

APPARENT ABSENCE OF REVERSAL OF OXAPHOSPHETANE FORMATION IN SOME WITTIG REACTIONS

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**Abstract:** Reversal of oxaphosphetane formation in the reaction of benzaldehyde with benzylidene(2-N,N-dimethylaminophenyl)diphenylphosphorane (1) and benzylidene(4-N,N-dimethylaminophenyl)diphenylphosphorane (2), respectively, is found not to occur in tetrahydrofuran solution. The reason for this is that the rates of dissociation of the oxaphosphetanes to stilbenes and the corresponding triarylphosphine oxide are faster than reversal to the reagents.

Oxaphosphetanes, shown to be key intermediates in the Wittig olefination,<sup>1</sup> have been observed to be formed in a reversible reaction in some systems while not in others.<sup>1,2</sup> In our continuing investigation of 2p-3d overlap effects in the Wittig reaction,<sup>3,4,5</sup> we have found that oxaphosphetanes 3 and 4, obtained by reaction of benzaldehyde with benzylidene (2-N,N-dimethylaminophenyl)diphenylphosphorane (1) and benzylidene(4-N,N-dimethylaminophenyl)-diphenylphosphorane (2), respectively, apparently do not undergo reversal to ylide and aldehyde in competition with dissociation to products, mainly cis-stilbene (plus small amounts of trans-stilbene) and the respective triarylphosphine oxides, 5 and 6, in tetrahydrofuran solution. The evidence for the absence of reversal of oxaphosphetane formation is that no crossover products (3-chlorostilbenes) are formed when 3-chlorobenzaldehyde is added to the reaction mixtures after benzaldehyde and the respective ylides have been allowed to react at -78°C in tetrahydrofuran solution.

Examination of the reaction solution by means of <sup>31</sup>P NMR spectroscopy at -70°C immediately following addition of benzaldehyde to either 1 or 2 revealed only two peaks, (1, δ = 11.10; 2, δ = 10.40) corresponding to the respective ylides and (1, δ = 32.86; 2, δ = 30.03) corresponding to the respective triarylphosphine oxides. Thus, it is evident that the oxaphosphetanes are undergoing dissociation to stilbenes and the respective phosphine oxides as soon as they are formed.

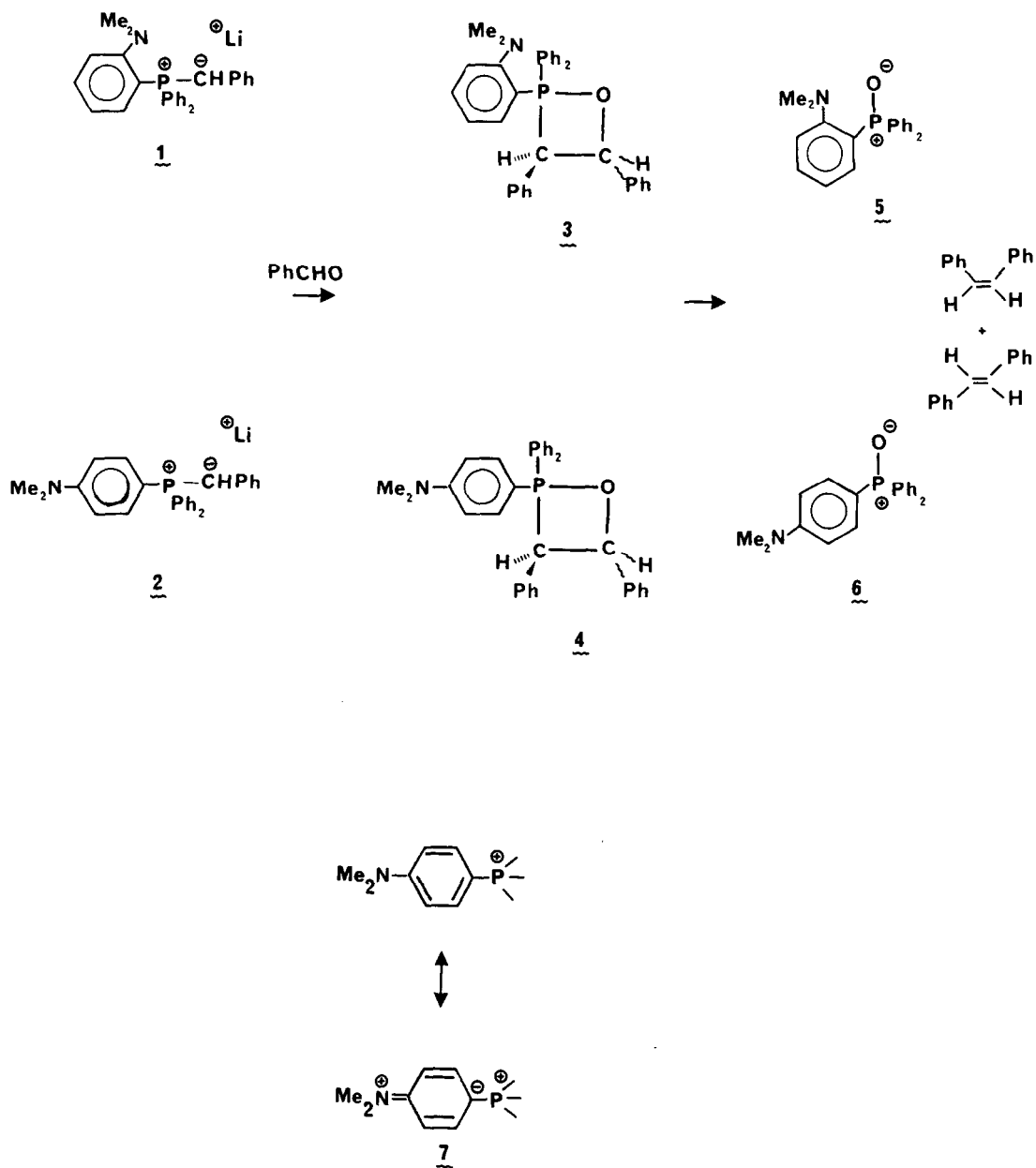
In a private communication, E. Vedejs has stated that, in his experience with moderated ylides, he has not been able to trap an intermediate at -70°C in any instance unless lithium salts and a suitable solvent are present to precipitate it. He believes that "moderated ylide-derived oxaphosphetanes seem to have very short lifetimes in general." Accordingly, we have carried out the reaction of 1 with benzaldehyde in anhydrous ether solution at -78°C. A precipitate appeared immediately on addition of benzaldehyde, and the typical red color of 1 disappeared in about 30 seconds. At this point, we added an equivalent of m-chlorobenzaldehyde, allowed the mixture to warm to room temperature and analyzed the products by vpc. We found a

96% yield of stilbenes and a 4% yield of m-chlorostilbenes. Although this result raises at least the possibility of a slight degree of reversal of 3 to 1 plus benzaldehyde in this system, we do not believe that this is necessarily true for two reasons: (1) On the basis of the disappearance of the red color of 1 as an indicator of completion of formation of an intermediate, we do not believe that we can distinguish between 100% reaction and 96% reaction, particularly in the presence of a precipitate. (2) We can write a reasonable mechanism for the formation of crossover products with m-chlorobenzaldehyde which involves only the lithium bromide adducts of betaines and the betaines themselves without the necessity for reversal of 3 to 1 plus benzaldehyde. (The reaction of 2 with benzaldehyde at  $-78^{\circ}\text{C}$  in ether solution proved to be too complex to evaluate without an enormous amount of additional work to be carried out.)

In a theoretical study of the hypothetical Wittig reaction of  $\text{H}_3\text{P}^{\oplus}\text{-CH}_2^{\ominus} + \text{H}_2\text{C}=\text{O} \rightarrow \text{CH}_2=\text{CH}_2 + \text{H}_3\text{P}^{\oplus}\text{-O}^{\ominus}$ , Volatron and Eisenstein<sup>6</sup> have calculated the activation energy for formation of the initial oxaphosphetane in which the oxygen atom occupies an axial position of the trigonal bipyramidal phosphorus to be 6.6 kcal/mol, the oxaphosphetane being 32.3 kcal/mol more stable than the reactants. A pseudorotation at phosphorus interchanges the positions of the oxygen and the carbon atoms, a small activation energy being required for the process. This second oxaphosphetane, having an axial carbon atom, is 3.7 kcal/mol less stable than the initially formed oxaphosphetane. The activation energy for dissociation of the second oxaphosphetane to  $\text{H}_3\text{P}^{\oplus}\text{-O}^{\ominus}$  and  $\text{CH}_2=\text{CH}_2$  is 29.4 kcal/mol, the products being more stable than the second oxaphosphetane by 21.2 kcal/mol. Similar results were obtained by Höller and Lischka<sup>7</sup> in a previous theoretical study.

Although one might ask how this hypothetical reaction relates to real Wittig reactions,<sup>8</sup> the numbers cited above can be used as a basis for comparisons with real systems, provided there is a parallelism between the relative energies of reagents, intermediates and products in the potential energy diagrams of both the real and hypothetical systems. For example, the through space  $2p\text{-}3d$  overlap effect<sup>9</sup> would be expected to decrease the relative energies of 1 and 5 as compared to the analogous compounds for the reaction of benzylidetriphenylphosphorane with benzaldehyde. At the same time, the presence of the o-dimethylamino group in 3 would be expected to increase its relative energy due to repulsion of valence shell electron pairs on nitrogen and the nearby oxygen. Finally, lithium ion catalysis of the dissociation of 3 to cis-stilbene and 5, as described previously,<sup>5</sup> would be expected to lower the relative energy of activation for this step. The net result of these effects is evidently to make the energy of activation for formation of 3 from 1 and benzaldehyde greater than that for dissociation of 3 into cis-stilbene and 5.<sup>10</sup> This offers an explanation as to why the  $^{31}\text{P}$  NMR spectrum of a fresh reaction mixture at  $-70^{\circ}\text{C}$  shows the presence of 1 and 5, but not of 3.

Essentially the same concepts explain the behavior of 2 in its reaction with benzaldehyde. The major difference is that electron donation to positive phosphorus in 2 and 6, respectively, arises through an inductive effect made possible by the contribution of a resonance structure such as 7 to the state of each molecule. There is convincing evidence available that  $p_{\pi}\text{-}d_{\pi}$  overlap is of little importance in compounds such as 2 and 6.<sup>11</sup>



The NMR samples were prepared by adding a 0.16 g ( $3.3 \times 10^{-4}$  mol) portion of the appropriate phosphonium salt to a 10 mm NMR tube which was then flushed with argon and covered with a rubber septum. To this was added 5 mL of dry THF by means of a syringe. To the resultant suspension was added 0.25 mL of *n*-butyllithium ( $3.3 \times 10^{-4}$  mol), 1.45 M in hexane, whereupon a red homogeneous solution was formed. The ylide solution was cooled to  $-78^{\circ}\text{C}$ , and  $3.3 \times 10^{-4}$  mol of benzaldehyde was added. The reaction solution was immediately placed in the NMR probe which had been cooled to  $-70^{\circ}\text{C}$ . A spectrum was obtained immediately, revealing only the two peaks described previously. An external reference of 85%  $\text{H}_3\text{PO}_4$  in  $\text{d}_8$ -THF was used. In quantitative experiments carried out on larger samples, the reaction of 1 with benzaldehyde gave 66.9% of *cis*-stilbene and 33.1% of *trans*-stilbene (100% combined yield). The reaction of 2 with benzaldehyde gave 79.3% of *cis*-stilbene and 20.7% of *trans*-stilbene (100% combined yield).

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