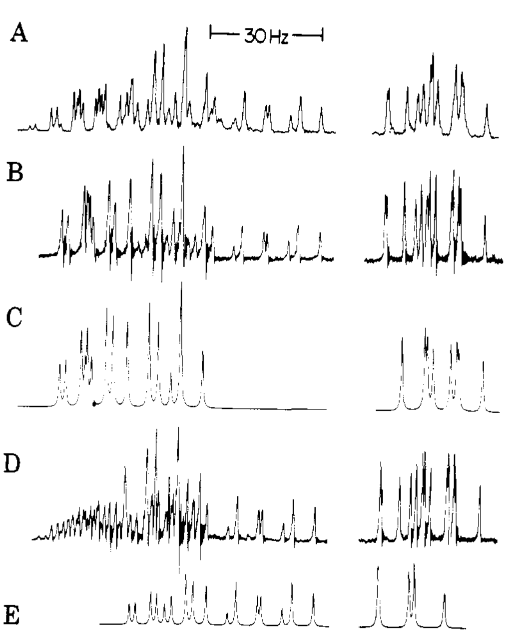
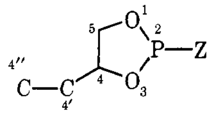


Figure 1. ^{1}H NMR spectra of **9**, methylene and methine protons: (A) **9a–9b** mixture in C$_6$D$_6$, no decoupling; (B) irradiation of ring methyl of trans isomer (**9b**); (C) simulated spectrum of **9b**; (D) irradiation of ring methyl of cis isomer (**9a**); (E) simulated spectrum of **9a**.

In Table I, the coupling constant designations J_{25}, J_{35}, etc., refer to the protons at positions 1–4 as indicated in the structure of phosphorus, designated as nucleus 5.

The analyses of the 4-substituted-1,3,2-dioxaphospholanes are typified by the Me$_2$N compound **9**. With the exception of **14**, the ring methyls for cis and trans isomers (doublets) absorb at different frequencies. The major isomer with methyl at higher field is assigned the trans geometry (to be discussed later). Selective homonuclear decoupling was used to simplify various portions of the ^{1}H NMR spectrum (Figure 1a) of the mixture of stereoisomers. Thus, on radiation of the high-field methyl, the spectrum of the adjacent methine proton, which appears farthest downfield in Figure 1a, is simplified to eight lines (left-hand portion of Figure 1b). From the spacings of the methine signals and the knowledge that $J_{\text{gem}} \simeq -8.5$ Hz in 1,3,2-dioxaphospholanes, it was possible to pick out all the transitions for the AKMX system represented by the trans isomer **9b**. The simulated spectrum for **9b** is shown in Figure 1c. The transitions for the minor isomer **9a** were assigned in similar fashion by radiation of the low-field methyl signal (Figure 1d). The very low-field methine proton resonance of the trans isomer is now very complex because of partial (off-resonance) decoupling. Fortunately, the methine proton of *cis*-**9** is upfield of that region, although it overlaps the downfield methylene hydrogen of *trans*-**9**. The more upfield methylene hydrogen of *cis*-**9** (H^4, δ 366 Hz) is well separated in Figure 1d from the other methylene resonances. By expansion of the region (50-MHz sweep width), the methine transitions of *cis*-**9** were assigned without difficulty. The simulated spectrum for **9a** is given in Figure 1e.

Table II. ^{13}C and ^{31}P Spectral Parameters for 2-Z-4-R-1,3,2-Dioxaphospholanes[a]



				δ ^{13}C[c]					
Compound	R	Z	δ ^{31}P[b]	C-4	C-4′	C-4″	C-5	C-2α	C-2β
9a	cis-Me	Me_2N	−147.34	72.78 (7.5)[d]	17.41 (3.0)		69.80 (7.5)	34.98[e] (19.8)	
9b	trans-Me	Me_2N	−142.51	71.78 (8.1)	20.14 (4.1)		70.74 (9.5)	34.98[e] (19.8)	
10a	cis-Me	CH_3O	−139.62	74.23 (9.8)	18.99 (<3)		70.01 (7.6)	49.17[f] (9.1)	
10b	trans-Me	CH_3O	−135.25	72.84 (9.4)	19.97 (4.2)		70.82 (8.3)	49.17[f] (9.1)	
11a	cis-Me	*t*-BuO	−140.22	73.82 (9.0)	20.64 (<3)		68.98 (7.6)	75.44[g] (7.5)	31.27[h] (9.1)
11b	trans-Me	*t*-BuO	−137.84	71.21 (7.8)	19.64 (4.5)		69.58 (7.6)	75.44[g] (7.5)	31.27[h] (9.1)
12a	cis-Me	*t*-Bu	−207.37	74.07 (6.4)	17.03 (3.4)		70.95 (6.6)	37.06[g] (43.7)	23.99[h] (19.9)
12b	trans-Me	*t*-Bu	−201.48	73.58 (8.8)	20.09 (4.5)		71.96 (7.6)	37.79[g] (44.9)	23.35[h] (18.6)
13a	cis-Me	$PhCH_2$	−190.36	74.44 (9.7)	18.79 (<3)		69.89 (8.4)	46.10[i] (49.2)	
13b	trans-Me	$PhCH_2$	−185.44	72.45 (9.8)	19.77 (3.7)		70.61 (8.0)	44.65[i] (47.6)	
14a	cis-Me	Ph	−169.00	75.08 (9.5)	18.45 (<3)		70.19 (8.6)		
14b	trans-Me	Ph	−165.19	72.52 (8.9)	19.36 (3.7)		70.52 (7.9)		
15a	cis-*t*-Bu	OMe	−143.10	85.94 (9.9)	32.50	25.91	64.31 (6.9)	49.08[f] (9.7)	
15b	trans-*t*-Bu	OMe	−135.73	84.45 (9.7)	33.55 (3.7)	25.04	65.49 (8.1)	49.08[f] (9.7)	
16a	cis-*t*-Bu	$N(CH_3)_2$	−150.40	~83.7	33.15 (3.5)	25.91	64.35 (6.3)	34.92[e] (19.7)	
16b	trans-*t*-Bu	$N(CH_3)_2$	−143.83	83.96 (10.2)	33.90 (4.0)	25.18	65.45 (8.7)	34.92[e] (19.7)	
17a	cis-*t*-Bu	*t*-Bu	−209.17	85.02 (4.1)	32.85 (4.1)	26.20	65.49 (6.2)	36.88[g] (43.5)	22.94[h] (17.6)
17b	trans-*t*-Bu	*t*-Bu	−202.04	85.56 (9.2)	34.18 (3.2)	25.18	66.61 (8.0)	38.04[g] (44.8)	23.29[h] (17.7)

[a] Measured in benzene at 30°. ^{13}C NMR spectra were obtained using a Varian XL-100-15 spectrometer equipped with a Varian 620-F computer and operating in the Fourier transform mode. ^{31}P NMR spectra were obtained using a Varian XL-100-15 spectrometer operating in the continuous wave mode. [b] In ppm downfield from external 85% H_3PO_4. [c] In ppm downfield from internal Me_4Si. Referenced experimentally relative to C_6H_6. Referred to Me_4Si, $\delta_{Me_4Si} = 128.55 - \delta_{C_6H_6}$. [d] $|J_{CP}|$ in Hz. [e] Me_2N. [f] MeO. [g] $\mathit{C}(\mathrm{CH}_3)_3$. [h] $\mathrm{C}(\mathit{CH}_3)_3$. [i] CH_2Ph.

^{13}C and ^{31}P NMR Spectra. Recorded in Table II are ^{31}P and ^{13}C spectral parameters[10] for the various 2-Z-4-methyl-1,3,2-dioxaphospholanes (**7–14**). All ^{13}C shift assignments were checked by off-resonance decoupling methods.

NMR Studies of 2-Z-4-*tert*-Butyl-1,3,2-dioxaphospholanes. In similar fashion, a series of **3** with R equal *tert*-butyl was synthesized (compounds **15–17**). ^1H, ^{13}C, and ^{31}P NMR data were analyzed by methods similar to those used for **7–14**. Unfortunately, the minor isomer in **15–17** is present in such a small percentage that it was not possible to analyze its ^1H NMR spectrum. The analyses for ***trans*-15–17** were aided by phosphorus spin decoupling to give an ABC proton spectrum. Spectral data for **15–17** also appear in Tables I and II.

Equilibration Studies. After they stood for several days at room temperature in benzene, solutions of **9–14** were treated with sulfur to convert them to the corresponding sulfides. This reaction is generally recognized to be stereospecifically retentive.[11] Trans/cis sulfide ratios were then determined quantitatively by GLC. Certain of **9–14** could be initially prepared or even distilled in a thermodynamically nonequilibrated state; but over a few days at room temperature, trans/cis ratios underwent change to a new and eventually constant value. These ratios were all (65 ± 2)/(35 ± 2) regardless of Z.

Table III. Equilibration Studies of 2-Z-4-*tert*-Butyl-1,3,2-dioxaphospholanes[a]

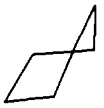
Compound	Probe temp, °C	trans/cis
15	32	78/22
	120	74/26
	32[b]	78/22
16	32	81/19
	120	78/22
	32[b]	81/19
17	32	84/16
	120	83/17
	32[b]	84/16

[a] Ca. 20% (v:v) degassed solutions in *o*-dichlorobenzene. [b] Reequilibration. Small drop of CF_3COOH added.

The ^1H NMR spectra in benzene were used to determine trans/cis ratios of **15–17** as well (4-*tert*-butyl signals). In Table III are recorded ratios determined first at ambient probe temperature (32°), then after reequilibration at 120°, and finally again at 32°. Addition of a small drop of CF3COOH to the samples at 32° to speed equilibration failed to change the ratios. Unlike **9–14**, the ratios for **15–17** respond to change in Z.

Discussion

Cis–trans Geometries and Conformations of 2-Z-4-*tert*-Butyl-1,3,2-dioxaphospholanes. 1,3,2-Dioxaphospholanes are analogous to cyclopentane for which envelope (**18**) and half-chair (**19**) conformations are usually considered. For the 2-Z-1,3,2-dioxaphospholanes, certain of the P-, O-, and C-flap envelope conformers are **20, 21,** and **22**, respectively. In the gas phase, electron diffraction studies are consistent with a P-flap envelope conformation for 2-chloro-1,3,2-dioxaphospholane[12] (**20**, Z = Cl) and pyrocatechol chlorophosphite (**23**),[13] as well as for the closely related 2-chloro-1,3-dithiaphospholane (**24**),[14] and *N*-methyl-1,3,2-oxazaphospholane (**25**).[15] However, 2-chloro-4,4,5,5-tetramethyl-1,3,2-dioxaphospholane (**26**)[16] appeared to be in a half-chair form analogous to **27**.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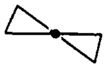
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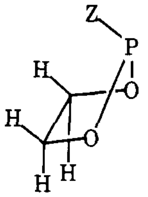

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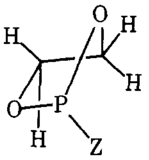

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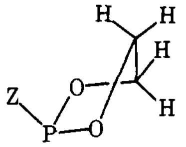

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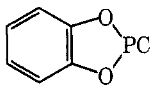

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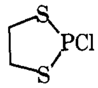

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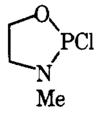

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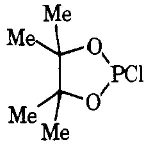

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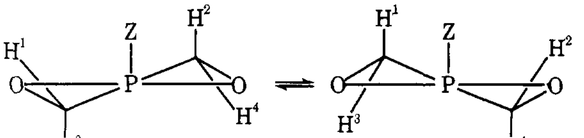
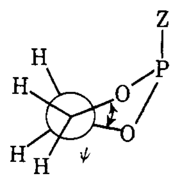
The effect of *medium* on conformation in these systems is apparent from ^{1}H NMR studies[5b,8,9,17] which show that the ring hydrogens cannot be eclipsed as in **20**, and so-called twist envelope forms (**28**) have been proposed.[5b,8a] This conformation arises from **27** via a slight puckering of the ring at phosphorus.



27a **27b**



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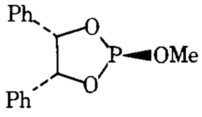
X-Ray crystallographic work has established a C-flap conformation like **22** for *trans*-4,5-diphenyl-2-methoxy-1,3,2-dioxaphosphorinane (**29**),[18] while for 2,2′-(ethylenedithio)bis-1,3-dithia-2-phospholane (**30**),[19] the structure closely approximates that of an S-flap form similar to **21**.

Amongst **20–22** and **27**, in all but **20**, the ring hydrogens are noneclipsed as is consistent with the above mentioned ^{1}H NMR results.[5b,8,9,17] Although attempts might be made to choose from amongst **21, 22, 27,** and **28** by use of the Karplus relation,[20] the dihedral angle ψ (see structure **28**) cannot be determined with sufficient reliability as will be emphasized later. Furthermore, energy minima corresponding to the above forms may be very shallow, allowing for extensive pseudolibration of each form. Likely, none of the above are very different in energy, and the exact conformation favored in any case could be determined by a ring substituent, medium, or crystal-packing forces. Therefore, in the paragraphs which follow, for sake of simplicity, we will interpret our results and those of previous workers in terms of the equilibrium between the two half-chair forms **27a** and **27b** (shown in Newman projection as **31a** ⇌ **31b**).



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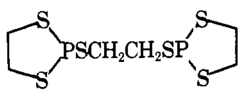

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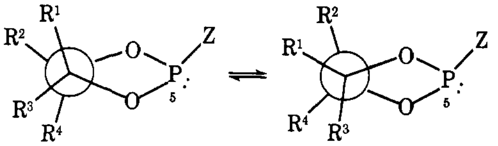


31a **31b**

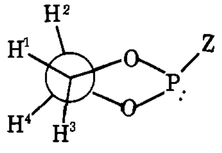
The choice of **27** for the purpose of simplification is quite arbitrary. Our NMR data do exclude **20**, in which the ring hydrogens are eclipsed; but we recognize that **21, 22,** or **28** may be populated as well as or in preference to **27** (**31**). It will be noted below that coupling constants derived for **31a** and **31b** are in reasonable agreement with their geometries, but they probably could fit other conformers as well.

When R^1, R^3 = Me (**8**), then one expects the equilibrium **31a** ⇌ **31b** could be biased sterically toward **31b**. Consistent with this view are the values (Table I) of J_{25} (0.01 Hz) and J_{45} (15.17 Hz) for **8** (R^1 = R^3 = Me, Z = Me$_2$N) and also those for the series of 2-Z-4,4-dimethyl-1,3,2-dioxaphospholanes reported[5b] earlier (R^1 = R^3 = Me; Z = MeO, *i*-PrO, *t*-BuO, PhO, and Ph). The latter ranged 0.27–0.39 Hz for J_{25} and 12.99–13.43 Hz for J_{45}. The strong bias of **8** toward one conformation is further shown by the relatively large $^4J_{HH}$ we note between H^2 and the Me at position R^3. This long range coupling could occur only for the case where Me (R^3) and a H (H^2) are nearly coplanar as in **31b.** (In the discussion, J_{25}, e.g., refers to the coupling between the hydrogen at position R^1 in **31** and phosphorus, designated nucleus 5.)

The same sort of steric bias is predicted for the cis isomers of **9–14** (R^1 = Me). The ranges of J_{25} (−0.31 to −1.10 Hz) and J_{45} (12.97–15.26 Hz) of Table I for **9a–14a** are comparable to those of **8** (and other 4,4-dimethyl compounds)[5b] and consistent with the *assignment of cis geometry to* ***9a–14a.*** Furthermore, when R^1 = R^4 = Me, and Z is Cl[8b] or *t*-BuO[5b] (*d,l*,-2-Z-4,5-dimethyl-1,3,2-dioxaphospholanes), steric considerations apparently again favor **31b** and lead to reported J_{25} = 0–0.25 Hz and J_{35} = 4.2 Hz, couplings similar to those we find for **9a–13a** (J_{25} = −0.31 to −1.0 Hz; J_{35} = 0.71–5.0 Hz).[21] Additional evidence for the cis geometries of **9a–14a** will be presented later.

The above results allow the assignment of *approximate* values to three of the phosphorus–hydrogen couplings in conformer **32:** J_{25}, J_{35},[21] and J_{45}. Unsubstituted 2-Z-1,3,2-dioxaphospholanes in our view will equally populate **31a** and **31b** in an equilibration rapid on the NMR time scale. This notion is supported by the J_{HP} values found[8] for the equivalent hydrogens cis to the phosphorus lone pair. For those 2-Z-1,3,2-dioxaphospholanes with Z equal F, Cl,

$J_{15} = 3\text{-}4$ Hz
$J_{25} = -1\text{-}{+0.4}$ Hz
$J_{35} = 4\text{-}5$ Hz
$J_{45} = 13\text{-}15$ Hz



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MeO, MeCO$_2$, PhCO$_2$, PhO, Ph, J_{HP} for the hydrogens cis to the lone pair runs 8.97–10.0 Hz, about the average of J_{35} and J_{45} given above. For these same heterocycles, J_{HP} values for the trans hydrogens are in the range of 1.2–1.9 Hz. *Such an averaged J_{HP} would result if J_{15} in **32** were assigned a value of 3-4 Hz.* Also consistent with these J_{HP} assignments is the fact that *cis-meso*-2-chloro-4,5-dimethyl-1,3,2-dioxaphospholane (31, R^1 = R^2 = Me; Z = Cl) has $^3J_{HP}$ of 9 Hz,[8b] while $^3J_{HP}$ for the trans isomer is 2 Hz.[8b]

The assignments of hydrogens to cis or trans positions in 4,5-dimethyl compounds were very recently confirmed by the x-ray crystallographic study[18] of *trans-meso*-2-methoxy-4,5-diphenyl-1,3,2-dioxaphospholane mentioned earlier. In CDCl$_3$, the two ring hydrogens trans to the phosphorus lone pair showed a $^3J_{HP}$ of 2 Hz.[18] This result is in complete agreement with our assignment of those small J_{HP} values in **9–14** to the hydrogens trans to the phosphorus lone pair (i.e., J_{15} and J_{25}).

The estimated J_{HP} values of **32** also lead to reasonable results when applied to trans **9–14**, the b isomers. With R^3 = Me, **31b** (Me pseudoaxial) may be somewhat disfavored energetically by 1,3 interactions involving a ring oxygen and phosphorus; but these are known[3] in six-membered rings to be much less severe than 1,3-interactions involving axial hydrogens. If **31a** and **31b** contribute equally, **32** predicts J_{HP} values like those for the unsubstituted materials, i.e., $J_{15} = J_{25} \simeq 2$ Hz and $J_{45} \simeq 9$ Hz. Table I shows J_{15} = 0.33–1.57 and mostly below 0.79 Hz, and J_{25} = 2.03–6.09. (Only for Z = *t*-Bu or Me$_2$N is the latter >3.0 Hz.) For J_{45}, values of 6–8 Hz are found, all below 9 Hz. These couplings probably indicate some bias of **9a–14a** towards **31a.**

The effect of cis-trans geometry on the equilibrium **31a** $\rightleftharpoons$ **31b** is also reflected in the vicinal hydrogen-hydrogen couplings, $^3J_{HH}$. For the trans isomers, **9b–14b,** J_{12} and J_{14} are nearly equal at 6–7 Hz. But J_{23} for **9a–14a** (cis isomers) is 9–10 Hz with J_{34} = 6–7 Hz. The values of J_{23} and J_{34} are consistent with the predominance of **31b** for **9a–14a,** while J_{12} and J_{14} reflect a greater averaging of **31a** $\rightleftharpoons$ **31b** in the trans isomers. Vicinal couplings in the 4,5-dimethyl compounds mentioned above[5b,8b] also respond as predicted by the effects discussed earlier of Me-substitution on **31a** $\rightleftharpoons$ **31b.** It is notable as well that, for the series of *cis*-**9–14,** J_{23} values with different Z increase in the order *t*-BuO < MeO < Me$_2$N < *t*-Bu, presumably because **31b** is progressively populated in response to increasing size of Z. This size order is also found in the 2-Z-5-*tert*-butyl-1,3,2-dioxaphospholanes.[1]

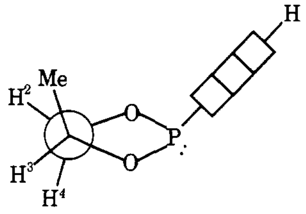
Vicinal couplings often have been used to estimate torsional angles within ring compounds. In fact, for **7–14,** values of J_{12} and J_{34} can be employed to calculate the critical OCCO dihedral angle (ψ) in these systems. Both the Karplus equation[20] and "*R* value"[22] approaches are available. However, it has been recently shown[23] that the "*R* value" method consistently overestimates such angles in five-membered rings. (It has been recognized[24] for sometime that dihedral angles calculated in this way are averages of all conformations, and that in five-membered rings such considerations are further complicated by the ease of pseudolibration within a shallow energy minimum.) It is suggested[23] that expression 1 probably comes closest to giving accurate ψ values but requires an accurate estimate of *A*.

$$J_{\text{cis}} = A\cos^2\psi \qquad (1)$$

Because *A* is unknown for these systems, we would be unwilling to attach any significance to the absolute values of ψ so estimated.

What can be shown, however, by use of J_{cis} (J_{12} or J_{34}) and an assumed[25] *A* of 10 is that ψ varies by only a few degrees over the whole range of values so calculated, although this whole procedure is rendered less precise by the fact that $J_{12} \neq J_{34}$. In **7** this gives an uncertainty of ±3° and also means that some small but unknown correction should be applied in **9–14** depending on whether J_{cis} refers to J_{12} or J_{34}. For the series of substituted derivatives **9–14,** ψ varies only over the range 34–41°. The high end of the range (40, 41°) applies to those compounds with bulky Z, *cis*- and *trans*-Me$_2$N and *cis-t*-Bu, where steric repulsions might be expected to limit the population of various conformers and could thus lead to an increased average ψ. (Effects of population on J_{14} and J_{23} were considered earlier.)

Other useful criteria of cis-trans geometry with the 1,3,2-dioxaphospholanes **9–14** are the relative chemical shifts of ring protons cis or trans to the phosphorus lone pair. Thus, the absorption of the methine hydrogen cis to the phosphorus lone pair in **9–13** (Table I) is *downfield* of where it is found when it is trans (cis isomers). Furthermore, the methylene hydrogen shifts depend greatly on the orientation of the ring methyl as a result of its shielding effect and in a manner also easily related to cis and trans geometry. In addition the methyl shift itself is *downfield* in the cis isomer of what it is in the trans. (The same is true of the 2-R-4-Me-1,3-dioxanes.[26]) The only exception is **14.** The phenyl on phosphorus in **14** apparently exerts a shielding influence on the cis ring methyl such that its shift becomes identical to what it is in the trans isomer. This suggests a phenyl orientation as shown in **33.** The same sort of effect causes spectral overlaps which prevent analysis of the ^{1}H NMR spectrum for the cis isomer of **14.** (This is also true with **13.**) The chemical shift effects are consistent with the postulated cis and trans geometries of isomers of **9–14.** Similar shielding effects were seen previously with *cis*-2-phenyl-5-*tert*-butyl-1,3,2-dioxaphosphorinane.[1]



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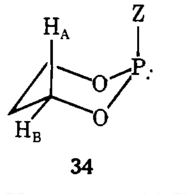
To this point nothing has been said about whether in fact the various J_{HP} values agree reasonably with expected geometries for half-chair conformers (**27, 31**). $^3J_{HP}$ values generally follow roughly a Karplus-type dihedral angle relationship.[27] In the six-membered rings (eq 1) we have found[1,2a] $^3J_{HCOP}$ to depend *both* on the dihedral angle HCOP *and* on the orientation of the lone pair on phosphorus. Thus in **34** $J_{H_AP} \sim 2$ Hz, $J_{H_BP} \sim 10$ Hz; whereas for **35** $J_{H_AP} \sim 2$ Hz, $J_{H_BP} \sim 20$ Hz. The lone pair effect is seen to operate on only one hydrogen and must be very sensitive to the precise relationship of the lone pair and the particular



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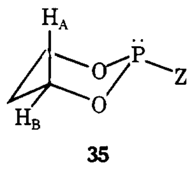


35

hydrogen (H_B). In **32** the only hydrogen which could *approximate* H_A of **35** in its relation to the lone pair on phosphorus is H^1. But even this could occur only if the phosphorus end of the molecule were bent such that Z were pseudoequatorial which, as explained later, is very unlikely. If the ring is actually in a half-chair conformation (**27a, 32**), then equatorial and axial designations do not apply to substituents on phosphorus. H^1 of **32** will be in a position such that its HCOP angle will exceed that of H_A in **34.** This is consistent with its somewhat larger J_{HP} (3–4 Hz). Dreiding models estimate this angle (structure **32**) at around 150°, depending on extent of twist. The same have $\angle H^2COP$ of the order of 90°, consistent with $J_{25} < J_{15}$ (Table I). The model also shows for H^3 and H^4 HCOP angles of roughly 90 and 150°, again consistent with the relative J_{HP}'s. The larger couplings noted for the hydrogens cis to the phosphorus lone pair may be a result of the effect on J_{HP} of that lone pair. Alternatively, if conformer **32** is a highly puckered O-envelope form with Z pseudoaxial (mirror image of **21**), then $\angle H^4COP$ becomes larger than $\angle H^1COP$, accounting for the difference in couplings. Angles H^2COP and H^3COP become, respectively, decreased and increased.

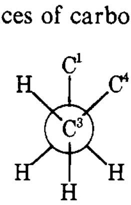
In three instances in Table I, values of J_{25} are larger than predicted by **31a** $\rightleftharpoons$ **31b** and the couplings worked out for **32.** These cases involve Z which are found[1] in 1,3,2-dioxaphosphorinanes to be sterically large: $Me_2N^{2a,28}$ (**7**, $J_{15} = J_{25} = 4.35$ Hz; **9b**, $J_{25} = 6.09$ Hz); *t*-Bu (**12b**, $J_{25} = 4.84$ Hz). For **7** this may indicate a distortion of ring geometry which increases $\angle H^1$ COP (such as a shift from an O-flap to a C-flap form) since a value of 6–8 Hz is required in this case for J_{15} of **32.** The same applies to **9b** and **12b.** (Recall the unusually low J_{35} for **9a** and **12a** as well, vide supra.) Previous mention was made of a slight bias towards **31a** for the trans isomers **9b–14b** as reflected in their J_{45} values. This coupling is seen to be smallest for Z equal Me_2N and *t*-Bu, indicating a greater bias. This effect could be simply a result of ring distortion; or an increase in Z size may distort the ring such that the 1,3-interactions of the trans Me is increased in **31b,** thus shifting the equilibrium towards **31a.** To say any more about these changes in *J* values at this time would be gross overinterpretation.

The values of J_{45} of 13–15 Hz are larger than any seen in the 1,3,2-dioxaphosphorinanes with Z axial (**34**). This may at first seem surprising, but it is important to realize that *bond angle* effects on $^3J_{HP}$ may very well play an important role since they are well recognized[20] in ethylenic systems (HCCH). The COP angles likely are considerably smaller in **3** than in **1** (vide infra). It also is difficult to predict precisely what the lone pair orientation effect (vida supra) should be.

2-Z-4-*tert*-Butyl-1,3,2-dioxaphospholanes. The data of Table I for the *trans*-2-Z-4-*tert*-butyl-1,3,2-dioxaphospholanes (**15–17**) are similar to those of **9b–14b** suggesting analogous conformations. It is surprising that J_{14} does not increase somewhat when the 4-Me of *trans*-**9–14** is replaced by *t*-Bu. The slight bias towards **31a** in *trans*-**9–14** could have been predicted to increase. The ~2 Hz *decrease* in J_{25} and 1–2 Hz increase in J_{45} in the 4-*t*-Bu compounds also is unexplained and may be the result of our having limited the number of structures considered or of distortion of geometry. In relating J_{12} in *trans*-**15–17** to dihedral angle ψ according to eq 1, there is in each case a 5–6° *decrease* in ψ on substitution of 4-*t*-Bu for 4-Me. Obviously, effects of substituent change on geometry and conformer population are not yet fully interpretable.

Trans/Cis Ratios. Comparison of trans/cis ratio data from Table III with that of the (65 ± 2)/(35 ± 2) ratio of **9–14** ($\Delta G° = 0.4$ kcal/mol) shows a substantial increase in proportion of trans isomer in the 2-Z-4-*tert*-butyl-1,3,2-dioxaphosphorinane series (**15–17**) ($\Delta G° = 0.8$–1.0 kcal/mol). This is consistent with an increase in steric repulsions when the 4-*tert*-butyl and Z are cis. The increase is not so large as might be expected for the increase in size of the 4 substituent. It also is surprising that changing the steric size of Z has not a greater effect, although it is measurable in the 4-*tert*-butyl series. Small effects of substituent on equilibrium are the rule in five-membered ring systems of this general type. (Comparisons with rings **4** and **42–44** will be given below.) Compensatory loss of entropy in the cis isomers is responsible to some extent. As noted below, steric interactions appear to be great enough to result in an effect of Z on δ ^{13}C of the cis 4-Me of **9a–14a** and on the relative δ ^{31}P of cis and trans isomers.

^{31}P Shifts and the δ Effect. The results in Table II show that there is a very simple way to identify cis and trans isomers of 2-Z-4-Me-1,3,2-dioxaphospholanes (**9–14**). In every case, δ ^{31}P for the cis isomer is *downfield* of that for the trans form. This effect is just *opposite* of that noted[1,2a,29] in the 1,3,2-dioxaphosphorinanes. Z in the axial position of *cis*-2-Z-5-*tert*-butyl-1,3,2-dioxaphosphorinanes (**34**) is subject to steric interactions with hydrogens on a carbon γ to Z. The upfield shift experienced by phosphorus is similar to that found in ^{13}C NMR. Thus in carbon systems[30] the ^{13}C resonances of carbons 2 and 3 of **36** are *upfield* shifted as a result of the γ *interaction* between C-1 and C-4. It is not surprising that ^{31}P shifts should respond in analogous fashion in view of the similarities found between ^{13}C, ^{15}N, and ^{31}P chemical shift patterns.[31]



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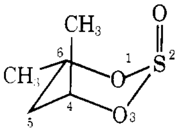
By contrast, the 4-Me group of *cis*-**9–14** is δ to the substituent Z (**31**). In such systems, so-called δ effects are observed[32] which are opposite to the γ type. For example, δ ^{13}C for the axial methyl in **37** is *downfield* of that for the methyl equatorial[32a] (γ interaction with axial H also present). Similar effects are seen in certain norbornyl alcohols.[32b] For example, δ ^{13}C of the Me of **38** is subject to a 2.0 ppm *downfield* shift compared to that in **39** as a result of the δ-OH. Furthermore, the carbinyl carbon of **38** and analogous cases as well as C-4 of **37** are *downfield* shifted by such interactions. This sort of an effect may be the cause of the downfield shift of phosphorus in the *cis*-2-Z-4-R-1,3,2-dioxaphospholanes. The fact that the relative ^{31}P chemical shifts of cis–trans isomers of **9–14** are just the reverse of those in the six-membered rings (**2, 34, 35**) shows clearly *the danger of extrapolating ^{31}P chemical shift effects from one ring system to another.*[33]



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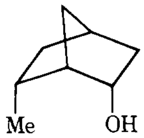

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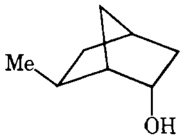

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With the larger *tert*-butyl group at C-4 (**15–17**), the relationship is no longer a δ one, but the effect ($\Delta\delta$ ^{31}P) is still present and even magnified. It should be noted that it is the δ ^{31}P of the *cis isomer* which is greatly affected by the change to 4-*t*-Bu as expected on steric grounds. The increase in $\Delta\delta$ ^{31}P with increased steric interaction also can be found in the data of Denney et al.[34] who noted an increase in proportion of supposed trans isomer and increased downfield ^{31}P shift for *cis-meso*-4,5-dimethyl-2-methoxy-1,3,2-dioxaphospholane ($\delta = -150$) compared to *cis*-4-methyl-2-methoxy-1,3,2-dioxaphospholane. Thus our results and the x-ray study of Newton et al.[18] confirm the suggestions of Denney et al. as to cis–trans geometry and are consistent with our assignments in **9–17**. It is significant that the trans diphenyl compound studied by Newton has δ ^{31}P of -131.[35]

^{13}C Shifts and Ring Geometry. Cis–trans geometries can be assigned readily to 2-Z-4-Me-1,3,2-dioxaphospholanes on the basis of certain ^{13}C parameters as well. For the 4-methyl series, the C-4 shift of the cis isomers is downfield by 0.5–2.6 ppm of that for the trans form. This sort of δ-effect shift is consistent with what is found[32] for **37–39** and related compounds (vida supra). The δ-effect phenomenon is also found for C-2α of **13a** for which δ ^{13}C is 1.45 ppm *downfield* of the **13b** C-2α shift. There is also a small but consistent effect of cis–trans geometry on δ ^{13}C for C-5 (data in Table II).

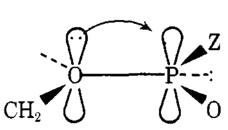
The δ effect predicts that δ ^{13}C for the C-4′ Me of **9–14** should be shifted downfield in the cis isomer.[32] In Table II the opposite trend is noted except for **12.** It has been shown, however, that the δ ^{13}C values for axial 5-methyl groups in *trans*-2-methoxy-5-methyl-1,3,2-dioxaphosphorinane[29,36] and *cis*-2-R-5-methyl-1,3-dioxanes[37] are at *lower* fields than those for their equatorial counterparts. The importance of the equilibrium **31a** $\rightleftharpoons$ **31b,** which places the 4-Me pseudoaxial for the trans isomer in each case for **9–14,** was emphasized previously. If the downfield shift effect of the axial methyl is the dominant one, the apparent anomaly regarding the C-4′ shifts for **9–14** is explained.[38]

It should be emphasized that the assignments of cis and trans geometries to the isomers of **9–14** are consistent with the effect of changing Z on δ ^{13}C of the 4′-Me. *Only when Z and Me are cis does δ ^{13}C respond to changes in Z ($\Delta\delta$ = 3.6 ppm).* This effect is complementary to that seen on ^{31}P shifts of exchanging the 4-Me for a 4-*tert*-butyl (compounds **15–17**).

The three 5-*tert*-butyl compounds (**15–17**) also show δ ^{13}C trends which can be correlated with ring geometry. The C-4 shifts are irregular, but the C-5 resonance is shifted downfield in each case in the trans isomer. The possible steric interactions for 4-*tert*-butyl and Z substituents are no longer either γ or δ in nature, and it is difficult to predict how the chemical shifts of the 4′ and 4″ carbons should change with geometry. Surprisingly the C-4′ and C-4″ resonances move in opposite directions, contrary to what is observed in comparing axial and equatorial *tert*-butyl at the 5 position of 1,3-dioxanes[37] and 1,3,2-dioxaphosphorinanes[39] and at the 2 position in trimethylene sulfites.[32a]

Certain correlations of J_{CP} with geometry also are observed in Table II. It is difficult to say precisely what structural effects are responsible, but dihedral angular and lone-pair orientation dependences appear to affect $^3J_{CP}$ in important ways.[40]

Orbital Overlap and Conformation. In an earlier paper,[1] we concluded that in 1,3,2-dioxaphospholanes the substituent on phosphorus prefers an axial orientation. It was proposed that vicinal interactions involving phosphorus and the ring oxygens overcome repulsive 1,3-synaxial interactions when the substituent is axial. The major stabilizing vicinal interaction was proposed to be that depicted by **40,** p-orbital back donation to an adjacent partially vacant p orbital.[4a] (A similar treatment in terms of p-σ* donation may be applied.[4b]) In *trans-meso*-2-methoxy-4,5-diphenyl-1,3,2-dioxaphospholane, the average of the two O-P-O bond angles in the ring was 112°[18] suggesting sp^3 hydridization about oxygen. An equivalent vicinal stabilization for this hybridization of oxygen is given by **41** or its 180° rotamer. These exact conformations are closest approximated by the: P-flap, Z-axial conformer (**20**); O-flap, Z-axial conformer (21); and C-flap conformer with C and Z cis (**22**). (Inspection of models suggests that the degree of interaction in **20–22** will vary slightly as a function of the closeness of the lone-pair-oxygen-phosphorus-partially vacant p-orbital dihedral angle to 0°.) This effect may be responsible for the positioning of the C flap in the *trans*-4,5-diphenyl-2-methoxy-1,3,2-dioxaphospholane as determined by x-ray study[18] since the C-flap-down conformer could partake of only one **41**-like stabilizing orbital overlap. The half-chair form (**27**) is similar in this regard. P- or O-flap forms with the ring puckered such that Z is pseudoequatorial do not benefit at all from **41** or its equivalent.



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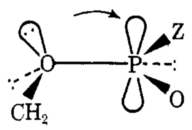

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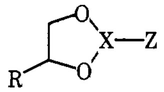
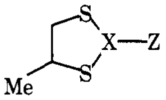
A delicate balance of both inter- and intramolecular stabilizing and destabilizing forces of similar magnitudes may well determine the conformational preferences of 1,3,2-dioxaphosphorinanes in various media. The relative importance of an interaction like that in **41** is not known, but, in view of its apparent applicability (**40**) to phosphorinane systems, it appears worthy of serious consideration.

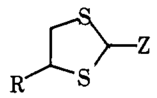
Comparisons to Other Five-Membered Ring Heterocycles. A wide variety of five-membered rings containing heteroatoms have now been studied as represented by **3, 4,** and **42–44.** As in six-membered rings, the presence of the lone pair electrons on X has an important stereochemical effect. For **4**[26] and **44,**[41] the cis isomer is thermodynamically *more stable* than is the trans (except for **44** with R = Z = Me). An explanation based on destabilizing steric repulsions between a pseudoaxial 2-H and the 4-R for trans **4** has been given.[26] Repulsions between axial alkyl groups and oxygen lone pairs are known[3] to be less important than corresponding 1,3-synaxial alkyl-hydrogen repulsions. By contrast for **42**[42] and **43,**[17,42a,43] as well as in the present study of **3,** it is asserted that the more stable isomer is that with Z and R (Me) trans. The absence in **3, 42,** and **43** of the 1,3-synaxial alkyl-hydrogen repulsion postulated to be present in **4** (and presumably **44**) could account for the reversal in cis-trans stabilities.



42a, X = As; Z = Ph; R = Me
b, X = S; Z = O; R = Me, Ph



43a, X = As; Z = Ph; R = Me
b, X = P; Z = Ph; R = Me



44, R = alkyl; Z = alkyl

The cis isomers of all but **4** give ^{1}H NMR evidence of restricted mobility or more strictly a differentiation energetically of various conformers. We have proposed above that this is the result in **3** of repulsive 1,3-interactions in **31a** (R^1 = Me) or an analogous conformer. A reduction in distance between R and Z could arise from reduced O-P-Z bond angle compared to O-C-Z in **4** or because of an increase in ψ in **31.** If the same *A* value for expression **1** is used for **3, 4,** and **42** (assumes only electronegativity effect operative on J_{vic}), the averaged ψ calculated for **3** and **4** are all 35–41° and for **42b,** 35–36°. For **42a,** ψ is increased to 45–48° (depending on whether J_{cis} for the trans or cis isomer is used). Thus O—P—Z and O—S=O bond angle effects may be

Table IV. Physical and Microanalytical Data for New Compounds

			Elemental analyses[c]			
Compound	bp, °C[a] (mm)	Percentage yield[b]	Formula	% C	% H	% P
9-Sulfide	73–74 (15)	59	$C_5H_{12}O_2PNS$	33.14 (33.48)	6.68 (7.13)	17.09 (17.08)
11[d]	48 (4.5)	55	$C_7H_{13}O_3P$	47.17 (47.40)	8.49 (8.57)	17.39 (17.39)
12-Sulfide	60–62 (6)	53	$C_7H_{15}O_2PS$	43.29 (43.51)	7.78 (8.09)	15.95 (15.33)
13-Sulfide	91–94 (0.5)	75	$C_{10}H_{13}O_2PS$	52.62 (53.21)	5.74 (5.39)	13.57 (13.59)
14-Oxide	68–72 (0.8)	60	$C_9H_{11}O_3P$	54.55 (54.33)	5.60 (5.87)	15.63 (15.23)
16-Sulfide	62–63 (1.6)	52	$C_8H_{18}O_2PNS$	43.04 (42.19)	8.13 (8.07)	13.87 (13.84)
17-Sulfide	48–49 (1.0)	45	$C_{10}H_{21}O_2PS$	50.83 (51.01)	8.96 (9.08)	13.11 (12.93)

[a] Boiling points are those for the trivalent phosphorus compounds. [b] Percentage yield refers to synthesis of the trivalent phosphorus compounds. No attempt was made to achieve maximum yield. [c] Experimental values found are in parentheses. [d] Analysis of the trivalent compound.

important in conformationally biasing forms like **31a** in *cis*-**3** and **42b**; whereas ring pucker may be operative in **42a**. That the ring is more puckered in **43** and **44** than in dioxa analogues has been previously postulated. Vicinal couplings[42b] for Me- and di-Me-substituted **42b** respond in completely analogous ways to those of the 4-methyl- and 4,5-dimethyl-2-Z-1,3,2-dioxaphospholanes discussed in this paper. Similar vicinal coupling constant patterns are found for **43b**.[17,42a,43]

Experimental Section

^{1}H NMR spectra were taken on Varian A-60 or XL-100-15 spectrometers. The latter was equipped with a Gyrocode decoupler. Pulser Fourier transform proton decoupled **^{13}C spectra** were recorded at 25.2 MHz on the XL-100-15 equipped with a Varian 620-F computer. **^{31}P spectra** were taken on the XL-100-15 operating in the continuous wave mode and were proton noise decoupled. Computer assisted ^{1}H NMR analyses were done on a Univac 1108 computer using the LAOCN3 program and spectral plots employed a Calcomp plotter. **Vapor phase chromatography** to determine ratios of sulfides of **9–17** was performed on a temperature-programmed F and M Model 810 dual column TC detector instrument on ¼ in. × 6 ft glass columns packed with 3% QF-1 on Chromosorb W. Product ratios were not corrected for possible small differences in sensitivities of cis and trans isomers. Good agreement was found between cis/trans ratios determined both by VPC and ^{1}H NMR. Microanalyses were performed by Schwartzkopf Microanalytical Laboratory, Woodside, N.Y.

Syntheses. Trivalent phosphorus compounds **7–17** were prepared in routine fashion using standard methods. Phosphites were made by combination of the alcohol, ROH, with the cyclic phosphorochloridite in the presence of Et_3N in pentane or ether solvent. Phosphorochloridites were the product of reaction of diol with PCl_3. *tert*-Butylethylene glycol was prepared according to the method of Brandstrom.[44] The dimethylamino compounds (phosphoramidites) were formed on reaction of $[(CH_3)_2N]_3P$ with the appropriate diol. Reaction of diol with *t*-$BuPCl_2$, $PhPCl_2$, or $PhCH_2PCl_2$ in ether or pentane in the presence of Et_2N yielded the cyclic phosphonite. Products in all cases were isolated and purified by vacuum distillation. Microanalyses (Table IV) were obtained for all new compounds, usually after conversion in benzene by S-8 to the corresponding sulfides, which generally were purified by distillation and analyzed as liquid mixtures of cis and trans isomers. Sulfides of **16** and **17** were purified by preparative GLC prior to analysis. The sulfides of **13** required purification by elution chromatography on Florosil silica gel (50/50) using hexane to which benzene was added progressively. Nonequilibrated cis/trans ratios of **9–11** were obtained under careful conditions even following distillation. With **12** ^{1}H NMR showed that the cis/trans ratio before distillation was higher than that following purification. The latter was unchanged after many days at room temperature in benzene (^{1}H NMR analysis of trivalent compound or GLC analysis of sulfides). Products **15–17** were obtained on distillation only as equilibrated mixtures of stereoisomers.

Table IV contains for all new compounds pertinent physical constants and yield as well as microanalytical data for the corresponding sulfides.

Equilibration Studies of 2-Z-4-*tert*-Butyl-1,3,2-chlorophospholanes in *o*-Dichlorobenzeene. Equilibration studies (no Me_4Si added) were performed by variation of NMR probe temperature: (1) trans/cis ratio was determined at ambient probe temperature (i.e., 32°C); (2) NMR probe was heated to 120°C and the trans/cis ratio was recorded; (3) NMR probe was cooled down to ambient temperature; again the trans/cis ratio was determined. The trans/cis ratio was determined by integration of the ^{1}H NMR signals for *tert*-butyl groups and/or the 2-Z groups. The addition of a drop of CF_3CO_2H to each tube failed to change the isomer ratio at 32°.

Conclusions

We conclude from the above that, for the 2-Z-4-alkyl-1,3,2-dioxaphospholanes, the trans isomers are thermodynamically more stable (in the solvents studied) than are their cis counterparts. This deduction is based on the collective interpretation of a variety of evidences: the correlation of J_{HP} values with those of similar compounds with known (x-ray) cis–trans geometries; the effect of phenyl on phosphorus on 4-methyl chemical shifts; the response of cis/trans ratio to increases in steric bulk of the 4-alkyl substituent (*tert*-butyl for Me); the response of the 4′-Me ^{13}C chemical shift only to changes in Z in the cis isomer; the response of ^{31}P chemical shift of the cis isomer only to changes in 4-alkyl substituent; the shielding effect of the phosphorus lone pair on the methine ring hydrogen of the cis isomer, an effect analogous to that found[1] in the 2-Z-5-*tert*-butyl-1,3,2-dioxaphosphorinanes; and the change in trans/cis ratios for the 4-*t*-Bu compounds to changes in steric bulk of Z. The ^{1}H NMR data (vicinal proton couplings and J_{HP} values) demonstrate clearly the conformational bias of the cis isomers in contrast to population by the trans forms of two or more conformations. The conformational equilibria may be largely explained by consideration of half-chair forms, although others cannot be rigidly excluded. Steric interactions between ring substituents are invoked in rationalization of the above phenomena. ^{1}H NMR data from previously studied 4-, 4,4′-, and 4,5-dialkyl substituted-2-Z-1,3,2-dioxaphospholane systems are also correlated on the basis of the equilibria considered. Our results shed further light on ^{13}C and ^{31}P chemical shift effects when ring substituents are δ to each other. The ^{13}C and ^{31}P chemical shift correlations noted allow ready assignment of cis and trans stereochemistries in such systems.

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References and Notes

(1) For paper III in this series, see W. G. Bentrude, Han-Wan Tan, and K. C. Yee, *J. Am. Chem. Soc.*, **97**, 573 (1975).

(2) (a) W. G. Bentrude and H.-W. Tan, *J. Am. Chem. Soc.*, **95**, 4666 (1973); (b) W. G. Bentrude and J. H. Hargis, *ibid.*, **92**, 7136 (1970); (c) W. G. Bentrude, K. C. Yee, R. D. Bertrand, and D. M. Grant, *ibid.*, **93**, 797 (1971).

(3) (a) E. L. Eliel and M. C. Knoeber, *J. Am. Chem. Soc.*, **90**, 3444 (1968); (b) F. G. Riddell and M. J. T. Robinson, *Tetrahedron*, **23**, 3417 (1967).

(4) This treatment applies theories outlined in (a) L. Radom, W. J. Hehre, and J. A. Pople, *J. Am. Chem. Soc.*, **94**, 2371 (1972); (b) S. David, O. Eisenstein, W. J. Hehre, L. Salem, and R. Hoffmann, *ibid.*, **95**, 3806 (1973).

(5) (a) K. Bergesen and T. Vikane, *Acta Chem. Scand.*, **26**, 2153 (1972); (b) R. H. Cox, B. S. Campbell, and M. G. Newton, *J. Org. Chem.*, **37**, 1557 (1972).

(6) See also, T. Mukaiyama, T. Fujisawa, Y. Tamura, and Y. Yokota, *J. Org. Chem.*, **29**, 2572 (1964).

(7) J. P. Dutasta, A. C. Guimaraes, J. Martin, and J. B. Robert, *Tetrahedron Lett.*, 1519 (1975).

(8) (a) P. Haake, J. P. McNeal, and E. J. Goldsmith, *J. Am. Chem. Soc.*, **90**, 715 (1968); (b) D. Gagnaire, J.-B. Robert, J. Verrier, and R. Wolf, *Bull. Soc. Chim. Fr.*, 3719 (1966).

(9) K. Bergesen, M. Bjoroy, and T. Gramstad, *Acta Chem. Scand.*, **26**, 3037 (1972); S. C. Peake, M. Fild, R. Schmutzler, R. K. Harris, J. M. Nichols, and R. G. Rees, *J. Chem. Soc., Perkin Trans. 2*, 380 (1972).

(10) A portion of the ^{13}C and ^{31}P work was reported earlier in preliminary form: W. G. Bentrude and H.-W. Tan, *Tetrahedron Lett.*, 619 (1975).

(11) D. P. Young, W. E. McEwen, D. C. Velez, J. W. Johnson, and C. A. Vander Werf, *Tetrahedron Lett.*, 359 (1964); L. Horner and H. Winkler, *ibid.*, 175 (1964).

(12) V. A. Naumov, N. M. Zaripov, and V. G. Dashevskii, *Dokl. Akad. Nauk SSSR*, **188**, 1062 (1969).

(13) B. A. Arbuzov, V. A. Naumov, S. A. Shaidulin, and E. T. Mukmenev, *Dokl. Akad. Nauk SSSR*, **204**, 859 (1972).

(14) G. Y. Schultz, I. Hargittai, J. Martin, and J. B. Robert, *Tetrahedron*, **30**, 2365 (1974).

(15) V. A. Naumov and M. A. Pudovik, *Dokl. Akad. Nauk SSSR*, **203**, 351 (1972).

(16) V. A. Naumov and N. M. Zaripov, *Z. Strukt. Khim.*, **11**, 1124 (1970).

(17) J. P. Albrand, A. Cogne, D. Gagnaire, J. Martin, J. B. Robert, and J. Verrier, *Org. Magn. Reson.*, **3**, 75 (1971); J. P. Albrand, D. Gagnaire, J. Martin, and J. B. Robert, *ibid.*, **5**, 33 (1973).

(18) M. G. Newton and B. S. Campbell, *J. Am. Chem. Soc.*, **96**, 7790 (1974).

(19) M. G. Newton, H. C. Brown, C. J. Finder, J. B. Robert, and J. Martin, *J. Chem. Soc., Chem. Commun.*, 455 (1974).

(20) M. Karplus, *J. Chem. Phys.*, **30**, 11 (1959); *J. Am. Chem. Soc.*, **85**, 2870 (1963).

(21) The J_{35} values for **9a** and **12a** may be unusually low because of ring distortions resulting from the large Me_2N and *t*-Bu substituents, vide infra.

(22) J. B. Lambert, *Acc. Chem. Res.*, **4**, 87 (1971); H. R. Buys, *Recl. Trav. Chim. Pays-Bas*, **88**, 1003 (1969).

(23) J. B. Lambert, J. J. Papay, S. A. Khan, K. A. Kappauf, and E. S. Magyar, *J. Am. Chem. Soc.*, **96**, 6112 (1974).

(24) V. Tabacik, *Tetrahedron Lett.*, 555, 561 (1968).

(25) The best value for cyclopentane appears to be 9.95.[23]

(26) W. E. Willy, G. Binsch, and E. L. Eliel, *J. Am. Chem. Soc.*, **92**, 5394 (1970).

(27) D. W. White and J. G. Verkade, *J. Magn. Reson.* **3**, 111 (1970); C. Benezra, *J. Am. Chem. Soc.*, **95**, 6890 (1973); R. B. Wetzel and G. L. Kenyon, *J. Chem. Soc., Chem. Commun.*, 287 (1973).

(28) J. A. Mosbo and J. G. Verkade, *J. Am. Chem. Soc.*, **94**, 8224 (1972).

(29) H.-W. Tan, unpublished results from this laboratory.

(30) D. K. Dalling and D. M. Grant, *J. Am. Chem. Soc.*, **94**, 5318 (1972), and earlier references therein; J. D. Roberts, F. J. Weigert, J. I. Kroschwitz, and J. H. Reich, *ibid.*, **92**, 1338 (1970); G. W. Buchanan, D. A. Ross, and J. B. Stothers, *ibid.*, **88**, 4301 (1966).

(31) R. L. Lichter and J. D. Roberts, *J. Am. Chem. Soc.*, **94**, 2495 (1972); J. P. Warren and J. D. Roberts, *J. Phys. Chem.*, **78**, 2507 (1974); L. D. Quin and J. J. Breen, *Org. Magn. Reson.*, **5**, 17 (1973).

(32) (a) G. W. Buchanan, J. B. Stothers, and G. Wood, *Can. J. Chem.*, **51**, 3746 (1973); (b) S. H. Grover, J. P. Guthrie, J. B. Stothers, and C. T. Tan, *J. Magn. Res.*, **10**, 227 (1973).

(33) A referee has suggested that the effect may instead be a result of comparing the 5 ring to a 5-substituted 6 ring (4-atom separation) rather than to the 2-Z-4-R-1,3,2-dioxaphosphorinane series.

(34) D. Z. Denney, G. Y. Chen, and D. B. Denney, *J. Am. Chem. Soc.*, **91**, 6838 (1969).

(35) M. G. Newton, private communication.

(36) H. Haemers, R. Ottinger, D. Zimmerman, and J. Reisse, *Tetrahedron*, **29**, 3539 (1973).

(37) A. J. Jones, E. L. Eliel, D. M. Grant, M. C. Knoeber, and W. F. Bailey, *J. Am. Chem. Soc.*, **93**, 4772 (1971).

(38) This effect in 1,3-dioxa compounds apparently results from an electronic deshielding effect of the γ ring oxygen which is maximum in the antiperiplanar arrangement: E. L. Eliel, W. F. Bailey, L. D. Kopp, R. L. Willer, D. M. Grant, R. Bertrand, K. A. Christensen, D. K. Dalling, M. W. Duch, E. Wenkert, F. M. Schell, and D. W. Cochran, *J. Am. Chem. Soc.*, **97**, 322 (1975).

(39) W. G. Bentrude, K. C. Yee, R. D. Bertrand, and D. M. Grant, unpublished results from this laboratory.

(40) J. Burdon, J. C. Hotchkiss, and W. B. Jennings, *Tetrahedron Lett.*, 4919 (1973); R. D. Lapper, H. H. Mantsch, and I. C. P. Smith, *J. Am. Chem. Soc.*, **95**, 2878 (1973); A. A. Borisenko, N. M. Sergeyev, E. Y. Nifant'ev, and Y. A. Ustynyuk, *Chem. Commun.*, 406 (1972); G. A. Gray and S. E. Cremer, *Tetrahedron Lett.*, 3061 (1971).

(41) R. Keskinen, A. Nikkila, and K. Pihlaja, *J. Chem. Soc., Perkin Trans. 2*, 1376 (1973).

(42) (a) D. W. Aksnes, and O. Vikane, *Acta Chem. Scand.*, **27**, 2135 (1973); (b) C. H. Green and D. G. Hellier, *J. Chem. Soc., Perkin Trans. 2*, 243, 1966 (1973).

(43) K. Bergesen and M. Bjoroy, *Acta Chem. Scand.*, **27**, 1103 (1973).

(44) A. Brandstrom, *Acta Chem. Scand.*, **13**, 611 (1959).