of $CH_3CN$ and 10 mL of saturated $NaHCO_3$ was added **9** (273 mg, 1.00 mmol). The mixture was stirred at 50 °C for 1 h. Workup as in method A afforded 161 mg (82% mass) of a 2:1 mixture of **10**:**24** (determined by $^1H$ NMR). Acidification and extraction of the aqueous layer gave 13 mg (8%) of **25**. Method C: To a prewarmed (50 °C) mixture of 10 mL of $CH_3CN$ and 10 mL of 2 N NaOH was added **9** (273 mg, 1.00 mmol). The mixture was stirred at 50 °C for 30 min, evaporated, and neutralized with 10% HCl. Workup as in method A produced 187 mg (92% mass) of a mixture of a 1:3.7 mixture of **10**:**24**. Acidification and extraction of the aqueous layer gave 13 mg (8%) of **25**. Method D: A solution of **9** (273 mg, 1.0 mmol) in 20 mL of methanol was stirred at 50 °C for 30 min. Workup as in method A afforded 182 mg (96%) of **10**. β-Keto amide **24** was cleanly isolated via 2 N NaOH extraction of a $CH_2Cl_2$ solution of a mixture of **10** and **24** followed by reacidification and extraction of the aqueous layer. **24**: mp 67.5-68.5 °C; $^1H$ NMR δ 11.96 (s, 1), 7.83 (m, 1), 7.49 (m, 1), 6.96 (m, 2), 4.13 (s, 2), 3.08 (s, 3), 3.02 (s, 3); $^{13}C$ NMR δ 199.8, 166.3, 162.5, 136.9, 130.7, 119.2, 118.4, 116.4, 45.5, 38.0, 35.5; $R_f$ 0.53, 10% MeOH/$CH_2Cl_2$; IR 1630, 1452, 1257, 1147, 766 $cm^{-1}$. Anal. Calcd for $C_{11}H_{13}NO_3$: C, 63.76; H, 6.32; N, 6.76. Found: C, 63.42; H, 6.24; N, 6.83. **25**: mp 214-214.5 °C (lit.[14] mp 216 °C dec); $^1H$ NMR (acetone-$d_6$) δ 11.40 (s, 1), 8.08 (m, 1), 7.84 (m, 1), 7.52 (m, 2), 5.87 (s, 1); $^{13}C$ NMR (acetone-$d_6$) δ 165.7, 162.3, 154.8, 133.2, 124.4, 123.9, 117.0, 116.5, 92.3; IR 1704, 1611, 1313, 1277 $cm^{-1}$. Anal. Calcd for $C_9H_6O_3$ (0.45% $H_2O$ found): C, 66.37; H, 3.76. Found: C, 66.10; H, 3.73.

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[14] Aldrich Chemical Co.

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# Reactions of Ethyl Phosphites with β-Nitrostyrenes. The Role of Nitrosoalkenes as Intermediates

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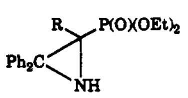
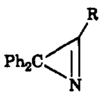
3-Phenyl-2-substituted-indoles are formed in high yields in the reaction of $Ph_2C{=}C(R)NO_2$ (R = H, Me, Ph) with $(EtO)_3P$ at 150 °C while reaction with $(EtO)_2PO^-/(EtO)_2P(O)H$ at room temperature forms the aziridines **1** with R = H, Me, Ph. 2,2-Diphenyl-3-substituted-2*H*-azirines formed by deoxygenation of the Michael-type adducts are postulated as intermediates. Reactions of $PhCH{=}C(R)NO_2$ (R = H, Me, Ph) with $(EtO)_3P$ at 150 °C or $(EtO)_2PO^-/(EtO)_2P(O)H$ at room temperature give products resulting from the addition of the phosphorus nucleophile at the benzylidene carbon atom. Evidence for the formartion of cyclic structures with pentacoordinated phosphorus atoms is presented for the reaction of $Ph_2C{=}C(Me)NO_2$ with $(EtO)_2PO^-/EtO)_2P(O)H$ and for $PhCH{=}C(R)NO_2$ (R = H, Me, Ph) with $(EtO)_3P$. The Michael-type adducts $PhCH[P(O)(OEt)_2]CH(R)NO_2$ (R = Me, Ph) undergo reaction upon treatment with aqueous base at 80-100 °C followed by acidification to yield the 3-(diethoxyphosphinyl)-2-R-*N*-hydroxyindoles. 4-(Diethoxyphosphinyl)-3-R-4*H*-1,2-benzoxazines (**13**, R = Me, Ph) are formed by reaction with 85% $H_2SO_4$ of the adducts of $PhCH{=}C(R)NO_2$ with $(EtO)_2PO^-$ (R = Me) or $(EtO)_3P$ (R = Ph).

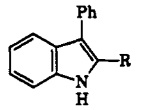
We have previously reported that reactions of $(EtO)_2PO^-$ with $Ph_2C{=}CHNO_2$ or $Ph_2C[P(O)(OEt)_2]CH_2NO_2$ in $Me_2SO$ or $(EtO)_2P(O)H$ solutions at room temperature yield the aziridine **1** (R = H), presumably formed via the 2*H*-azirine **2** (R = H).[1] Under similar conditions, $Ph_2C{=}C(SCMe_3)NO_2$ yielded **2** with R = *t*-BuS as the final product.[1] Heating $Ph_2C{=}C(R)NO_2$ at 150 °C in $(EtO)_3P$ formed the indoles **3** (R = H, *t*-BuS, PhS) in high yield, undoubtedly by a process involving the conversion of the azirine to the nitrene ($Ph_2C{=}C(R)\ddot{N}{:}$).[1] One possible deoxygenation process involves the intermediacy of nitrosoalkenes followed by reactions with $(EtO)_2PO^-$ or $(EtO)_3P$ to yield the reactive intermediates **4a** and **4b** (Scheme I) as precursors to the azirines. However, there is no direct evidence for the intermediacy of the nitrosoalkenes, and we will demonstrate that in several instances the key intermediates **4** are more reasonably formulated as arising from the deoxygenation of intermediate Michael-type adducts. Reactions of $PhCH{=}CHNO_2$ with $(EtO)_2PO^-$ (room temperature) or $(EtO)_3P$ (25-150 °C) fail to produce azirine or nitrene derived products and instead yield only products derived from other reactions of the initial Michael-type adducts.[1,2] To explore further the possibilities of azirine/nitrene formation and whether the addition of the phosphorus nucleophile precedes or follows deoxygenation of the nitro group, the reactions of **5** and **6** with R = Me and Ph have been examined.



**1**

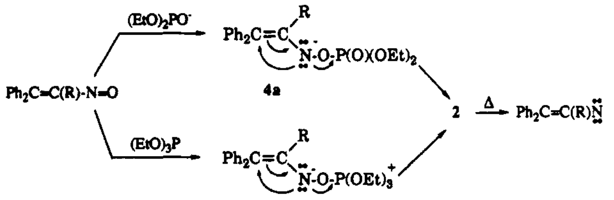


**2**



**3**

**Scheme I**



$Ph_2C{=}C(R)NO_2$
**5**, **a**, R=H
**b**, R=Me
**c**, R=Ph
**d**, R=OPh

$PhCH{=}C(R)NO_2$
**6**, **a**, R=H
**b**, R=Me
**c**, R=Ph

## Results and Discussion

**1-Nitro-2,2-diphenylethylenes.** Compounds **5b**,**c** gave reactions consistent with those previously observed for **5a**.[1] Heating the nitroalkenes in $(EtO)_3P$ solution at 150 °C formed the corresponding indoles (**3**, R = H, Me, Ph, OPh) in high yield although at room temperature there was no

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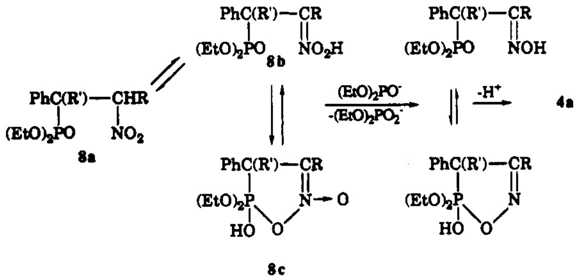
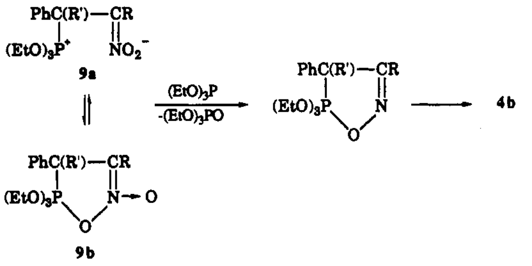
[1] Russell, G. A.; Yao, C.-F.; Tashtoush, H. I.; Russell, J. E.; Dedolph, D. F. *J. Org. Chem.* 1991, 56, 663.

0022-3263/92/1957-6508$03.00/0

Scheme II



Scheme III



appreciable reaction. Reactions of **5a–c** with excess $(EtO)_2PO^-/(EtO)_2P(O)H$ in $Me_2SO$, or with no additional solvent, produced the aziridines **1** (R = H, Me, Ph). With 5 equiv each of $(EtO)_2PO^-$ and $(EtO)_2P(O)H$ at room temperature, **5c** formed 94% of **1** (R = Ph) in 2 h using $Me_2SO$ as solvent and 88% in 5 h in the absence of any added solvent. The yields of the aziridine from **5b** were lower and in $Me_2SO$ decreased from 59% to 51% when the reaction period was increased from 10 min to 2 h.

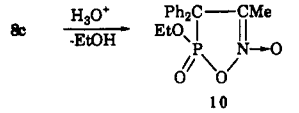
The aziridines **1** with R = Me or Ph underwent rearrangement upon heating to yield the imines **7** (reaction 1),

$$1(R{=}Me,\ Ph) \xrightarrow{\Delta} Ph_2\dot{C}{-}NH{-}\dot{C}(R)[P(O)(OEt)_2] \longrightarrow \underset{7}{Ph_2C{=}NCH(R)[P(O)(OEt)_2]} \qquad (1)$$

presumably via the 1,3-diradicals. Compound **7** (R = Ph) was formed in 92–93% yield upon heating **1** (R = Ph) in PhCl at 130 °C or in $(EtO)_3P$ at 150 °C for 1–2 h while **7** (R = Me) was formed in refluxing bromobenzene.

The postulated precursors to the azirines, i.e., **4a** or **4b**, can be reasonably formulated as arising from the Michael-type adducts without the intermediacy of nitrosoalkenes, Schemes II and III. Evidence for reactions proceeding by Scheme II can be advanced for **5a** and **5b**. Thus, the reaction of **5a** with $(EtO)_2PO^-/(EtO)_2P(O)H$ for 2 min followed by hydrolysis at pH 5 for several hours produced the adduct **8a** (R' = Ph, R = H) in 97% yield with no indication of the Nef reaction product ($Ph_2C[P(O)(OEt)_2]CHO$).[3] This adduct has been previously reported to be converted into **1** (R = H) by $(EtO)_2PO^-$ in $(EtO)_2P(O)H$ in 90% yield in a 4-h reaction.[1] In view of the rate and yield of adduct formation, it seems unlikely that **4a** is formed from **5a** via the nitrosoalkene.

Reaction of **5b** with $(EtO)_2PO^-$ in $(EtO)_2P(O)H$ also occurred readily. With 4 equiv of $(EtO)_2PO^-$ the nitroalkene was completely consumed within 5 min (by GC or $^1H$ NMR). Hydrolysis with brine of the reaction mixture after 5 min formed **10** in 74% yield, presumably by the loss of EtOH from **8c** (R' = Ph, R = Me), reaction 2. After



(2)

10

4 h of reaction, hydrolysis yielded 40% of **10** and 22% of **1** (R = Me) while after 24 h **1** was formed in 48% yield.

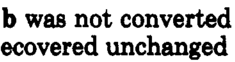
With **5c** there was no evidence of adduct formation upon hydrolytic workup, and perhaps Scheme I now applies. However, it is impossible to exclude Scheme II where the adducts **8** are formed slowly but are rapidly converted to **4a**. The possibility also exists that the Michael-type adduct might regenerate **5c** upon hydrolytic workup.

**Reactions of β-Nitrostyrenes with $(EtO)_2PO^-$.** The Michael-type adducts **11** could be isolated in only modest yields upon reaction of **6a–c** with $(EtO)_2PO^-/(EtO)_2P(O)H$. With **6a** the adduct **11a** was isolated in 51–56% yield with 5 equiv of $(EtO)_2PO^-$ and 10 equiv of $(EtO)_2P(O)H$ in a 30-min reaction followed by hydrolytic workup at pH 0 or with 85% $H_2SO_4$. The Nef product **12a** was not observed.[3] The yield of **11a** decreased with longer reaction periods, indicating further reactions of the initially formed adduct.

$PhCH[P(O)(OEt)_2]CH(R)NO_2$
11, a, R=H
b, R=Me
c, R=Ph

$PhCH[P(O)(OEt)_2]COR$
12, a, R=H
b, R=Me
c, R=Ph

With **6b,c** the reaction products isolated are readily formulated from the Michael-type adducts but depend upon the hydrolytic conditions employed. However, only minor amounts of the Nef reaction products **12** were found under all conditions employed. Reaction of **6b** with 1.1 equiv of $(EtO)_2PO^-$ and 5 equiv of $(EtO)_2P(O)H$ for 1 min followed by hydrolysis with brine for 1 h yielded 31% of **11b** and 7% of **12b**. Reaction with 5 equiv each of $(EtO)_2PO^-$ and $(EtO)_2P(O)H$ for 5 min at 0 °C followed by addition to aqueous acid at pH 0 gave 66% of **11b** and only a trace (~4%) of the ketone. However, when this reaction mixture was added dropwise to 85% $H_2SO_4$, **11b** was formed in 20% yield and the major product was the heterocycle **13** (R = Me) in 60% yield. The isolated adduct **11b** was not converted to **13** by 85% $H_2SO_4$ and could be recovered unchanged after several hours. However, when **11b** was dissolved in aq NaOH and the nitronate salt added to 85% $H_2SO_4$, **13** (R = Me) was formed in 42% yield. Apparently the aci form of **11b** reacts in 85% $H_2SO_4$ to form the nitroso alcohol (an intermediate in Nef reactions[5]) which undergoes an acid-catalyzed cyclization, Scheme IV.

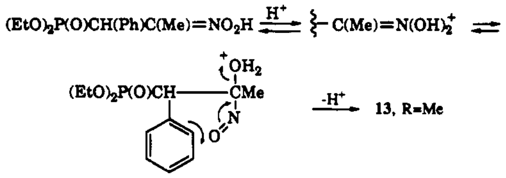


13

$PhCH{=}C(Ph)P(O)(OEt)_2$

14

Scheme IV



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(2) Kreuger, W. E.; McLean, M. B.; Rizwanivk, A.; Maloney, J. R.; Behelfer, G. L.; Boland, B. E. *J. Org. Chem.* **1978**, *43*, 2877.

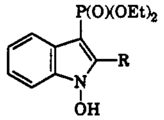
(3) Reaction of $Ph_2C{=}C(SPh)NO_2$ with $(EtO)_2PO^-/(EtO)_2P(O)H$ for 2 min followed by hydrolysis yields $Ph_2C[P(O)(OEt)_2]CHO$.[1] Apparently the initially formed Michael adduct undergoes a Perkow-type reaction with $(EtO)_2PO^-$ to form $PhS^-$ and $Ph_2C[P(O)(OEt)_2]CH{=}N(O)OP(O)(OEt)_2$ which may be hydrolyzed to the aldehyde. In the absence of hydrolysis this intermediate is converted into $Ph_2C[P(O)(OEt)_2]C{\equiv}N$ and, by reaction with $PhS^-$, into $PhSP(O)(OEt)_2$ and $Ph_2C[P(O)(OEt)_2]CH{=}NO_2^-$.[1]

(4) Zhang, R.; Liao, X.; Gao, Z. *Synthesis* **1990**, 801.

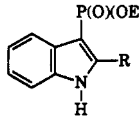
(5) Nielsen, A. T. *The Chemistry of the Nitro and Nitroso Groups*; Feuer, H., Ed.; John Wiley: New York, 1969; Part 1, p 349.

Reaction of **6c** with 1.2–5 equiv of $(EtO)_2PO^-$ in $(EtO)_2P(O)H$ solution for 5 min gave 28–34% of **11c** upon hydrolysis at pH 5. However, when the reaction mixture was added to 85% $H_2SO_4$, the vinylphosphonate **14** was formed in 66% yield. Compound **14** was formed in ~ 100% from the reaction of **11c** in 85% $H_2SO_4$ for 1 h, presumably by the elimination of $HNO_2$ from protonated $(-NO_2H^+)$ **11c** to form a benzylic cation.

The reaction of **6b** with $(EtO)_2P(O)H$ in the presence of excess $K_2CO_3$ in EtOH at 60–70 °C is reported to form the *N*-hydroxyindole **15** (R = Me).[4] Under similar conditions (70 °C, 13 h), **6c** yielded 36% of **15** (R = Ph) and 14% of the indole **16** (R = Ph). The formation of **15** can be rationalized by the dehydration of the Michael adducts (**11b** or **11c**) to form nitrosoalkenes which undergo acid-catalyzed cyclization, reaction 3. When the Michael adducts **11b** or **11c** were dissolved in aqueous NaOH and heated at 80–100 °C for 1–2 h, acidification yielded 15 with R = Me (79%) or Ph (59%). Possibly the formation of 16 (R = Ph) in the $EtOH/(EtO)_2PO^-/(EtO)_2P(O)H$ systems at 70 °C involves $PhC[P(O)OEt)_2]{=}C(Ph)N{=}O$ reacting in the manner described in Scheme I to yield the azirine 17 (R = Ph) as a precursor to 16, reaction 4 (R = Ph).

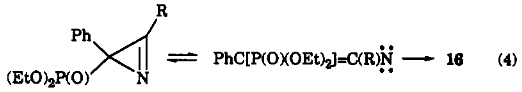


**15**



**16**

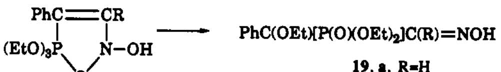
$$PhC[P(O)(OEt)_2{=}C(R)N{=}O \xrightleftharpoons{(EtO)_2P(O)H} PhC[P(O)(OEt)_2]{=}C(R)N{=}OH^+ \longrightarrow \xrightarrow{-H^+} \mathbf{15} \quad (3)$$



**17**

$$\rightleftharpoons PhC[P(O)(OEt)_2]{=}C(R)\ddot{\underset{\cdot\cdot}{N}} \longrightarrow \mathbf{16} \quad (4)$$

**Reactions of $\beta$-Nitrostyrenes with $(EtO)_3P$.** $\beta$-Nitrostyrene reacts with $(EtO)_3P$ at room temperature to yield a mixture of **11a**, its elimination product $PhC[P(O)(OEt)_2]{=}CH_2$, and the oxime $PhC(OEt)[P(O)(OEt)_2]CH{=}NOH$.[2] The latter product can be rationalized by tautomerization of the adduct **9b** (R′ = R = H) to yield **18a** followed by reaction 5.[2] A similar process is observed with **6b** (R = Me). A 20-h reaction of **6b** in $(EtO)_3P$ at room temperature produced a complex reaction mixture containing 60% of **19b**, 7% of $PhC[P(O)(OEt)_2]{=}CHCH_3$, 10% of $PhC(O)C(Me){=}NOH$, and 22% of the azirine **17** (R = Me). The formation of **17** is reasonably formulated by the elimination of EtOH from **18b** to form $PhC[P(O)(OEt)_2]{=}C(Me)N{=}O$ followed by cyclization according to Scheme I. The keto oxime observed could result from the hydrolysis of **18b**, or the nitrosoalkene, to form initially $PhC(OH)[P(O)(OEt)_2]C(Me){=}NOH$. At 130 °C the reaction of **6b** with $(EtO)_3P$ produced 24% of **19b**, but the azirine was no longer observed. The aminophosphonate **20** was now observed in 14% yield, possibly from trapping of the nitrene formed upon ring opening of **17** (reaction 4). However, the indole (**16**, R = Me) expected from the nitrene was not a significant product.



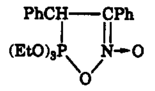
$$\longrightarrow PhC(OEt)[P(O)(OEt)_2]C(R){=}NOH \quad (5)$$

**18, a,** R=H
**b,** R=Me

**19, a,** R=H
**b,** R=Me

$(EtO)_2P(O)C(Ph){=}C(Me)NHP(O)(OEt)_2$

**20**



**21**

Reaction of **6c** with $(EtO)_3P$ is reported to form 16% of 2-phenylindole upon reaction for 8 h in refluxing $(EtO)_3P$.[6] At room temperature there is a rapid reaction in $(EtO)_3P$ solution to form a relatively persistent species **21** (analogous to **9b** in Scheme III) in ~100% yield by $^1H$ NMR. Compound **21** was obtained in a crude form upon removal of the excess $(EtO)_3P$ under vacuum but underwent hydrolysis when purification was attempted by column chromatography. The crude material gave the proper molecular weight by MS and had a $^{31}P$ NMR absorption consistent with a pentacoordinated P(V) atom[7] at $\delta = -37$ with a methine CH at $\delta_c = 53.8$ ($^1J_{PC} = 164.5$ Hz); $\delta_H = 4.72$ ($^2J_{PH} = 25.5$ Hz). Hydrolysis of **21** with 85% $H_2SO_4$ yielded the heterocycle **13** (R = Ph) in 40% yield. Hydrolysis of **21** apparently proceeds via the nitroso alcohol which cyclizes to **13** (Scheme IV). Interestingly, the Michael adduct **11c** does not form **13** (R = Ph) under similar conditions but instead eliminates $HNO_2$ to form **14**.

Heating solutions of **21** in $(EtO)_3P$, or reactions of **6c** in $(EtO)_3P$ at 120–150 °C for 1–2 h, produced small amounts of 2-phenylindole (<10%). The major products isolated were **22** (34%) and **23** (43%). These products are suggestive of azirine and aziridine formation from **21** via deoxygenation and ring opening to yield $PhCH{=}C(Ph)N^-{-}OP(OEt)_3^+$ (Scheme III) as a precursor to 2,3-diphenyl-2*H*-aziridine and 2-(diethoxyphosphinyl)-2,3-diphenylaziridine. The formation of **22** requires the aziridine rearrangement of reaction 1 via the doubly benzylic 1,3-diradical while the formation of **23** most reasonably involves a vinylnitrene → ketenimine rearrangement with very little cyclization of the vinylnitrene to the indole. The formation of the aziridines **1** from the 2,2-diphenyl-2*H*-azirines can be excluded in the reactions of **5** with $(EtO)_3P$ at 150 °C since the isomerization of reaction 1 is not observed. However, with 2,3-diphenyl-2*H*-azirine derived from **6c**, aziridine formation apparently occurs. This may be a result of a less efficient conversion of the nitrene (in equilibrium with the azirine) to the indole or possibly because of a more rapid addition of $(EtO)_3P$ to 2,3-diphenyl-2*H*-azirine than to the 2,2-diphenyl-2*H*-azirines. Compounds **22** and **23** were also formed when the reaction product of **6c** with $(EtO)_2PO^-/(EtO)_2P(O)H$ was warmed under vacuum to remove the excess $(EtO)_2P(O)H$. In this case, apparently **8c** (R′ = H, R = Ph) underwent deoxygenation (Scheme II) to form $PhCH{=}C(Ph)N^-{-}OP(O)(OEt)_2$ as a precursor to 2,3-diphenyl-2*H*-azirine.

$PhCH{=}NCH(Ph)P(O)(OEt)_2$

**22**

$PhCH{=}C[P(O)(OEt)_2]NHPh$

**23**

## Experimental Section

For general experimental information and instrumentation, see ref 1. Literature procedures were followed for the preparation of **5a**,[8] **5b**,[8] **5c**,[9] **5d**,[10] **6b**,[11] and **6c**.[8]

Products were isolated from reactions employing $(EtO)_2PO^-$ by hydrolysis in brine followed by $CH_2Cl_2$ extraction and flash

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(6) Cadogen, J. I. G.; Cameron-Wood, M.; Mackie, R. K.; Searle, R. J. G. *J. Chem. Soc.* **1965**, 4831.

(7) Verkade, J. G.; Quin, L. D. Vol. 8 in *Methods of Stereochemical Analysis*, VCH Publishers, Inc.: New York, 1987; Vol. 8, Phosphorus-31 NMR Spectroscopy in Stereochemical Analyses.

(8) Bordwell, F. G.; Garbisch, E. W. *J. Org. Chem.* **1962**, *27* 2322, 3049.

(9) Bergman, F.; Dimant, E.; Japhe, H. *J. Am. Chem. Soc.* **1948**, *70*, 1618.

(10) Russell, G. A.; Dedolph, D. F. *J. Org. Chem.* **1985**, *50*, 3878.

(11) Alles, G. A. *J. Am. Chem. Soc.* **1932**, *54*, 271.

column chromatography using 230–240-mesh, grade 60 Merck silica gel with hexane–EtOAc as the eluent. When $(EtO)_3P$ was the reactant, the volatile reagents were removed under vacuum before chromatography of the residue. Unless otherwise indicated the isolated title compounds showed no impurities by NMR or GC analysis and possessed purities > 95%.

**Preparation of 3-(Diethoxyphosphinyl)-3-R-2,2-diphenylaziridines (1).** The nitroalkenes **5b,c** (1 mmol) were added to 20 mL of $Me_2SO$ containing 5 mmol of $(EtO)_2PO^-$ and 5 mmol of $(EtO)_2P(O)H$, and the mixtures were stirred for 2 h at room temperature. Hydrolysis, extraction, and evaporation of the solvent gave oils which were analyzed by $^1H$ NMR with toluene as an internal standard. The yields thus determined for 1 (R = Me, Ph) were 51 and 94%, respectively. Under these conditions **5a** formed only **8a** (R′ = Ph, R = H) in up to 97% yield. Reaction of **8a** (R′ = Ph, R = H) with $(EtO)_2PO^-$ in $(EtO)_2P(O)H$ formed 1 (R = H) in 90% yield in 4 h.[1]

**3-(Diethoxyphosphinyl)-3-methyl-2,2-diphenylaziridine (1, R = Me).** The aziridine was eluted as an oil from a silica gel column with EtOAc after flash column chromatography with hexane (75%)–EtOAc (25%): FTIR (neat) 3254 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 7.61–7.15 (m, 10 H), 4.04 (pentet, $J$ = 7.2, 2 H), 3.85–3.75 (m, 1 H), 3.51–3.49 (m, 1 H), 2.17 (br s, 1 H), 1.29 (t, $J$ = 7.2 Hz, 3 H), 1.30 (d, $J$ = 5.7 Hz, 3 H), 1.03 (t, $J$ = 7.2 Hz, 3 H); $^{13}C$ NMR ($CDCl_3$) δ 141.5 (d, $J_{PC}$ = 2.2 Hz), 140.7 (d, $J_{PC}$ = 2.2 Hz), 128.2, 128.0, 127.9, 127.8, 127.1, 126.9, 62.0 (d, $^2J_{PC}$ = 7.5 Hz), 61.9 (d, $^2J_{PC}$ = 6.5 Hz), 54.1 (d, $^2J_{PC}$ = 2.2 Hz), 40.6 (d $^1J_{PC}$ = 181 Hz), 17.2, 16.2 (d, $^3J_{PC}$ = 6.0 Hz), 16.0 (d, $^3J_{PC}$ = 6.0 Hz); GC and HRMS $m/z$ (relative intensity 345 ($M^+$, 0.9), 344.1411 $(M - 1)^+$, 2.2, calcd for $C_{19}H_{23}NO_3P$ 344.1416), 208 (100), 165 (18), 105 (70); GCMS (CI, ammonia) 346 ($MH^+$, 100).

**3-(Diethoxyphosphinyl)-2,2,3-triphenylaziridine (1, R = Ph).** Material eluted from a silica gel column with EtOAc had the following properties: mp 118–119 °C; FTIR ($CDCl_3$) 3298 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 7.77–6.84 (m, 15 H), 3.86–3.66 (m, 2 H), 3.60–3.47 (m, 1 H), 3.40–3.26 (m, 1 H), 2.57 (br s, $D_2O$ exchangeable), 1.02 (t, $J$ = 7.2 Hz, 3 H) 0.84 (t, $J$ = 7.2 Hz, 3 H); $^{13}C$ NMR ($CDCl_3$) δ 140.96, 139.22, 134.24, 134.12, 129.42, 128.63, 127.97, 127.28, 127.16, 126.90, 126.16, 62.7 (d), 61.61 (d), 55.46, 49.09 (d, $^1J_{PC}$ = 184.2 Hz), 15.89, 15.67; GC and HRMS $m/z$ (relative intensity) 407.1639 ($M^+$, 0.8, calcd for $C_{24}H_{26}NO_3P$ 407.1650), 270 (100), 165 (17), 152 (7). Anal. Calcd for $C_{24}H_{26}NO_3P$: C, 70.75; H, 6.03; N, 3.44; P, 7.60. Found: C, 70.33; H, 6.42; N, 3.43; P, 7.60.

**2-Substituted-3-phenylindoles (3, R = Me, Ph, PhO).** Compounds **5b–d** (1 mmol) in 2 mL of $(EtO)_3P$ were heated to 150 °C for 2 h. Removal of the volatiles under vacuum gave oils which were analyzed by $^1H$ NMR with toluene as an internal standard to give yields of **3** (R = Me, Ph, OPh) of 100, 100, and 89%, respectively. The indoles were isolated as solids by flash column chromatography on silica gel with hexane (95%)–EtOAc (5%) as eluent. 2-Methyl-3-phenylindole: mp 57–59 °C (lit.[12] mp 58–60 °C); FTIR (neat) 3406 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 7.72 (br s, 1 H), 7.67–7.07 (m, 9 H), 2.40 (s, 3 H); GCMS $m/z$ (relative intensity) 208 (15), 207 ($M^+$, 100), 191 (2), 178 (9), 165 (7), 103 (17), 77 (5). 2,3-Diphenylindole: mp 113–114 °C from hexane–$CH_2Cl_2$ (lit. mp 113–114 °C from ligroin,[13] 114–116 °C from heptane[14]); FTIR ($CDCl_3$) 3412 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 8.11 (br s, 1 H), 7.67–7.11 (m, 14 H); $^{13}C$ NMR ($CDCl_3$) δ 135.8, 135.0, 134.0, 132.6, 130.1, 128.65, 128.6, 128.5, 128.1, 127.6, 126.2, 120.4, 119.6, 114.9, 110.0; GC and HRMS $m/z$ (relative intensity) 269.1200 ($M^+$, 100, calcd for $C_{20}H_{15}N$ 269.1204), 165 (16), 134 (25), 127 (16), 77 (12). 3-Phenyl-2-phenoxyindole: mp 112–114 °C; FTIR (neat) 3396 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 7.86–6.94 (m, 14 H), 7.72 (br s, 1 H); $^{13}C$ NMR ($CDCl_3$) δ 157.3, 142.7, 133.0, 130.9, 129.7, 128.5, 128.1, 126.1, 125.8, 123.3, 121.9, 120.6, 119.3, 116.3, 110.8, 102.4; GC and HRMS $m/z$ (relative intensity) 286 (22), 285.1153 ($M^+$, 100, calcd for $C_{20}H_{15}NO$ 285.1154), 208 (90), 180 (37), 152 (31), 77 (53). A trace of *N*-ethyl-3-phenyl-2-phenoxyindole was also isolated in the reaction of **5d** with $(EtO)_3P$ at 150 °C. This product had the following characteristics: $^1H$ NMR ($CDCl_3$) δ 7.91–6.91 (m, 14 H), 4.04 (q, $J$ = 7.2 Hz, 2 H), 1.28 (t, $J$ = 7.2 Hz, 3 H); GC and HRMS $m/z$ (relative intensity) 314 (28), 313.1459 ($M^+$, 100, calcd for $C_{22}H_{19}NO$ 313.1467), 236 (56), 207 (16), 193 (24), 180 (18), 165 (33), 152 (18), 77 (41).

**Diethyl [α-[(Diphenylmethylene)amino]benzyl]phosphonate (7, R = Ph).** This compound having mp 84–86 °C was isolated in 93% yield upon heating 1 (R = Ph) in refluxing PhCl for 90 min. Flash column chromatography with hexane (90%)–ethyl acetate (10%) gave 7 (R = Ph): FTIR ($CDCl_3$) 1620 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 7.73–7.10 (m, 15 H), 4.995 (d, $^2J_{PH}$ = 15.3 Hz), 4.12–3.91 (m, 4 H), 1.23 (t, $J$ = 7.2 Hz, 3 H), 1.19 (t, $J$ = 7.2 Hz, 3 H); $^{13}C$ NMR ($CDCl_3$) δ 170.35 (d), 139.4, 137.1, 137.0, 135.5, 130.3, 128.8, 128.7, 128.4, 128.2, 127.9, 127.6, 127.4, 66.7 (d, $^1J_{PC}$ = 157.1 Hz), 62.9 (d), 62.8 (d), 16.4, 16.1; GCMS identical to 1 (R = Ph). Anal. Calcd for $C_{24}H_{26}NO_3P$: C, 70.75; H, 6.43; N, 3.44. Found: C, 70.92; H, 6.35; N, 3.38.

**Diethyl [α-[(Diphenylmethylene)amino]ethyl]phosphonate (7, R = Me).** The reaction of **5b** with $(EtO)_2PO^-$ (5 equiv)/$(EtO)_2P(O)H$ (5 equiv) in 20 mL of $Me_2SO$ for 10 min gave 59% of 1 (R = Me) upon column chromatography. When the crude product was refluxed in 5 mL of PhBr for 1 h a 44% yield of 7 (R = Me) and a 21% yield of $Ph_2CH[P(O)(OEt)_2]$ was obtained. Compound 7 (R = Me): FTIR (neat) 1620 $cm^{-1}$: $^1H$ NMR ($CDCl_3$) δ 7.65–7.20 (m, 10 H), 4.25–4.08 (m, 4 H), 3.94 (dq, $J$ = 10.2, 6.9 Hz, 1 H), 1.43 (dd, $J$ = 18.3 6.9 Hz, 3 H), 1.33 (t, $J$ = 7.2 Hz, 3 H), 1.31 (t, $J$ = 7.2 Hz, 3 H); $^{13}C$ NMR ($CDCl_3$) δ 169.9 (d, $^3J_{PC}$ = 19.6 Hz), 139.3, 135.7, 130.2, 128.6, 127.9, 127.7, 62.4 (d), 62.3 (d), 56.8 (d, $^1J_{PC}$ = 146.7 Hz), 16.9, 16.8, 16.5; GC and HRMS $m/z$ (relative intensity) 345.1490 ($M^+$, 0.2, calcd for $C_{19}H_{24}NO_3P$ 345.1494), 208 (100), 193 (3), 165 (24), 105 (72), 77 (20).

**5-Ethoxy-3-methyl-4,4-diphenyl-4,5-dihydro-1,2,5-oxazaphosphole 2,5-Dioxide (10).** A mixture of **5b** (1 mmol), $(EtO)_2PO^-$ (5 mmol), and $(EtO)_2P(O)H$ (10 mmol) was stirred for 5 min at room temperature before hydrolysis with brine and extraction. Evaporation of the solvent left an oil which crystallized to yield 74% of **10** after washing with hexane: mp 194–195 °C; $^1H$ NMR ($Me_2SO$-$d_6$) δ 7.51–6.60 (m, 10 H), 3.87–3.62 (m, 2 H), 1.78 (d, $J$ = 2.7 Hz, 3 H), 1.07 (t, $J$ = 7.2 Hz, 3 H); $^{13}C$ NMR ($Me_2SO$-$d_6$) δ 154.1 (d), 150.9, 140.3, 130.6, 130.5, 130.4, 128.6, 128.5, 127.4, 123.0, 119.2, 119.1, 62.54 (d), 49.7 (d, $^1J_{PC}$ = 139.4), 20.2, 16.6; MS (CI, ammonia, solids probe) $m/z$ (relative intensity) 332 ($(M + 1)^+$, 24), 349 ($(M + 18)^+$, 100), 663 ($(2M + 1)^+$, 2), 679 ((2M + $18^+$), 0.5). Anal. Calcd for $C_{17}H_{18}NO_4P$: C, 61.63; H, 5.48; N, 4.23; P, 9.35. Found: C, 61.29; H, 5.58; N, 4.17; P, 8.88.

**Adducts of $(EtO)_2P(O)H$ with 6a–c (11a–c).** The adducts were isolated by flash column chromatography with hexane (75%)–ethyl acetate (25%). Diethyl (2-nitro-1-phenylethyl)phosphonate (**11a**): mp 66–67 °C; $^1H$ NMR ($CDCl_3$) δ 7.40–7.30 (m, 5 H), 4.95 (t, $J$ = 7.2 Hz, 2 H), 4.14–3.87 (m, 4 H), 3.82–3.69 (m, 1 H), 1.33 (t, $J$ = 7.2 Hz, 3 H), 1.12 (t, $J$ = 7.2 Hz, 3 H); GCMS $m/z$ (relative intensity) 287 ($M^+$, 0.1), 240 (32), 212 (18), 185 (11), 169 (16), 130 (15), 109 (68), 104 (100); CIMS (GC, $NH_3$) 305 ($(M + 18)^+$, 100), 285 ($(M + 1)^+$, 21).

Diethyl (2-nitro-1-phenylpropyl)phosphonate (**11b**) was isolated as a mixture of diastereomers of which the major isomer was a solid: mp 68–69 °C; $^1H$ NMR ($CDCl_3$) δ 7.36–7.29 (m, 5 H), 5.33–5.20 (m, 1 H), 4.18–4.01 (m, 2 H), 3.90–3.77 (m, 1 H), 3.67 (dd, $J$ = 22.2, 11.1 Hz, 1 H) 3.50–3.37 (m, 1 H), 1.98 (d, $J$ = 6.9 Hz, 3 H), 1.32 (t, $J$ = 7.2 Hz, 3 H), 1.00 (t, $J$ = 7.2 Hz, 3 H); $^{13}C$ NMR ($CDCl_3$) δ 132.6 (d), 129.1, 129.0, 128.8, 128.3, 85.6 (d), 63.7 (d), 62.0 (d), 49.3 (d, $^2J_{PH}$ = 138.2 Hz), 19.8, 16.4, 16.2; GC and HRMS $m/z$ (relative intensity) 301.1086 ($M^+$, 2; calcd for $C_{13}H_{20}NO_5P$ 301.1079), 256 (40), 227 (10), 111 (13), 199 (18), 183 (8), 117 (100), 109 (83). The minor isomer: $^1H$ NMR ($CDCl_3$) δ 7.36 (s, 5 H), 5.27–5.14 (m, 1 H), 4.15–4.05 (m, 2 H), 3.97–3.84 (m, 1 H), 3.87 (dd, $J$ = 21.6, 8.4 Hz, 1 H), 3.72–3.59 (m, 1 H), 1.44 (d, $J$ = 6.6 Hz, 3 H), 1.32 (t, $J$ = 7.2 Hz, 3 H), 1.04 (t, $J$ = 7.2 Hz, 3 H).

Diethyl (2-nitro-1,2-diphenylethyl)phosphonate (**11c**): mp 173–174 °C; $^1H$ NMR ($CDCl_3$) δ 7.73–7.29 (m, 10 H), 6.18 (dd, $J$ = 12.3, 5.7 Hz, 1 H), 4.23 (dd, $J$ = 21.9, 12.3 Hz, 1 H), 3.74–3.56 (m, 2 H), 3.41–3.29 (m, 1 H), 3.28–3.16 (m, 1 H), 0.83 (t, $J$ = 7.2 Hz, 6 H); GC and HRMS $m/z$ (relative intensity) 317.1307 ($(M - 46)^+$, 100; calcd for $C_{18}H_{22}O_3P$ 317.1302), 289 (6), 273 (6), 261 (19), 181 (44), 165 (13), 137 (13), 109 (65); CIMS (GC isobutane)

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317 ((M − 46)$^+$, 100), 364 ((M + 1)$^+$, 2.2).

**1-(Diethoxyphosphinyl)-1-phenylacetone (12b).** This compound separated from **11b** by flash column chromatography: FTIR at 1720 cm$^{-1}$; $^1$H NMR (CDCl$_3$) δ 7.48–7.28 (m, 5 H), 4.42 (d, $^2J_{PH}$ = 21.6 Hz, 1 H), 4.13–3.91 (m, 4 H), 2.31 (s, 3 H), 1.26 (t, $J$ = 7.2 Hz, 3 H), 1.18 (t, $J$ = 7.2 Hz, 3 H); $^{13}$C (CDCl$_3$) δ 200.9, 130.9, 130.8, 129.6, 129.5, 128.6, 127.8, 63.1 (d), 62.6 (d), 59.8 (d, $^1J_{PC}$ = 132.5 Hz), 30.5, 16.1; GC and HRMS *m/z* (relative intensity) 270.1016 (M$^+$, 9, calcd for $C_{13}H_{19}O_4P$ 270.1021), 228 (100), 200 (21), 172 (74), 118 (32), 105 (29).

**α-(Diethoxyphosphinyl)-α-phenylacetophenone (12c).** This compound separated from **11c** by flash column chromatography: mp 175–176 °C: FTIR 1683 cm$^{-1}$; $^1$H NMR (CDCl$_3$) δ 7.96–7.94 (m, 10 H), 5.34 (d, $^2J_{PH}$ = 22.2 Hz), 4.15–3.99 (m, 4 H), 1.21 (t, $J$ = 7.2 Hz, 3 H), 1.19 (t, $J$ = 7.2 Hz, 3 H); $^{13}$C NMR (CDCl$_3$) δ 193.5, 136.4 (d), 133.3, 129.6, 129.5, 128.8, 128.7, 128.5, 127.8, 63.1 (d), 62.9 (d), 54.3 (d, $^1J_{PC}$ = 141.6 Hz), 16.3, 16.1; GC and HRMS *m/z* (relative intensity) 332.1172 (M$^+$, 16, calcd for $C_{18}H_{21}PO_4$ 332.1177), 282 (6), 208 (23), 183 (100), 115 (80).

**4-(Diethoxyphosphinyl)-3-methyl-4*H*-1,2-benzoxazine (13, R = Me).** The reaction product from **6b** (1 mmol) with (EtO)$_2$PO$^-$ (5 mmol) and (EtO)$_2$P(O)H (10 mmol) at 0 °C for 5 min was added to 10 mL of 85% $H_2SO_4$ at 0 °C, and the mixture was stirred for 30 min before the addition of ice/water and $CH_2Cl_2$ extraction. The reaction product was analyzed by $^1$H NMR to contain 20% of **12b** and 60% of **13** (R = Me). Reaction of **11b** (0.163 mmol) with 10 mL of aqueous 0.26 M NaOH for 4 h followed by addition to 10 mL of 85% $H_2SO_4$ also gave **13** (R = Me) in 42% yield. Material isolated by flash column chromatography with hexane (50%)–ethyl acetate (50%) had the following characteristics: $^1$H NMR (CDCl$_3$) δ 7.47–7.03 (m, 4 H), 4.10 (pentet, $J$ = 7.2 Hz, 2 H), 2.31 (d, $^4J_{PH}$ = 1.2 Hz, 3 H), 1.29 (t, $J$ = 7.2 Hz, 3 H), 1.19 (t, $J$ = 7.2 Hz, 3 H); $^{13}$C NMR (CDCl$_3$) δ 153.7 (d), 152.5 (d), 128.8, 128.1 (d), 123.9, 114.2, 113.7 (d), 63.4 (d), 40.1 (d, $^1J_{PC}$ = 144.1 Hz), 20.8, 16.2; GC and HRMS *m/z* (relative intensity 283.0967 (M$^+$, 4, calcd for $C_{13}H_{18}NO_4P$ 283.0973), 146 (100), 77 (6); MS (CI, solids probe, NH$_3$) 284 ((M + 1)$^+$, 7), 301 ((M + 18)$^+$, 100), 567 ((2M + 1)$^+$, 0.6), 584 ((2M + 18)$^+$, 0.7).

**4-(Diethoxyphosphinyl)-3-phenyl-4*H*-1,2-benzoxazine (13, R = Ph).** Compound **6c** (0.5 mmol) and (EtO)$_3$P (1 mL) were stirred for 1 h before removal of the (EtO)$_3$P under vacuum and addition of the residue to 10 mL of $H_2SO_4$ at 0 °C. Hydrolysis, extraction and solvent evaporation left an oil which contained 40% of **13** (R = Ph) and 3% of **12c**. Chromatography yielded **13** as an oil: $^1$H NMR (CDCl$_3$) δ 7.95–7.13 (m, 9 H), 4.75 (d, $^2J_{PH}$ = 25.2 Hz, 1 H), 3.96–3.71 (m, 4 H), 1.16 (t, $J$ = 7.2 Hz, 3 H), 1.06 (t, $J$ = 7.2 Hz, 3 H); $^{13}$C NMR (CDCl$_3$) δ 153.7 (d), 153.0 (d), 132.9, 130.4, 128.8, 128.3, 127.0, 124.3, 114.7, 114.6, 63.5 (d), 63.18 (d), 37.8 (d, $^1J_{PC}$ = 142.1 Hz), 16.0; HRMS *m/z* 345.1134 (M$^+$, calcd for $C_{18}H_{20}NO_4P$ 345.1130); CIMS (solids probe, NH$_3$) 346 ((M + 1)$^+$, 29), 363 ((M + 18)$^+$, 100), 691 ((2M + 1)$^+$, 2), 708 ((2M + 18)$^+$, 8).

**Diethyl (1,2-Diphenylvinyl)phosphonate (14).** Reaction of **11c** (0.085 mmol) with 10 mL of 85% $H_2SO_4$ for 1 h followed by hydrolysis with ice/water yielded 100% of **14**: mp 57–58 °C; $^1$H NMR (CDCl$_3$) δ 7.63 (d, $^3J_{PH}$ = 25.5 Hz, 1 H), 7.38–7.03 (m, 10 H), 4.15–4.06 (pentet of d, $J$ = 7.2, 1.2 Hz, 4 H), 1.27 (t, $J$ = 7.2 Hz, 6 H); $^{13}$C NMR (CDCl$_3$) δ 143.5 (d), 135.4 (d), 134.5 (d), 130.9 (d, $^1J_{PC}$ = 180 Hz), 130.2, 129.02, 128.97, 128.8, 126.7, 126.0, 127.6, 62.0 (d), 16.2; GC and HRMS *m/z* (relative intensity) 316.1227 (M$^+$, 21, calcd for $C_{18}H_{21}O_3P$ 316.1229), 287 (4), 259 (7), 206 (30), 178 (100), 129 (5). Anal. Calcd for $C_{18}H_{21}O_3P$: C, 68.34; H, 6.69; P, 9.80. Found: C, 68.02; H, 6.40; P, 9.69.

**3-(Diethoxyphosphinyl)-1-hydroxy-2-phenylindole (15, R = Ph).** Compound **6c** (0.87 mmol), (EtO)$_2$P(O)H (0.87 mmol), and $K_2CO_3$ (4 mmol) were stirred at 70 °C for 13 h in 5 mL of EtOH. The mixture was filtered, the EtOH evaporated, and the residue chromatographed to yield 36% of **15** (R = Ph) and 14% of **16** (R = Ph). Compounds **15** (R = Ph, Me) were also prepared from **11b,c** by dissolution in 10 mL of 2 M NaOH, heating to 100 °C for 1–2 h, and then acidification to yield **15** (R = Me, Ph) in 79 and 59% yields, respectively. Compound **15** (R = Ph): mp 117–118 °C; FTIR (neat) 2814 cm$^{-1}$; $^1$H NMR (CDCl$_3$) δ 11.26 (br s, 1 H), 7.82–7.05 (m, 9 H), 3.72–3.51 (m, 4 H), 0.93 (t, $J$ = 6.9 Hz, 6 H); $^{13}$C NMR (CDCl$_3$) 143.5 (d, $^2J_{PC}$ = 9.0 Hz), 134.3 (d, $^3J_{PC}$ = 9.0 Hz), 130.7, 129.1 (d, $^2J_{PC}$ = 19.7 Hz), 128.6, 127.2, 126.4 (d, $^1J_{PC}$ = 23.5 Hz), 124.7, 122.6, 121.5, 120.4, 103.5, 61.6, 15.8; GC and HRMS *m/z* (relative intensity) 345.1128 (M$^+$, 100, calcd for $C_{18}H_{20}NO_4P$ 345.1128), 330 (12), 329 (78), 286 (3), 272 (6), 255 (16), 238 (15), 193 (100); CIMS (GC, NH$_3$) 363 ((M + 18)$^+$, 14), 346 ((M + 1)$^+$, 90), 330 (100). Anal. Calcd for $C_{18}H_{20}NO_4P$: C, 62.61; H, 5.84; N, 4.06; P, 8.97. Found: C, 62.65; H, 5.98; N, 4.05; P, 8.82.

**3-(Diethoxyphosphinyl)-2-phenylindole (16, R = Ph).** Material chromatographically separated in the previous experiment initially gave spectra consistent with the 1*H*-indole. However, in solution additional peaks slowly developed, suggesting the formation of small amounts of the 3*H*-indole. The indole had the following characteristics: mp 171–174 °C; FTIR (neat) 3132 cm$^{-1}$; $^1$H NMR (CDCl$_3$) δ 10.05 (br s, 1 H), 8.05–7.15 (m, 9 H), 4.04–3.78 (m, 4 H), 1.11 (t, $J$ = 7.2 Hz, 6 H); $^{13}$C NMR (CDCl$_3$) δ 145.7 (d, $^2J_{PC}$ = 24.5 Hz), 136.2 (d, $J_{PC}$ = 13.3 Hz), 131.8, 130.3 (d, $J_{PC}$ = 13.8 Hz), 129.5, 128.9, 128.0, 122.8, 121.3, 111.4, 61.2 (d, $^2J_{PC}$ = 21.3 Hz), 16.2 (d, $^3J_{PC}$ = 20.4 Hz); GC and HRMS *m/z* (relative intensity) 329.1176 (M$^+$, 76, calcd for $C_{18}H_{20}NO_3P$ 329.1181), 301 (12), 273 (7), 255 (16), 238 (14), 193 (100); CIMS (GC, NH$_3$) 347 ((M + 18)$^+$, 13), 330 ((M + 1)$^+$, 100). Anal. Calcd for $C_{18}H_{20}NO_3P$: C, 65.65; H, 6.12; N, 4.25. Found: C, 65.66; H, 6.24; N, 4.13.

**Reaction of 6b with (EtO)$_3$P.** Reaction of **6b** (2 mmol) with 2 mL of (EtO)$_3$P for 20 h at room temperature yielded a mixture analyzed by $^1$H NMR to contain **19b** (60%), PhC[P(O)(OEt)$_2$]=CHCH$_3$ (7%), PhCOC(Me)=NOH (10%), and **17** with R = Me (22%). The products were separated by flash column chromatography using hexane (50%)–ethyl acetate (50%). When the reaction mixture was heated to 130 °C for 2 h, 24% of **19b** and 14% of **20** were isolated by chromatography.

**α-(Diethoxyphosphinyl)-α-ethoxy-α-phenylacetone Oxime (19b).** The compound had the following properties: mp 143–146 °C; FTIR 3229, 1661 cm$^{-1}$; $^1$H NMR (CDCl$_3$) δ 10.93 (s, 1 H), 7.57–7.27 (m, 5 H), 4.30–3.97 (m, 5 H), 3.53 (pentet of d, $J$ = 7.2, 1.2 Hz, 1 H), 1.62 (s, 3 H), 1.31 (t, $J$ = 7.2 Hz, 3 H), 1.26 (t, $J$ = 7.2 Hz, 3 H), 1.14 (t, $J$ = 7.2 Hz, 3 H); $^{13}$C NMR (CDCl$_3$) δ 154.4 (d), 137.7, 127.7, 127.48, 127.46, 85.3 (d, $^1J_{PC}$ = 161.4 Hz), 63.3 (d), 63.1 (d), 62.1, 16.4, 16.3, 15.8, 10.5; GC and HRMS *m/z* (relative intensity) 329.1392 (M$^+$, 6.3, calcd for $C_{15}H_{24}NO_5P$ 329.1392), 192 (100), 164 (21).

**1-(Diethoxyphosphinyl)-1-phenylpropene.** The alkene was isolated as a liquid: $^1$H NMR (CDCl$_3$) δ 7.41–7.19 (m, 5 H) 6.97 (dq, $J$ = 23.1, 6.9 Hz, 1 H), 4.14–4.00 (m, 4 H), 1.73 (dd, $J$ = 6.9, 3.3 Hz, 3 H), 1.25 (t, $J$ = 7.2 Hz, 6 H); GC and HRMS *m/z* (relative intensity) 254.1067 (M$^+$, 36, calcd for $C_{13}H_{19}O_2P$ 254.1072), 226 (10), 197 (34), 144 (7), 129 (16), 117 (47), 115 (60).

**2-(Diethoxyphosphinyl)-3-methyl-2-phenyl-2*H*-azirine (17, R = Me).** The compound was isolated as a liquid: FTIR 1601 cm$^{-1}$; $^1$H NMR (CDCl$_3$) δ 7.43–7.27 (m, 5 H), 4.24–4.07 (m, 4 H), 2.59 (s, 3 H), 1.30 (t, $J$ = 7.2 Hz, 3 H), 1.29 (t, $J$ = 7.2 Hz, 3 H); $^{13}$C NMR (CDCl$_3$) δ 163.3, 136.5 (d), 128.3, 127.4, 127.1, 62.6, 62.6, 34.5 (d, $^1J_{PC}$ = 214.3 Hz), 16.3, 12.5; GC and HRMS *m/z* (relative intensity) 267.1018 (M$^+$, 8, calcd for $C_{13}H_{18}NO_3P$ 267.10243), 238 (8), 210 (17), 193 (9), 130 (14), 104 (38), 93 (19), 89 (14), 77 (27), 65 (39), 43 (100). Anal. Calcd for $C_{13}H_{18}NO_3P$: C, 58.42; H, 6.79; N, 5.24; P, 11.59. Found: C, 56.60; H, 6.98; N, 5.16; P, 12.16.

**Diethyl *N*-[1-(Diethoxyphosphinyl)-1-phenyl-2-propenyl]phosphoric Monoamide (20).** The compound was isolated as a liquid: FTIR 3123 cm$^{-1}$; $^1$H NMR (CDCl$_3$) δ 9.71 (d, $J$ = 9.9 Hz, 1 H), 7.35–7.12 (m, 5 H), 4.18 (pentet of d, $J$ = 7.2, 0.9 Hz, 4 H), 4.00 (pentet of d, $J$ = 7.2, 0.9 Hz, 4 H), 1.98 (s, 3 H), 1.38 (td, $J$ = 7.2, 0.6 Hz, 6 H), 1.23 (t, $J$ = 7.2 Hz, 6 H); $^{13}$C NMR (CDCl$_3$) δ 154.2 (dd, $J$ = 10.4, 4.2 Hz), 135.9 (d), 131.0 (d), 128.1, 126.9, 100.7 (dd, $J$ = 181.0, 12.3 Hz), 63.3 (d), 66.7 (d), 18.5, 18.3, 16.0; GC and HRMS *m/z* (relative intensity) 405.1470 (M$^+$, 100; calcd for $C_{17}H_{29}NO_6P_2$ 405.1470), 268 (2.7), 206 (43), 178 (43), 137 (24), 77 (18).

**5,5,5-Triethoxy-3,4-diphenyl-4,5-dihydro-1,2,5-oxazaphosphole 2-Oxide (21).** Reaction of **6c** (1 mmol) with 2 mL of (EtO)$_3$P at room temperature for 2 h followed by the removal of the excess (EtO)$_3$P under vacuum gave by $^1$H NMR a quantitative yield of **21** contaminated with a trace of (EtO)$_3$PO. Compound **21** was unstable to GC or silica gel column chromatography: $^1$H NMR (CDCl$_3$) δ 8.00–7.21 (m, 10 H), 4.72 (d, $^2J_{PH}$ = 25.5 Hz, 1

H), 4.04–3.98 (m, 6 H), 1.14 (td, $J = 7.2, 1.2$ Hz, 9 H); $^{13}$C NMR ($CDCl_3$) $\delta$ 132.9 (d), 128.52, 128.48, 128.3, 128.1, 128.0, 127.3, 126.6, 120.8 (d), 63.6 (d), 53.8 (d, $^{1}J_{PC} = 164.5$ Hz), 16.1; $^{31}$P NMR ($CDCl_3$) $\delta$ −37.1 (octet, $J \sim 8.1$ Hz); HRMS $m/z$ 360.1487 ($(M - 31)^+$, calcd for $C_{20}H_{25}O_4P$ 360.1491), 345.1128 ($(M - 46)^+$, calcd for $C_{18}H_{20}O_4NP$ 345.1130); CIMS (solids probe, $NH_3$) 392 ($(M + 1)^+$, 100), 409 ($(M + 18)^+$, 0.2).

**Diethyl [$\alpha$-(Benzylideneamino)benzyl]phosphonate (22).** Heating of **6c** (1 mmol) with 2 mL of $(EtO)_3P$ at 120–150 °C for 1–2 h produced a trace of 2-phenylindole (<10%), 34% of **22**, and 43% of **23**. Compound **22** isolated by chromatography with hexane (75%)–ethyl acetate (25%) had a purity of ~90% from $^1$H NMR: $^1$H NMR ($CDCl_3$) $\delta$ 8.41–7.28 (m, 11 H), 4.93 (d, $^{2}J_{PH} = 18.6$ Hz, 1 H), 4.12–3.92 (m, 4 H), 1.23 (t, $J = 7.2$ Hz, 3 H), 1.20 (t, $J = 7.2$ Hz, 3 H); GC and HRMS $m/z$ (relative intensity) 331.1332 ($M^+$, 45, calcd for $C_{18}H_{22}NO_3P$ 331.1338), 240 (56), 193 (33), 178 (28), 165 (18), 152 (8), 137 (23), 109 (37), 104 (100), 91 (20), 77 (15); CIMS (GC, $NH_3$) 332 ($(M + 1)^+$, 100), 349 ($(M + 18)^+$, 21), 663 ($(2M + 1)^+$, 3).

**Diethyl (1-Anilino-2-phenylvinyl)phosphonate (23).** The crude reaction product from the previous experiment showed only a single isomer of **23** by $^1$H NMR but after column separation a second minor isomer was found. Major isomer: mp 103–104 °C; FTIR 3287 cm$^{-1}$; $^1$H NMR ($CDCl_3$) $\delta$ 7.42–6.57 (m, 11 H), 7.00 (d, $^{3}J_{PH} = 16.8$ Hz, 1 H), 5.59 (d, $J = 7.2$ Hz, $D_2O$ exchangeable, 1 H), 4.22–4.01 (m, 4 H), 1.28 (t, $J = 7.2$ Hz, 6 H); $^{13}$C NMR ($CDCl_3$) $\delta$ 141.6, 134.0 ($^{2}J_{PC} = 19.6$ Hz), 130.1, 129.8, 128.6, 128.3, 128.0, 126.5 (d, $^{1}J_{PC} = 198.3$ Hz), 119.8, 115.6, 62.4 (d, $J = 4.5$ Hz), 16.2 (d, $J = 6.4$ Hz); GC and HRMS $m/z$ (relative intensity) 331.1332 ($M^+$, 14, calcd for $C_{18}H_{22}NO_3P$ 331.1337), 228 (15), 193 (100), 165 (11), 116 (11), 91 (13), 77 (12); CIMS (GC, $NH_3$) 332 ($(M + 1)^+$, 100), 349 ($(M + 18)^+$, 20), 663 ($(2M + 1)^+$, 2). Anal. Calcd for $C_{18}H_{22}NO_3P$: C, 65.25; H, 6.69; N, 4.23; P, 9.35. Found: C, 64.97; H, 6.62; N, 4.13; P, 9.25.

The 2nd isomer isolated by chromatography had the following characteristics: FTIR 3167 cm$^{-1}$; $^1$H NMR ($CDCl_3$) $\delta$ 7.58–7.21 (m, 10 H), 5.94 (s, 1 H), 5.15 (d, $J = 6.3$, 1 H), 4.05–3.87 (m, 4 H), 1.17 (td, $J = 7.2, 0.9$ Hz, 6 H); $^{13}$C NMR ($CDCl_3$) $\delta$ 138.7, 136.8 (d, $^{1}J_{PC} = 136.8$ Hz), 129.2, 128.6, 128.3, 127.9, 127.8, 127.0, 116.1 (d), 62.9 (d), 15.9 (d); MS (solids probe) $m/z$ (relative intensity) 331.1339 ($M^+$, 0.2, calcd for $C_{18}H_{22}NO_3P$ 331.1337), 303 (1), 274 (2), 243 (43), 127 (15), 105 (100), 91 (15), 77 (100).

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**Supplementary Material Available:** $^1$H NMR spectra for 1 (R = Me), 7 (R = Me), **12a,b**, **13** (R = Me), **20** and **21**, $^{13}$C NMR spectra for 1 (R = Me), 3 (R = OPh), **13** (R = Me, Ph), and **21**, and $^{31}$P NMR spectrum for **21** (15 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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# A Facile Synthesis of Furo[3,4-*c*]isoxazoles: Precursors to 3,4-Disubstituted Isoxazoles

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Nitrile oxide–olefin cycloaddition reactions deliver heterocyclic products with a wide variety of functionality and provide a particularly powerful means of preparing substituted isoxazoles by the intermolecular 1,3-dipolar cycloaddition of a nitrile oxide with a monosubstituted alkyne to give a preponderance of the 3,5-disubstituted isoxazole. In this study, an extension of the intramolecular nitrile oxide–olefin cycloaddition reaction is reported for the facile synthesis of furo[3,4-*c*]isoxazoles (**5**) which are in turn shown to be useful precursors to 3,4-disubstituted or 3,4,5-trisubstituted isoxazole derivatives (**6**). The method consists of a high-yield preparation of a broad spectrum of furo[3,4-*c*]isoxazoles by intramolecular nitrile oxide–alkyne cycloaddition of acetylenic nitro ethers (**3**), in turn prepared by Michael addition of various propargylic alkoxides (**2**) to appropriate nitro olefins (**1**).

The INOC (intramolecular nitrile oxide–olefin cycloaddition) reaction continues to receive a great deal of synthetic attention as it both provides a particularly powerful means of relative stereochemical control[1] and delivers heterocyclic products with a wide variety of functionality.[2] With regard to the latter, INOC applications in the synthesis of new drugs and agrochemicals[3] containing substituted isoxazoles[4] are particularly important. Indeed, since Claisen's report in 1891,[5] many methods have been developed for the preparation of substituted isoxazoles which can generally be broken into two strategic categories. The first involves the condensation reaction of an hydroxylamine with a carbonyl compound (generally, $\alpha,\beta$-dihalo ketones, $\beta$-alkoxy enones, $\beta$-chloro enones, or ynones)[3] and provides easy access to 3,5-disubstituted isoxazoles. Introduction of a substituent at C-4 by this method is, however, not convenient. The second category involves the 1,3-dipolar cycloaddition of a nitrile oxide with an alkyne. In this transformation, nitrile oxides react intermolecularly with monosubstituted

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