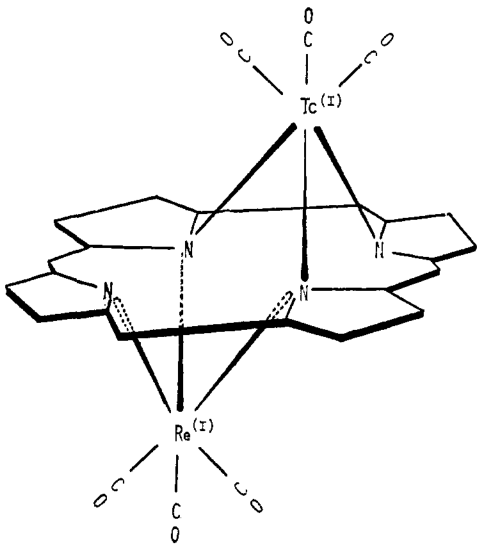

Figure 2. Schematic picture of $(OC)_3TcMPRe(CO)_3$ (I); the alkyl substituents on the porphine ring are left out of the figure for clarity.

structures identical with that of IV were proposed for II[1] and III.[7] For the same reason, the structure shown in Figure 2 is proposed for I.

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Indole Alkaloid Rearrangements in Acetic Acid

Sir:

Scott and Qureshi in 1968[1] claimed the conversion of (−)-tabersonine into (±)-catharanthine (12% yield) and (±)-pseudocatharanthine (28%), and of (+)-stemmadenine into (±)-tabersonine (12%), (±)-catharanthine (9%), and (±)-pseudocatharanthine (16%) *in refluxing glacial acetic acid* over periods ranging from 16 to 72 hr; even after extensive exchange of experimental information with the above authors we were unable to reproduce these results, indeed we failed to observe even traces of the rearrangement products claimed. With reluctance, we eventually felt obliged to publish our findings,[2] more recently with full experimental details.[3,4] One simple example of a result which could not be affected by experimental factors such as added boiling chips, external bath temperature, etc., is our observation that, on a 500-mg scale, catharanthine survives to the extent of less than 1% in refluxing acetic acid after 12 hr,[3] and that on a 5-mg scale it ceases to be detectable by tlc even after only 30 min; this makes the isolation of the order of 10% of (±)-catharanthine[1] under such conditions difficult to understand.

We wish to state quite simply that none of the experimental work now described in preliminary form by Scott and Wei[5a,c,d] contradicts our findings; there is mention of general factors on which the success of the original rearrangements apparently depends, but these factors are not quantified,[5a] and we still await the full experimental details of the original work of Scott and Qureshi.[1]

It must be pointed out that the only reaction in acetic acid described in the four papers is that of (−)-tabersonine, from which only the isolation of allocatharanthine is now reported,[5c] in keeping with our own observations[2,4] and not with those of Scott and Qureshi.[1] The remaining reactions[5a,c,d] are carried out under *completely different* conditions (four on silica at 150° and one in methanol) and in any case on *none* of the original compounds studied by us (stemmadenine, tabersonine, and catharanthine). We wish to refrain from commenting on this new work.

The substance referred to by Scott as the "levorotatory preparation to which they allude as pseudocatharanthine" was prepared as described by Gorman *et al.*,[6] except that it was not crystallized, and was fully characterized spectrally;[3] the fact that the recrystallized material handled by Scott is fully racemic is not surprising, as the ∼10% excess of one of the enantiomers in the total material would not be expected to cocrystallize. Our ∼90% racemic pseudocatharanthine was not used at all by us as a reference compound in the sense indicated by Scott[5b] for the simple reason that pseudocatharanthine, whether partially or fully racemic, never turned up in the reactions of stemmadenine and tabersonine; Scott's criticisms are thus void.

Scott states that "the manipulation of microgram quantities in biomimetic experiments is an art which, in our experience, has oft-times required several hundred trials before declaring a negative result";[5b] whatever this statement may mean, it has no relevance to our work, which was carried out on the larger scale of 5–20 mg, with the exception of the preparative experiments, which approached the gram scale.

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(1) A. A. Qureshi and A. I. Scott, *Chem. Commun.*, 947 (1968).

(2) R. T. Brown, J. S. Hill, G. F. Smith, K. S. J. Stapleford, J. Poisson, M. Muquet, and N. Kunesch, *Chem. Commun.*, 1475 (1969).

(3) R. T. Brown, J. S. Hill, G. F. Smith, and K. S. J. Stapleford, *Tetrahedron*, **27**, 5217 (1971).

(4) M. Muquet, N. Kunesch, and J. Poisson, *Tetrahedron*, **28**, 1363 (1972).

(5) (a) A. I. Scott and C. C. Wei, *J. Amer. Chem. Soc.*, **94**, 8266 (1972); (b) A. I. Scott, *ibid.*, **94**, 8262 (1972); (c) A. I. Scott and C. C. Wei, *ibid.*, **94**, 8263 (1972); (d) *ibid.*, **94**, 8264 (1972).

(6) M. Gorman, N. Neuss, and N. J. Cone, *J. Amer. Chem. Soc.*, **87**, 93 (1965).

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Direct Observation of Oxaphosphetanes from Typical Wittig Reactions

Sir:

Nonstabilized phosphorus ylides attack simple ketones or aldehydes at −70° to form 1:1 adducts which decompose into triphenylphosphine oxide and olefins above 0°. This sequence of events is traditionally explained by assuming that a betaine such as **1** or its metal halide adduct is formed and that fragmentation to alkene occurs by way of an oxaphosphetane.[1] The latter is variously described as an intermediate of higher energy than the betaine or as the transition state leading to olefin.

We have investigated the reaction of ethylidenetriphenylphosphorane with typical carbonyl compounds by ^{31}P nmr to clarify the structure of the Wittig intermediates. A filtered solution of the ylide (from ethyltriphenylphosphonium bromide and butyllithium) in tetrahydrofuran was treated with a small excess of cyclohexanone, −70° throughout, and the slightly turbid solution was examined at 40.5 MHz using Fourier transform nmr with proton noise decoupling. A single sharp signal was observed at $\delta_{^{31}P}$ 66.5 ppm relative to external 85% phosphoric acid. No other signals of $\geq 1\%$ relative intensity were present. The spectrum did not change up to −15°, but at higher temperatures a singlet at δ −26.1 due to the $(C_6H_5)_3P{=}O \cdot LiBr$ complex appeared at the expense of the δ 66.5 signal. The δ 66.5 signal was partially resolved as a quartet of doublets upon selective decoupling of the aromatic protons (Figure 1), $J_{PCH} = 6.5$ Hz, $J_{PCCH_3} = 15$ Hz. Addition of acetic acid at −70° caused immediate disappearance of the δ 66.5 signal and appearance of an amorphous precipitate of the well-precedented[2] β-hydroxyalkylphosphonium salt **3**, characterized as the crystalline bromide (mp 126° dec) by elemental analysis and the nmr spectrum. The signal for the methine proton next to phosphorus at δ 5.00 ppm consists of six lines ($J_{CHCH_3} = 7$ Hz, $J_{CHP} = 14$ Hz) while the methyl group appears at δ 1.47 ppm as a doublet of doublets ($J_{CHCH_3} = 7$ Hz, $J_{CH_3P} = 20$ Hz) overlapping a complex methylene region. Complex aromatic protons are observed between δ 7.4 and 8.1 ppm and a broad singlet at δ 3.88 ppm accounts for the hydroxyl proton.

The high-field ^{31}P chemical shift rules out tetravalent phosphorus species such as betaines, ylides, or phosphine oxides, but is consistent with the oxaphosphetane **2**.[3] Related structures have been proposed on the basis of $\delta_{^{31}P}$ 15–54 ppm[3b,d,f] and the compound **4** ($\delta_{^{31}P}$ 32.1 ppm), prepared by Ramirez, *et al.*, has been characterized by X-ray crystallography.[4] The previously reported oxaphosphetanes contain electronegative substituents or sp^2-hybridized carbons in the four-membered ring, structural features which deshield phosphorus in the nmr spectrum and which also retard considerably the rate of Wittig fragmentation to alkene.

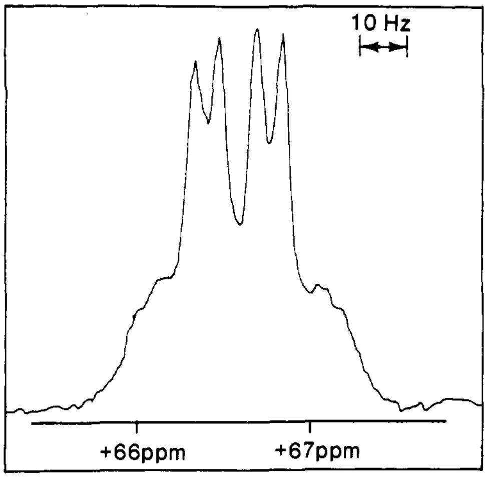


Figure 1. Nmr spectrum of the cyclohexanone–ethylidenetriphenylphosphorane adduct (−70°, THF), phenyl hydrogens decoupled.

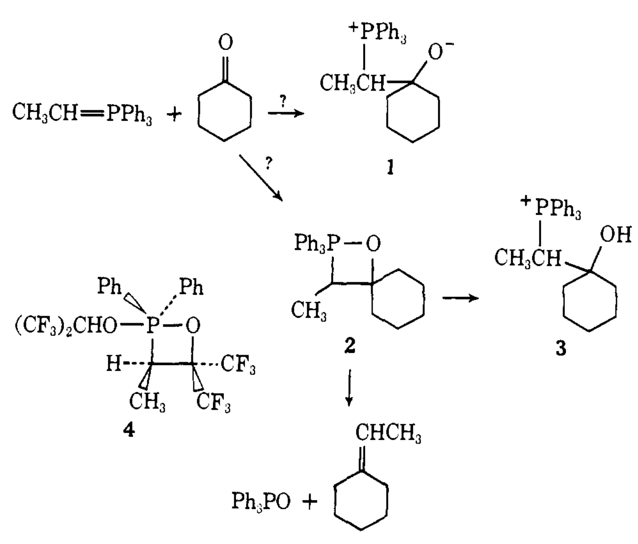
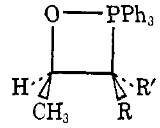


Table I. Oxaphosphetanes from the Wittig Reaction of Ethylidenetriphenylphosphorane in THF

Carbonyl component	Oxaphos-phetane	$\delta_{^{31}P}$ at −70°	Cis:trans olefin ratio
Cyclohexanone	**2**	+66.5	
$(CH_3)_3CCHO$	**5a**	64.2	99:1
C_6H_5CHO	**6a,b**	62.7	2:1
$C_6H_5CH_2CH_2CHO$	**7a,b**	61.9	7:3



5a, R = $C(CH_3)_3$; R′ = H
b, R = H; R′ = $C(CH_3)_3$
6a, R = C_6H_5; R′ = H
b, R = H; R′ = C_6H_5
7a, R = $C_6H_5CH_2CH_2$; R′ = H
b, R = H; R′ = $C_6H_5CH_2CH_2$

Oxaphosphetanes were observed similarly using pivalaldehyde, benzaldehyde, and dihydrocinnamaldehyde as the carbonyl substrates (Table I). Both **6** and **7** were relatively stable below −20° but the sterically crowded oxaphosphetane **5a** decomposed even at −70° with a half-life of several hours.[5] In the benzaldehyde reaction, the proton noise-decoupled spectrum at −70°

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[1] A. W. Johnson, "Ylide Chemistry," Academic Press, New York, N. Y., 1966, Chapter 4; A. Maercker, *Org. React.*, 14, 270 (1965); S. Trippett, *Quart. Rev., Chem. Soc.*, 17, 406 (1963).

[2] (a) G. Wittig and U. Schöllkopf, *Chem. Ber.*, **87**, 1318 (1954); (b) M. Schlosser and K. F. Christmann, *Justus Liebigs Ann. Chem.*, **708**, 1 (1967).

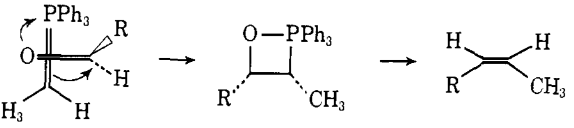
[3] (a) M. Grayson and E. J. Griffith, Ed., *Top. Phosphorus Chem.*, 5, 1 (1967); (b) G. Wittig and A. Haag, *Chem. Ber.*, **96**, 1535 (1963); (c) I. Kawamoto, T. Hata, Y. Kishida, and C. Tamura, *Tetrahedron Lett.*, 2417 (1971); (d) G. H. Birum and C. N. Matthews, *Chem. Commun.*, 137 (1967); (e) S. O. Grim, W. McFarlene, and T. J. Marks, *ibid.*, 1191 (1967); (f) F. Ramierz in "Chimie Organique d'Phosphore," Centre National de la Recherche Scientifique, Paris, 1970, p 61, and references therein.

[4] F. Ramirez, C. P. Smith, and J. F. Pilot, *J. Amer. Chem. Soc.*, 90, 6726 (1968); Mazhar-Ul-Haque, C. N. Caughlan, F. Ramirez, J. F. Pilot, and C. P. Smith, *ibid.*, **93**, 5229 (1971).

[5] A related reaction conducted in Me_2SO affords 98.5% cis alkene: E. J. Corey and G. T. Kwiatkowski, *ibid.*, **88**, 5653 (1966).

consisted of an unusually broad singlet at δ 62.7 (width at half-height, 15 Hz). Upon warming the sample to −5°, *ca.* 70% decomposition to triphenylphosphine oxide was observed after 5 min and the residual high-field signal was now resolved into two sharp singlets 10 Hz apart, indicating the presence of both cis and trans isomers **6a** and **6b**. The signal of the oxaphosphetane **7** could not be resolved into two components, however, and attempts to resolve the ^{31}P–CH coupling constants of **5**, **6**, and **7** were unsuccessful.

Since the Wittig intermediates from ethylidenetriphenylphosphorane exist >98% in the pentavalent phosphorus form[6] oxaphosphetanes would have to be more stable than betaines if the latter are formed initially under our conditions. However, there is no direct evidence that betaines are involved in nonstabilized ylide reactions.[2a,7] Pending such evidence it is appropriate to focus attention on mechanisms which avoid betaine intermediates, especially since the betaine mechanism fails to account for predominant formation of cis alkenes as listed in Table I and elsewhere.[2b,5,9] We suggest a cycloaddition rationale which requires no ionic intermediates or polar transition states.[10] Orthogonal approach of ylide and aldehyde π bonds in the least hindered orientation would lead directly to the most hindered oxaphosphetane by $_{\pi}2_s + _{\pi}2_a$ cycloaddition[11] and would result in selective cis olefin formation. In accord with preliminary experimental results (Table I; also ref 9) this mechanism predicts the highest cis selectivity in Wittig reactions between bulky aldehydes and nonstabilized ylides having unbranched alkyl substituents at the α carbon. The cycloaddition rationale also is consistent with the absence of major solvent polarity effects on the cis:trans ratio[9b] and explains the selectivity of certain oxyylide reactions.[12] Lower cis selectivity in the presence of added lithium salts[2b] may be due to competing formation of the betaine–lithium halide adduct.



Additional studies are under way to test some aspects of the cycloaddition rationale.[14] We are also investigating the influence of solvent, metal salts, and other variables on the structure of Wittig intermediates.

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[6] We have observed analogous pentavalent phosphorus products from methylidenetriphenylphosphorane with cyclohexanone and pivalaldehyde, δ ^{31}P +74.2 and 72.5 ppm, respectively.

[7] The precipitate which forms upon mixing ethereal methylidenetriphenylphosphorane containing lithium bromide with benzaldehyde is believed to be a betaine–lithium bromide adduct.[2,8] We have found that the precipitate is too insoluble in tetrahydrofuran for ^{31}P nmr; the only signal observed is indistinguishable from triphenylphosphine oxide. To our knowledge, the only reported characterization of this precipitate is conversion to styrene at 65° or conversion into a β-hydroxyalkylphosphonium salt by acid, reactions which cannot distinguish between oxaphosphetanes and betaines.

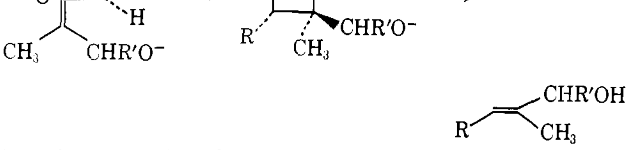
[8] S. Fliszar, R. F. Hudson, and G. Salvadori, *Helv. Chim. Acta*, **46**, 1580 (1963).

[9] (a) M. Schlosser, *Top. Stereochem.*, **5**, 22 (1970); (b) L. D. Bergelson, L. I. Barsukov, and M. M. Shemyakin, *Tetrahedron*, **23**, 2709 (1967).

[10] W. P. Schneider, *Chem. Commun.*, 785 (1969).

[11] M. Rey, S. Roberts, A. Dieffenbacher, and A. S. Drieding, *Helv. Chim. Acta*, **53**, 417 (1970); P. R. Brook, J. M. Harrison, and A. J. Duke, *Chem. Commun.*, 589 (1970).

[12] For oxyylides having a fully substituted ylide α carbon, the favored transition state is chosen to minimize oxygen–oxygen interactions as follows



Assuming that Wittig fragmentation is faster than oxaphosphetane ring opening to the betaine for R = alkyl or aryl (but not for R = H), it is obvious why only one of the two oxygens is lost as triphenylphosphine oxide.[13]

[13] E. J. Corey and H. Yamamoto, *J. Amer. Chem. Soc.*, **92**, 226, 3523 6636, 6637 (1970); M. Schlosser and D. Coffinet, *Synthesis*, 380 (1971); 575 (1972).

[14] Kinetic evidence consistent with a cycloaddition mechanism has been reported recently: P. Froyen, *Acta Chim. Scand.*, **26**, 2163 (1972).

[15] Alfred P. Sloan Fellow, 1971–1973.

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An Asymmetric Single-Minimum Hydrogen Bond in the Bifluoride Ion. A Neutron Diffraction Study of *p*-Toluidinium Bifluoride[1]

Sir:

In virtually every experimental study[2–6] of the bifluoride ion, (F–H–F)$^-$, carried out within the past 30 years, the same conclusion has been reached, *viz.*, the anion contains the shortest strongest hydrogen bond known and possesses a symmetrical (centered) hydrogen bond. The symmetrical nature of the hydrogen bond has become accepted as intrinsic to this system, possibly because no one has demonstrated the existence of an asymmetric hydrogen bond in $(HF_2)^-$. However, in the case of KHF_2, Blinc[7] has pointed out some difficulties that arise with the single-minimum symmetric H-bond interpretation. Past studies have been confined mainly to the alkali metal and ammonium bifluorides, in which the anion is located in a symmetrical environment in the crystal. The title compound has been chosen because of the asymmetric crystal environment about the bifluoride ion, which could leave the $(HF_2)^-$ ion free to assume a configuration not obscured by symmetry.

We wish to report the first experimental proof of the existence of a linear asymmetric (single-minimum) hydrogen bond in the (F–H–F)$^-$ ion as derived from a neutron diffraction study of *p*-toluidinium bifluoride.

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[1] Research performed under the auspices of the U. S. Atomic Energy Commission.

[2] Thermodynamic measurements: E. F. Westrum, Jr., and K. S. Pitzer, *J. Amer. Chem. Soc.*, **71**, 1940 (1949); E. F. Westrum, Jr., and G. A. Burney, *J. Phys. Chem.*, **65**, 344 (1961).

[3] Neutron diffraction: S. W. Peterson and H. A. Levy, *J. Chem. Phys.*, 20, 704 (1952); B. L. McGaw and J. A. Ibers, *ibid.*, **39**, 2677 (1963); J. A. Ibers, *ibid.*, 40, 402 (1964).

[4] Neutron, infrared, and Raman spectroscopy: J. J. Rush, L. W. Schroeder, and A. J. Melveger, *J. Chem. Phys.*, **56**, 2793 (1972); P. A. Giguère and K. Sathianandan, *Can. J. Phys.*, **45**, 2439 (1967), and references therein.

[5] Nuclear magnetic resonance: J. S. Waugh, F. B. Humphrey, and D. M. Yost, *J. Phys. Chem.*, **57**, 486 (1953).

[6] Dielectric measurements: D. Polder, *Nature (London)*, **160**, 870 (1947).

[7] R. Blinc, *Nature (London)*, **182**, 1016 (1958).